NATIONAL AIRSPACE SYSTEM

System Engineering Manual

Federal Aviation Administration
ASD-100
Architecture and System Engineering

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ASD

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1 INTRODUCTION

The System Engineering Manual (SEM) is a "how to" guidebook. The SEM defines major System Engineering (SE) elements and establishes best practices regarding application of these elements to the National Airspace System (NAS). The SEM is a selected compilation of those proven practices within the SE domain that are deemed most appropriate to analysis, planning, design, acquisition, lifecycle support, and management of Federal Aviation Administration (FAA) programs.

There are many definitions of SE in textbooks, professional journals, and classrooms. The following definition has been selected for the SEM:

> *A discipline that concentrates on the design and application of the whole (system) as distinct from the parts. It involves looking at a problem in its entirety, taking into account all the facets and all the variables and relating the social to the technical aspect.*

SE addresses translation of stakeholder needs into system requirements and facilitates the process by which the specification of systems and/or components satisfies those requirements. Although programs differ in underlying requirements, SE provides a logical sequence of steps toward deriving good requirements and transforming them into solutions regardless of the program's size or complexity. These steps generate a series of work products that specify characteristics of systems (at any level), demonstrate and document the traceability to stakeholder needs (expressed or implied), and define how the requirements are validated and the systems (and associated components) are verified. To maximize effectiveness, SE commences before any significant product development activities and continues throughout the program's lifecycle. When performed correctly, SE helps to ensure that program execution is right from the start. If problems are encountered, they are detected and resolved early. This process reduces program cost and risk.

1.1 Purpose

The four primary purposes of this manual are to:

- Define the FAA's integrated practice of SE to be used by any engineer or group performing a task requiring an SE approach; by design, this practice is compatible with all components of the agency and consistent with sound government and industry best policies and guidelines
- Provide methods and tools that result in effective and consistent SE
- Supply detailed information on work products of SE activities that are needed to ensure uniform and consistent high-quality products Enable
- SE to participate in and support Program Management needs
- Enable SE to participate in and support Program Management

1.2 Scope

The SEM describes 12 major SE elements as they are applied within the FAA. The SEM supports the Acquisition Management System (AMS) by identifying the proper application of SE elements in the AMS decision and acquisition processes. Figure 1.2-1 shows the 12 SE elements.

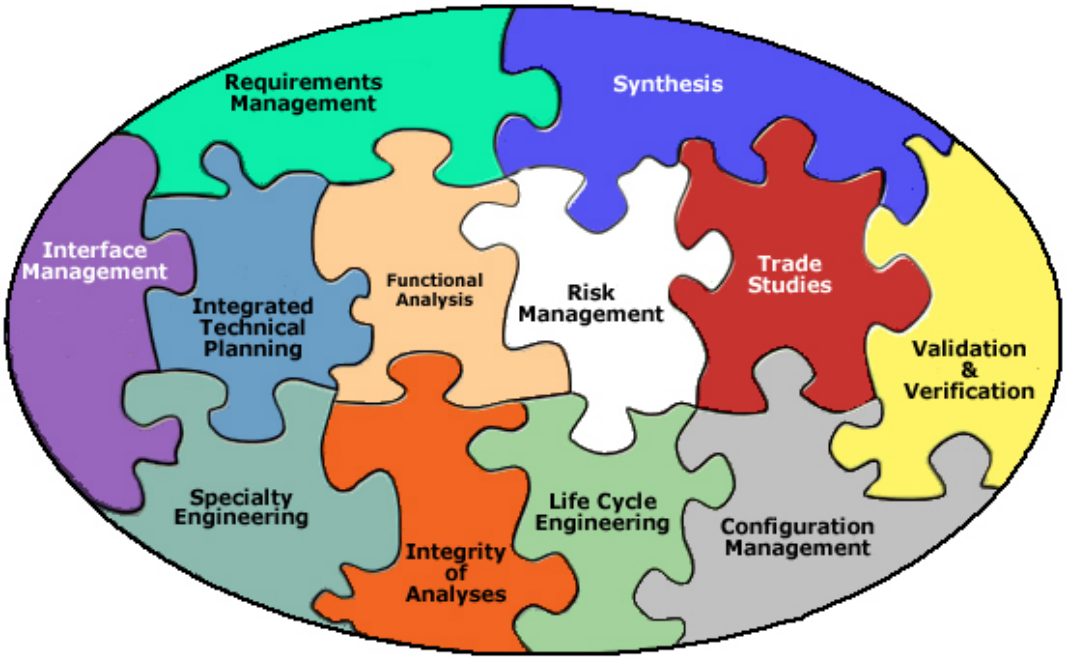


Figure 1.2-1. Federal Aviation Administration System Engineering Elements

As a how-to manual for SE, the SEM defines the constituent SE elements to be performed throughout the program lifecycle. The term “program” is intended to mean projects of all sizes and complexity, ranging from the NAS to individual parts. While the SEM is primarily directed at NAS modernization, it is recommended that individual programs tailor the application of processes, tools, and techniques according to program requirements. Further, implementation of these processes are to be directed by the appropriate SE management authority designated in the NAS System Engineering Management Plan (SEMP) or, on a given program, by the Chief System Engineer or Program Manager. This manual includes guidance on tailoring (see Section 3.6).

The SEM defines the FAA SE elements as well as the work products generated from each SE element. The 12 elements appear in Table 1.2-1 along with each element’s purpose or function. A 13th element listed provides for process management and maintenance of the other 12 elements.

Table 1.2-1. System Engineering Elements

System Engineering Element	Purpose of Element
Integrated Technical Planning	Plans the SE efforts and products.
Requirements Management	Identifies and manages the requirements that describe the desired characteristics of the system.
Functional Analysis	Describes the functional characteristics (what the system needs to do) that are used to derive requirements.
Synthesis	Transforms requirements into physical solutions.
Trade Studies	Assists decisionmaking by analyzing and selecting the best-balanced solutions to requirements.
Interface Management	Identifies and manages the interactions between segments within a system or interactions with other peer systems.
Specialty Engineering	Analyzes the system, requirements, functions, solutions, and/or interfaces using specialized skills and tools. Assists in the derivation of requirements, synthesis of solutions, selection of alternatives, and validation and verification of requirements.
Integrity of Analyses	Ensures that the analyses provide the required level of fidelity and accuracy.
Risk Management	Identifies, analyzes, and manages the uncertainties of achieving program requirements by developing strategies to reduce the severity or likelihood of those uncertainties.
Configuration Management	Establishes and maintains consistency and manages change in the system performance, functional, and physical attributes.
Validation and Verification	Determines if system requirements are correct. Determines that the solution meets the validated requirements.
Lifecycle Engineering	Identifies and manages requirements for system lifecycle attributes, including real estate management, deployment and transition, integrated logistics support, sustainment/technology evolution, and disposal.
System Engineering Process Management	Manages and maintains SE processes to meet FAA goals. Gains agencywide skill and standardization by continuously improving the effectiveness and efficiency of SE processes and tools.

1.3 Organization of the Manual

Chapter 1 contains the Purpose, Scope, Manual Organization, Relationship Between the SEM and the SEMP, System Engineering Process Descriptions, and Process-Based Management and System Engineering. The historical background and context for the SE practice appear in Chapter 2. Chapter 3 provides a fairly high-level description of the relationship between this manual and each phase of the FAA AMS. A detailed discussion of each of the major SE elements and their interrelationships appears in Chapter 4. Also included is a correlation between each of the SE elements (with its associated Chapter 4 paragraph number) and the reference to the associated section of the integrated Capability Maturity Model (iCMM) (e.g., SEM 4.12; iCMM PA 08).

The following appendices are included:

- Acronyms
- Glossary
- Initial System Requirements Review Checklist
- Concerns and Issues
- Integrated Technical Planning Details
- AMS Lifecycle Phase and Associated SE Element Work Products

1.4 Relationship Between the SEM and the SEMP

The SEM and SEMP are designed to work together. The SEM answers SE questions related to what and how, while the SEMP answers SE questions related to what, who, when, and why (i.e., why a particular organization or program is implementing or not implementing a particular SE element versus the SEM's discussion regarding a SE element's purpose). The "what" or products and activities of SE directly connect them. This relationship between the SEM and SEMP appears in Figure 1.4-1

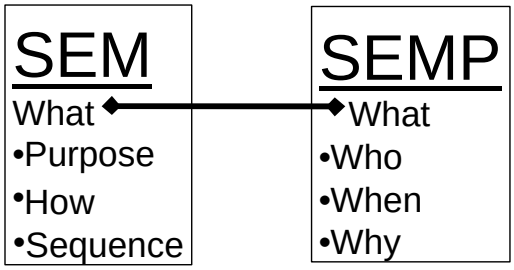


Figure 1.4-1. Relationship Between the System Engineering Manual and the System Engineering Management Plan

1.5 System Engineering Process Descriptions

The SE process descriptions in Chapter 4 include the following information:

- **Process Definition.** Included are the purpose for carrying out the specific SE process and a narrative description of the specific SE process. This narrative discusses the function for the process (what to do). Program implementers may use this information to tailor specific activities to align them with the development events of the program.

- **Process-Based Management (PBM) Charts.** Each SE element section in Chapter 4 contains a standard template that uses PBM charts to describe the SE element process. The templates indicate the major steps of the SE process, inputs to the process and associated providers, possible outputs generated, and associated product customers (from an SE view). The SEM also identifies the supplying (inputs) and using (outputs) processes that are used during process implementation to establish necessary program communication, documentation, and review activities.

The granularity of products, both input and output, depends on the phase of the AMS lifecycle to which the particular SE element being discussed is applied. For example, synthesis results in much greater solution development than during Mission Analysis.

The process descriptions consist of all aspects of each SE process, including the need to design for safety as well as for affordability, performance, usability, operational suitability, and cost of ownership. On some programs, a given activity may be performed informally (e.g., in an engineer's notebook) or formally, with interim products under formal baseline control.

Each SE process includes these major workflow tasks, which are also shown in PBM chart form.

- **How To Do It.** The SEM discusses specific approaches or techniques for implementing each SE process and provides guidance for selecting the right approach for a given program phase. It summarizes the key points, focusing on the what and why as well as the how.

- **Inputs.** This category includes information from external sources or other processes that initiates the process or is received during the conduct of the process.

- **Outputs.** This category includes information developed during and by the conduct of the process.

- **Entrance Criteria.** This category is what is required to start the process.

- **Exit Criteria.** This category includes the set of activities and products that are to be completed by the end of the process.

- **Metrics.** This category includes examples of metrics for measuring the level of performance for the process, as well as the work products generated by the process.

- **Methods/Tools.** This category includes specific tools or methods that are necessary (or desirable) to efficiently implement the process as described. They also let the user know what is available within the AMS FAA Acquisition System Toolset (http://fast.faa.gov/).

- **Examples.** This category includes examples of both SE work products and the standard templates for producing the SE work products. Examples may be contained either within a particular section of Chapter 4, an appendix to the SEM, or on the FAA's intranet, in which case a reference uniform resource locator (URL) is provided.

- **References.** This category includes documents from the government, industry, and academia that cover relevant topics regarding that section.

1.6 Process-Based Management and System Engineering

It is very difficult to develop a generic, top-level process model that reflects all interactions among the processes for the SE elements shown earlier in Table 1.2-1. The interactions and iterations between the SE elements may be different depending on the program under consideration. Chapter 3 contains a definition of the SE element interaction for each of the major phases of the AMS (i.e., Mission Analysis, Investment Analysis, Solution Implementation, In-service Management, and Disposal). In addition, Figure 3.1-1, System Engineering Functional N^2 Diagram, contains an N^2 diagram that depicts the interrelationships, inputs, outputs, and products from the related processes. As stated above, Chapter 4 contains a standard template that uses PBM charts to describe the SE element process.

2 OVERVIEW OF SYSTEM ENGINEERING

This section traces several key developments and lessons learned that led to today's championing of SE as a powerful approach to organizing and conducting complex programs, such as those found in the NAS. SE continues to evolve, with an emphasis on stronger commercial- and team-based engineering organizations, as well as organizations without technical products. Before World War II, architects and civil engineers were, in effect, system engineers who worked on large, primarily civil, engineering projects, including the Egyptian pyramids, Roman aqueducts, Hoover Dam, the Golden Gate Bridge, and the Empire State Building, while other architects worked on trains and large ships. However, "early" system engineers operated without any theory or science to support SE. Thus, they lacked defined and consistently applied processes or practices. During World War II, a program manager and chief engineer might oversee development of an aircraft program, while others managed key subsystems, such as propulsion, controls, structure, and support systems, leading to a lack of uniformity throughout the process.

Some additional SE elements, such as operations research and decision analysis, gained prominence during and after World War II. Today, with more complex requirements and systems, chief engineers use SE to develop requirements and to integrate the activities of the program teams.

SE began to evolve as a branch of engineering during the late 1950s. At this time—when both the race to space and the race to develop missiles equipped with nuclear warheads were considered absolutely essential for national survival—the military services and their civilian contractors were under extreme pressure to develop, test, and place in operation nuclear-tipped missiles and orbiting satellites. In this climate, the services and their contractors sought tools and techniques to improve system performance (mission success) and program management (technical performance, delivery schedule, and cost control). Engineering management evolved, standardizing the use of specifications, interface documents, design reviews, and formal configuration management. The advent of hybrid and digital computers permitted extensive simulation and evaluation of systems, subsystems, and components that facilitated accurate synthesis and tradeoff of system elements.

The lessons learned with development programs led to innovative practices in all phases of high-technology product development. A driving force for these innovations was attainment of high-system reliability. Some examples of changes introduced during the period are:

- Parts traceability
- Materials and process control
- Change control
- Product accountability
- Formal interface control
- Requirements traceability

2.1 What Is System Engineering?

Beyond the definition used in the Introduction (Chapter 1), SE is an overarching process that trades off and integrates elements within a system's design to achieve the best overall product and/or capability known as a system. Although there are some important aspects of program management in SE, it is still much more of an engineering discipline than a management discipline. SE requires quantitative and qualitative decisionmaking involving tradeoffs, optimization, selection, and integration of the results from many engineering disciplines.

SE is iterative—it derives and defines requirements at each level of the system, beginning at the top (the NAS level) and propagating those requirements through a series of steps that eventually leads to a physical design at all levels (i.e., from the system to its parts). Iteration and design refinement lead successively to preliminary design, detail design, and final approved design. At each successive level, there are supporting lower-level design iterations that are necessary to gain confidence for decisions. During these iterations, many concept alternatives are postulated, analyzed, and evaluated in trade studies. These iterative activities result in a multi-tier set of requirements. These requirements form the basis for structured verification of performance. SE closely monitors all development activities and integrates the results to provide the best solution at all system levels.

2.2 What Is a System?

A system is an integrated set of constituent parts that are combined in an operational or support environment to accomplish a defined objective. These integrated parts include people, hardware, software, firmware, information, procedures, facilities, services, and other support facets. People from different disciplines and product areas have different perspectives on what makes up a system. For example, software engineers often refer to an integrated set of computer modules as a system. Electrical engineers might refer to a system as complex integrated circuits or an integrated set of electrical units. The FAA has an overarching system of systems called the NAS that includes, but is not limited to, all the airports; aircraft; people; procedures; airspace; communications, navigation, and surveillance/air traffic management systems; and facilities.

At times, it is difficult to agree on what comprises a system, as it depends entirely on the focus of those who define the objective or function of the system. For example, if the objective is to print input data, a printer may be defined as the system. However, another might consider the electricity required for the printer. Expanding the objective to processing input data and displaying the results yields a computer as the system. Further expansion of the objective to include a capability for computing nationwide or worldwide data and merging data/results into a database results in a computing network as the system, with the computer and printer(s) as subsystems of the system.

SE first defines the system at the top level, ensuring focus and optimization at that level, thus precluding narrow focus and suboptimization. It then proceeds to increasingly detailed lower levels until the system is completely decomposed to its basic elements. This hierarchy is described in the following paragraph.

2.2.1 System Hierarchy

A system may include hardware, software, firmware, people, information, techniques, facilities, services, and other support items. Figure 2.2-1 establishes a common reference for discussing

the hierarchy of a system/subsystem within the NAS. Each system item may have its own associated hierarchy. For example, the various software programs/components that may reside in a system have a commonly accepted hierarchy as depicted in Figure 2.2-2. Thus, Figure 2.2-2 is a subset of Figure 2.2-1 in that a system/subsystem may have multiple Computer Software Configuration Items. The depths of this common hierarchy may be adjusted to fit the complexity of the system. Simple systems may have fewer levels in the hierarchy than complex systems and vice versa. Because there may be varying hierarchal models referenced in the realm of SE, it is important for those who define the objective or function of a given system/subsystem to also lay out the hierarchal levels of the system in order to define the system's scope.

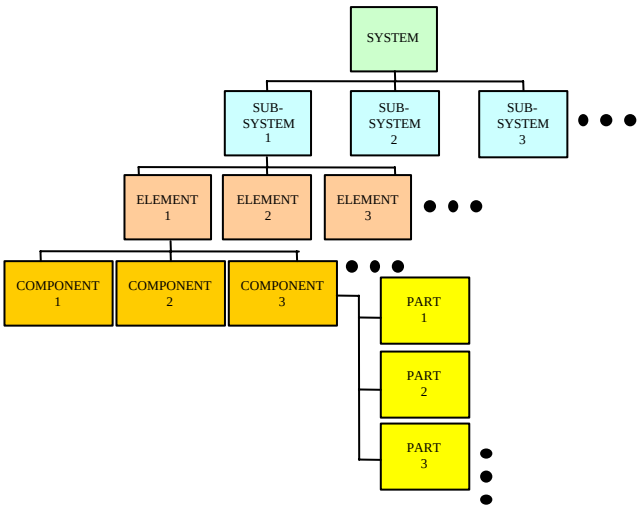


Figure 2.2-1. System Hierarchy

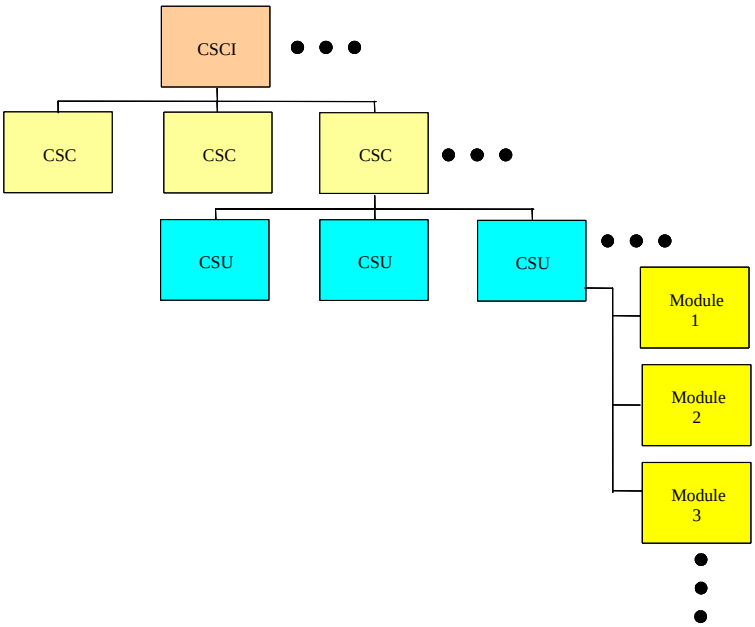


Figure 2.2-2. Common Software Hierarchy

Succeeding levels with the system/subsystem hierarchy are defined below:

- **System.** An integrated set of constituent parts that are combined in an operational or support environment to accomplish a defined objective. These parts include people, hardware, software, firmware, information, procedures, facilities, services, and other support facets.
- **Subsystem.** A system in and of itself (reference the system definition) contained within a higher-level system. The functionality of a subsystem contributes to the overall functionality of the higher-level system. The scope of a subsystem's functionality is less than the scope of functionality contained in the higher-level system.
- **Element.** An integrated set of components that comprise a defined part of a subsystem (e.g., the fuel injection element of the propulsion subsystem).
- **Component.** Composed of multiple parts; a clearly identified part of the product being designed or produced.
- **Part.** The lowest level of separately identifiable items within a system.
- **Software.** A combination of associated computer instructions and computer data definitions required to enable the computer hardware to perform computational or control functions.
- **Computer Software Configuration Item (CSCI).** An aggregation of software that is designed for configuration management and treated as a single entity in the Configuration Management process (Section 4.11).
- **Computer Software Component (CSC).** A functionally or logically distinct part of a CSCI, typically an aggregate of two or more software units.
- **Computer Software Unit.** An element specified in the design of a CSC that is separately testable or able to be compiled.
- **Module.** A program unit that is discrete and identifiable with respect to compiling, combining with other units, and loading.

2.3 Why Use System Engineering?

The need for effective SE is most apparent with large, complex system developments, such as weapons and transportation systems. However, SE is also important in developing, producing, deploying, and supporting much smaller systems, such as cameras and printers. The growing complexity in development areas has increased the need for effective SE. For example, about 35 years ago in the semiconductor industry, a single chip was no more complex than a series of a few gates or, at most, a four-stage register. Today, Intel's Pentium processor is far more complex, which immensely expands the application horizon but demands far more sophisticated analysis and discipline in design.

The movement to concurrent engineering as the technique for performing engineering development is actually performing good SE. SE provides the technical planning and control mechanisms to ensure that the activities/results of concurrent engineering meet overall system requirements.

A driving principle for SE is the teaming that often occurs during development programs. In this case, teaming is among several entities that may have different tools, analysis capabilities, and

so on. SE principles defined in this manual may provide an improved ability to plan and control activities that require interaction and interfacing across boundaries.

The strongest argument for using the SE processes is that they increase the likelihood that needs may be fully and consistently met in the final product.

3 SYSTEM ENGINEERING IN THE ACQUISITION MANAGEMENT SYSTEM PROGRAM LIFECYCLE

3.1 Introduction

This chapter discusses the relationship between the SE elements and their association with the phases of the AMS. The products generated by each of the SE elements and the inputs to and outputs from these elements are described for each AMS phase, and the elements are associated with the JRC decision points.

This SEM reflects the recently approved SE standards, methodologies, and processes. It recognizes that the current state of the referenced AMS, SE documents, and processes herein may not currently be in total agreement because that documentation and the SEM are in different update cycles.

The inputs, SE activities, and outputs of each of the AMS phases appear graphically. Also, included is a section is to provide guidance on tailoring the SE process to a particular program.

3.1.1 Relationship Between the System Engineering Elements

Chapter 1 (see Table 1.2-1) lists the SE elements. This section discusses the relationships between the SE elements by portraying the inputs to and the outputs from the various elements. This approach describing these interrelationships uses an N^2 diagram for the SE elements. The SE elements are arrayed along the diagonal in Figure 3.1-1. The interpretation of the N^2 diagram is to take the intersection of the rows and columns interconnecting any two elements and reading the contents of those blocks. The information contained therein indicates the interface between the elements in the form of inputs, outputs, and products.

3.1.2 Relationship of the System Engineering Elements to the Acquisition Management System Program Lifecycle

The program lifecycle includes all activities and products associated with a system, from initial concept to disposal and elimination. This falls in line with the global aspects of SE's definition. Definitions of the program lifecycle phases serve different purposes for different SE elements. It is recommended that System sponsors and high-level management executives use these phases and their associated milestones (e.g., Mission Need Decision (MND), Initial and Final Investment Decisions, and In-Service Decision) to determine whether to continue or terminate the endeavor. Thus, it is recommended that the phases be used to measure a program's progress and develop input to the Joint Resources Council (JRC), which ultimately makes the noted decisions.

EXTERNAL	FAA Policy Integrated Program Schedule Corporate Strategy and Goals	Constraints FAA Management Decisions Govt & Intl Regulations & Statutes Legacy System Stakeholder Needs Standards Technology	FAA Management Decisions Legacy System	Constraints Legacy System Market Research Standards Technology	Market Research Technology Constraints Integrated Program Schedule	FAA Policy Legacy System Standards Interface Change Request	FAA Policy Standards	Technology Constraints	External Environmental Forces Constraints Technology Concerns/Issues Integrated Program Schedule	FAA Policy	Need Standards	Technology Test & Assessment Articles	Constraints External Environmental Forces Govt & Intl Regulations & Statutes Market Research FAA Policy Technology Concerns/Issues Integrated Program Schedule	
Integrated Program Plan	**INTEGRATED TECHNICAL PLANNING**	Integrated Lifecyle Plan Integrated Program Plan NAS Architecture SEMP	Integrated Program Plan SEMP	Integrated Program Plan SEMP	Constraints Integrated Logisitics Support Plan Integrated Program Plan SEMP	Integrated Program Plan NAS Architecture SEMP	Integrated Lifecyle Plan Integrated Program Plan NAS Architecture SEMP	Integrated Program Plan SEMP	Concerns/Issues Integrated Program Plan SEMP	Integrated Program Plan NAS Architecture SEMP	Integrated Program Plan NAS Architecture SEMP	Integrated Program Plan Master Verification Plan NAS Architecture SEMP	Integrated Lifecyle Plan Integrated Program Plan NAS Architecture SEMP	
Requirements RVCD	Planning Criteria	**REQUIREMENTS MANAGEMENT**	Mission Need Statement Requirements	Requirements RVCD	Constraints Requirements	Requirements Mission Need Statement	Requirements RVCD	Requirements Tools/Analysis Requirements	Requirements RVCD Concerns/Issues	Requirements	Requirements	Requirements VRTM	Mission Need Statement Requirements	
	Concept of Operations NAS CONOPS Planning Criteria	Concept of Operations Functional Architecture OSED	**FUNCTIONAL ANALYSIS**	Functional Architecture OSED	Constraints Functional Architecture OSED	Concept of Operations Functional Architecture OSED	Concept of Operations Functional Architecture OSED	Tools/Analysis Requirement	Concerns/Issues	Functional Architecture OSED	Concept of Operations Functional Architecture OSED	Functional Architecture	OSED	
	Planning Criteria	Constraints Requirements Physical Architecture	Physical Architecture	**SYNTHESIS**	Physical Architecture Design Constrain Constraints Description of Alternatives	Operational Concept Dem Physical Architecture	Description of Alternatives Physical Architecture	Tools/Analysis Requirements	Concerns/Issues	Configuration Description	Operational Concept Dem Physical Architecture	Physical Architecture	Design Constrain Operational Concept Demo	
Trade Study Reports	Planning Criteria	Trade Study Reports		Trade Study Reports	**TRADE STUDIES**	Trade Study Reports		Tools/Analysis Requirements	Concerns/Issues				Trade Study Reports	
	Planning Criteria	Interface Control Documents Interface Requirements Documents	Interface Control Documents	Interface Requirements Documents	Constraints	**INTERFACE MANAGEMENT**	Interface Control Documents		Concerns/Issues	Interface Revision Proposal Interface Requirements Documents Interface Control Documents	Interface Requirements Documents	Interface Control Documents		
Certification Package	Planning Criteria	Design Analysis Reports Requirements	Design Analysis Reports	Design Analysis Reports	Design Analysis Report Constraints	Design Analysis Reports	**SPECIALTY ENGINEERING**	Design Analysis Reports Tools/Analysis Requirements	Concerns/Issues Design Analysis Reports		Demonstrations Design Analysis Reports	Demonstrations Verification Criteria Design Analysis Reports	Design Analysis Reports	
Credible Analysis Results	Analysis Criteria Planning Criteria	Analysis Criteria	Analysis Criteria	Analysis Criteria	Analysis Criteria Constraints		Analysis Criteria	**INTEGRITY OF ANALYSES**	Concerns/Issues Analysis Criteria	Credible Analysis Results		~~Analysis Criteria~~	Analysis Criteria	
Program Risk Register Program Risk Summary Risk Mitigation Plan Summary Risk Mitigation Plans	Planning Criteria	Risk Mitigation Plans		Risk Mitigation Plans	Constraints			Tools/Analysis Requirements	**RISK MANAGEMENT**					
	Planning Criteria	Approved Baseline Changes Configuration Status Report Updated Baselines		Configuration Status Report Updated Baselines Approved Baseline Changes	Constraints		Baselines	Baselines	Baselines Concerns/Issues	**CONFIGURATION MANAGEMENT**		Validation Reports Updated Baselines Configuration Status Report Approved Baseline Changes	Updated Baselines Configuration Status Report Approved Baseline Changes	
	Planning Criteria	Validation Reports	Validated Need		Constraints		Validation Reports		Concerns/Issues		**VALIDATION**			
	Planning Criteria	RVCD VRTM			Constraints			Tools/Analysis Requirements	Concerns/Issues			**VERIFICATION**		
	Planning Criteria			Lifecycle Cost Estimate	Lifecycle Cost Estimate Constraints			Tools/Analysis Requirements	Concerns/Issues Constraints				**LIFE CYCLE ENGINEERING**	
NAS SEMP	NAS SEMP	NAS SEMP	NAS SEMP	NAS SEMP	NAS SEMP	NAS SEMP	NAS SEMP	NAS SEMP	NAS SEMP	NAS SEMP	NAS SEMP	NAS SEMP	NAS SEMP	**Maintain SE Process**

Figure 3.1-1 System Engineering Functional N2 Diagram

Each program decision milestone is associated with a review. The reviews and milestones are:

- **JRC 1/MND milestone.** During the mission analysis phase, an Investment Analysis Readiness Review (IARR) is conducted just prior to the JRC 1 MND milestone. An IARR briefing is presented to the Federal Acquisition Executive (FAE) and the sponsors for approval. Following the successful approval of the IARR, a briefing for review by the JRC is conducted before the MND.

- **JRC 2a/Initial Investment Decision milestone.** A briefing for review by the JRC is conducted before the Initial Investment Decision.

- **JRC 2b/Final Investment Decision milestone.** During the final Investment Analysis (IA) stage of the IA phase, an optional Initial System Requirements Review (ISRR) may be conducted a couple of months prior to the Final Investment Decision Milestone. A briefing for review by the JRC is conducted before the Final Investment Decision.

- **JRC 3/In-Service Decision milestone.** The In-service Review checklist is reviewed and a briefing for review by the appointed decision authority is conducted before the In-Service Decision.

3.2 Systems Engineering Elements and the AMS

Following are the FAA SE elements associated with each of the AMS phases (Figure 3.2-1).

Mission Analysis	**Investment Analysis**
Integrated Technical Planning	Integrated Technical Planning
Requirements Management	Requirements Management
Functional Analysis	Functional Analysis
Synthesis	Synthesis
Interface Management	Trade Studies
Specialty Engineering	Interface Management
Integrity of Analyses	Specialty Engineering
Validation	Integrity of Analyses
Lifecycle Engineering	Risk Management
	Validation
	Lifecycle Engineering

Solution Implementation	**In- Service Management**
Integrated Technical Planning	Integrated Technical Planning
Requirements Management	Requirements Management
Functional Analysis	Functional Analysis
Synthesis	Synthesis
Trade Studies	Trade Studies
Interface Management	Interface Management
Specialty Engineering	Specialty Engineering
Integrity of Analyses	Integrity of Analyses
Risk Management	Risk Management
Configuration Management	Configuration Management
Verification	Verification
Lifecycle Engineering	Lifecycle Engineering

Figure 3.2-1. AMS Program Phase and Associated SE Elements

3.3 AMS/System Engineering Work Products Inputs and Outputs

To introduce the system engineering inputs, outputs, and work products associated with system engineering activities during each phase of the AMS, Table 3.3-1 contains a legend for the AMS phase inputs and outputs and developmental status of the work products and documents.

Table 3.3-1. Legend for AMS/System Engineering Work Products Inputs and Outputs for AMS Phases

Abbreviation		Meaning
C	=	Conceptual draft (precedes initial draft): The general notion and structure of the document has been created with minimal content.
I	=	Initial draft: The document has been populated with the majority of required content, but it still requires review for accuracy of information.
F	=	Final draft: The document is complete, accurate, and awaiting signature.
SD	=	Sustaining Document: For work products that are formal documents, the documents are sustained in the given phase. For work products that are not formal documents, the products are introduced, further developed, or sustained in the given phase.
SE	=	System Engineering

3.3.1 Associating System Engineering Work Products Inputs and Outputs With AMS Phases

The following sections of Chapter 3 associate the SE activities with each phase of the AMS lifecycle. Data Flow Diagrams highlight the SE processes and work products that are predominant during the associated AMS phase. In addition, a table is included that:

- Identifies the SE work products that are inputs and/or outputs to/from each of the AMS phases
- Identifies work products generated from processes external to SE that are necessary to initiate SE activities within the given phase

Table 3.3-2 is a high-level view of the various SE inputs, outputs, and work products and the AMS phases during which it is recommended that they be developed.

Table 3.3-2. AMS/System Engineering Work Products Inputs and Outputs for AMS Phases

AMS/SE INPUT, OUTPUT, OR WORK PRODUCT	JRC 1	JRC 2a	ISRR	JRC 2b	JRC 3
Acquisition Program Baseline (APB)		I	SD	F	SD
Analysis Criteria	I	F	SD	SD	SD
Approved Baseline Changes					SD
Certification Package				I	F
Concept of Operations (CONOPS)	F	SD	SD	SD	SD
Concerns/Issues	SD	SD	SD	SD	SD
Configuration Description		I		F	
Configuration Status Report		SD	SD	SD	SD
Constraints	SD	SD	SD	SD	SD
Corporate Strategy and Goals	SD	SD	SD	SD	SD
Credible Analysis Results	SD	SD	SD	SD	SD
Demonstrations		SD	SD	SD	SD
Description of Alternatives	I	F			
Design Analysis Reports (DAR)	SD	SD	SD	SD	SD
Design Constraint	SD	SD	SD	SD	SD
External Environmental Forces	SD	SD	SD	SD	SD
FAA Management Decisions	SD	SD	SD	SD	SD
FAA Policy	SD	SD	SD	SD	SD
Functional Architecture	I	F[1]	SD	SD	SD
Functional Specification (i.e., E-spec.)		I		F	
Government and International Regulations and Statutes	SD	SD	SD	SD	SD
Integrated Lifecycle Plan		I		F	SD
Integrated Program Plan (IPP)		I		F	SD
Integrated Program Schedule		I		F	SD
Interface Change Request					SD
Interface Control Documents (ICD)				I	F
Interface Requirements Documents (IRD)		I		F	
Interface Revision Proposal				SD	SD
Investment Analysis Plan	I	F			
Investment Analysis Readiness Review	F				
Legacy System	SD	SD	SD	SD	SD
Lifecycle Cost Estimate	I			F	
Market Research	SD	SD	SD	SD	
Master Verification Plan (MVP)		I		F	SD
Mission Need Statement (MNS)	F	SD	SD	SD	SD
NAS Architecture	SD	SD	SD	SD	SD
NAS Concept of Operations (CONOPS)	SD	SD	SD	SD	SD
NAS System Engineering Management Plan	SD	SD	SD	SD	SD
Operational Concept Demonstrations		SD	SD	SD	

Table 3.3-2. AMS/System Engineering Work Products Inputs and Outputs for AMS Phases (Continued)

AMS/SE INPUT, OUTPUT, OR WORK PRODUCT	JRC1	JRC2A	ISRR	JRC2B	JRC3
Operational Services and Environmental Description		I		F	
Physical Architecture	C	I		F	
Planning Criteria	SD	SD	SD	SD	SD
Program Risk Register		SD	SD	SD	SD
Program Risk Summary		SD	SD	SD	SD
Requirements	I	F[1]	SD	SD	SD
Requirements Verification Compliance Document (RVCD)		I		F	
Risk Mitigation Plan Summary	I	F	SD	SD	SD
Risk Mitigation Plans	I	F	SD	SD	SD
Stakeholder Needs	F	SD	SD	SD	SD
Standards	I	F	SD	SD	SD
Statement of Work		I		F	
System Engineering Management Plan (SEMP)		I		F	
Technology	SD	SD	SD	SD	SD
Test and Assessment Articles				I	F
Tools/Analysis Requirements		SD	SD	SD	SD
Trade Study Reports		SD	SD	SD	SD
Updated Baselines				SD	SD
Validated Need	I	F			
Validation Reports	SD	SD	SD	SD	SD
Verification Criteria	SD	SD	SD	SD	SD
Verification Requirements Traceability Matrix (VRTM)	C	I		F	SD
Work Breakdown Structure		I		F	

NOTE:
1. This does not imply that there is no further decomposition. For example, “Final” requirements at this point pertain to the final Requirements Document, yet further decomposition takes place to generate a functional specification (i.e., E-spec.).

3.4 AMS Program Phase

3.4.1 Mission Analysis Phase

3.4.1.1 Mission Analysis Phase Objectives

The basic objectives of the Mission Analysis (MA) phase is to correctly identify a capability shortfall, quantify a need, and identify potential technological opportunities to begin to resolve that need. Nonmaterial solutions are also evaluated during this phase. In most cases, the MA consists of activities to validate high-level needs and to seek approval to proceed to the Investment Analysis phase. It has two dimensions: a technical dimension and a program-

planning dimension. The technical dimension is to ensure that a complete understanding of the demand for services has been identified and quantified. This is accompanied by identification and quantification of existing and projected supply of services. The program-planning dimension is to identify potential project-scope and estimated resource requirements. The primary outputs of this phase are the final Mission Need Statement (MNS), an initial Requirements Document (iRD), initial Alternatives, Concept of Use, and an Initial Investment Analysis Plan. The MA phase ends with an MND. Figure 3.4-1 is an overview of the primary SE activities that occur during MA.

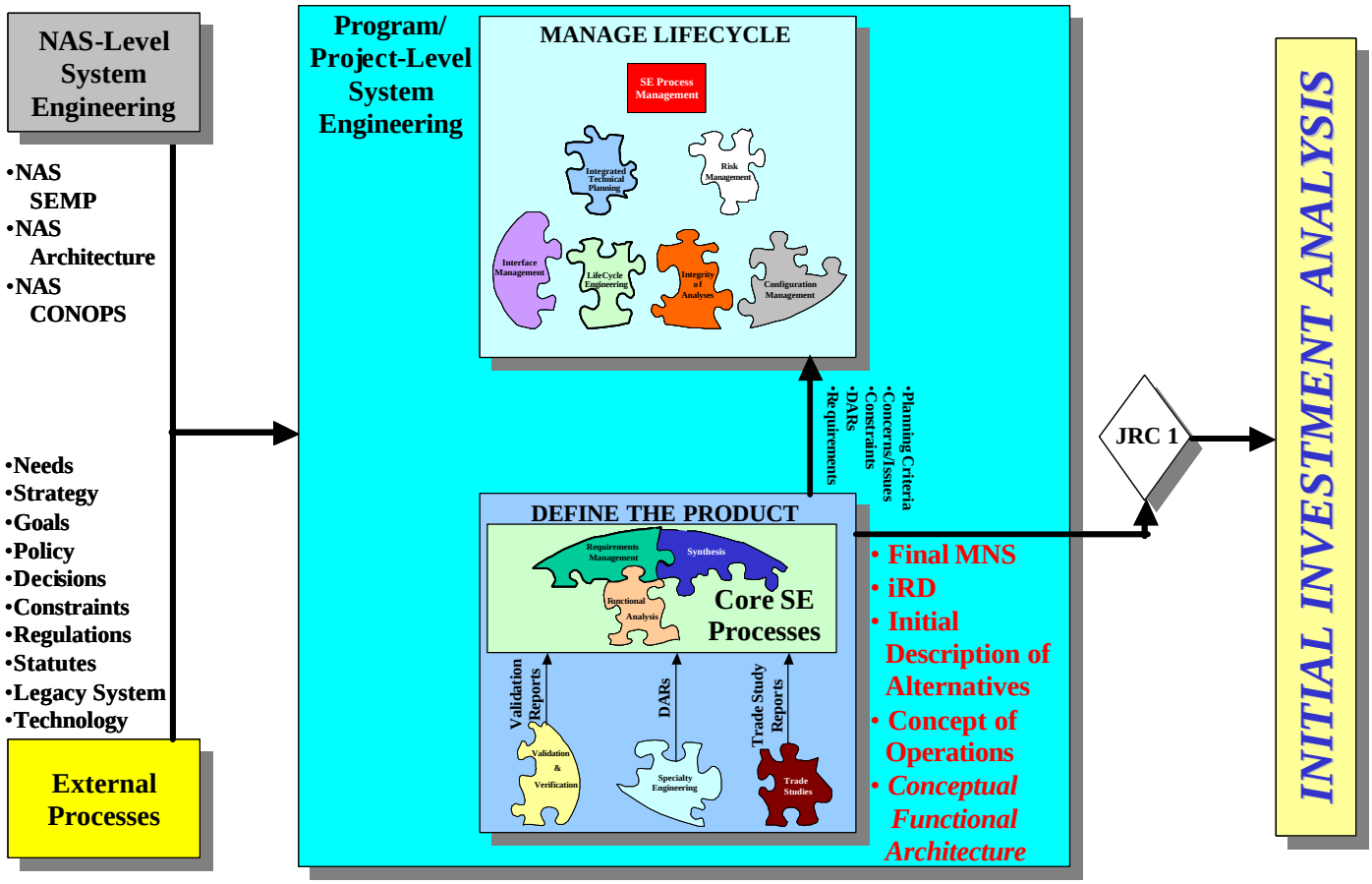


Figure 3.4-1 Mission Analysis System Engineering Inputs and Outputs

Table F-1, in Appendix F contains a legend for all of the SE Work Products and Inputs and Outputs for each AMS phase. Table F-2 in Appendix F lists the inputs and outputs for the MA phase and their association with that SE element that produces them.

3.4.1.2 Mission Analysis Inputs

The primary entrance criteria are the concept of a given “need” and approval to initiate SE efforts during the MA phase. Figure 3.4-1 shows the external processes that occur and influence the origination of a particular MA. But the two most important inputs are the

recognized “need” and the decision to proceed. The column labeled “JRC 1” in Table 3.3-2 contains the inputs and outputs and work products associated with the MA phase.

3.4.1.3 Mission Analysis System Engineering Activities

SE is initiated when a stakeholder need is recognized and is used to understand functionally what is required to meet the stated need. A system Concept of Operations (CONOPS) is developed via Functional Analysis (Section 4.4) and is used in Requirements Management (Section 4.3) to develop the MNS. The MNS is a primary SE output during the MA phase; it also drives the continued iterations of Functional Analysis and Requirements Management. The iRD is introduced here. The interaction of these two processes results in a high-level functional decomposition and, likewise, a high-level requirements decomposition. The resulting set of requirements is validated and is used, along with the high-level functional architecture, during the Synthesis process (Section 4.5) to develop a description of alternatives and associated design constraints. At this point in time, these alternatives and constraints are very high-level and are used as primary input into the IA phase to provide scope for the program. In addition to the core Functional Analysis, Requirements Management, and Synthesis activities, other SE processes are initiated during the MA phase. These activities involve technical planning to provide program management and guidance on planning both management and SE activities throughout the system’s lifecycle. This planning is required to provide proper guidance for SE activities, including identifying risks and plans to mitigate those risks and establishing analysis criteria for the various analyses that occur during system design. Any of the SE activities may surface concerns and issues to be processed by Risk Management (Section 4.10), as well as constraints to bound the activities of the Trade Studies process (Section 4.6) that occur during the follow-on phases.

Electronic Industries Alliance standard 731-2 defines a constraint as (1) a restriction, limit, or regulation or (2) a type of requirement that is not tradable against other requirements. Often, these are defined in work-scope statements given by project contributors during the cost definition process. This includes gathering stakeholder inputs on "needs," system constraints (costs, technology limitations, and applicable specifications and legal requirements), and system "drivers" (such as competition capabilities and critical environments). It is recommended that tradeoffs be done on the desirability of including a performance capability in the system versus a more affordable (or less risky) system approach. This tradeoff process often begins well before a firm set of needs is established and continues throughout the MA phase in which stakeholder interaction on specific items proposed may take place. Constraints may be further adjusted throughout later AMS phases. Like behavior deficiencies or shortfalls, these are excellent opportunities for preplanned product improvement. Funding, personnel, facilities, manufacturing capability, critical resources, or other reasons may cause constraints. The reason for each constraint is readily understood.

Risk always is present in the lifecycle of both developed and commercial systems. The system may be intended for technical accomplishments near the limits of the state of the art, creating technical risk. System development may be rushed to deploy the system as soon as possible to meet an urgent need, leading to schedule risk. All systems are funding-limited, so cost risk is present. Risk may be introduced by external constraints or may develop from within the program, since technical risk may create schedule risk that in turn may create cost risk. It is recommended that each SE element active during this phase surface concerns and issues that present risk to the program.

When the JRC 1 meeting is being planned and the briefing being prepared, it is recommended that each new initiative conduct an IARR. The FAE and sponsors conduct and approve the IARR. Documentation available for this review consists of the following:

- Final MNS
- iRD
- Initial Alternatives
- Rough Order of Magnitude Life Cycle Cost
- Concept of Use
- Initial Investment Analysis Plan

3.4.1.4 Mission Analysis Outputs

It is recommended that the following criteria be met before the program enters the IA phase:

- Initial Description of Alternative Solutions
- Successful conduct and approval of the IARR
- Completion of all work products identified as MA outputs (see column labeled JRC 1 in Table 3.3-2) to the version level specified

3.4.2 Investment Analysis Phase

3.4.2.1 Investment Analysis Phase Objectives

The IA phase of the AMS lifecycle has the following objectives:

- Further translate the final MNS and final Requirements Document (fRD) into lower-level requirements and eventually into functional specifications
- Select the optimum solution
- Refine the optimum solution from a NAS perspective
- Modify the architecture to the recommended solution
- Complete the Acquisition Program Baseline (APB), Integrated Program Plan (IPP), and all additional program plans
- Complete the functional architecture to a level appropriate to requirements (i.e., those levels needed to support development of the fRD or system specification)

- List and analyze all programmatic risks
- Provide risk mitigation plans with associated costs

3.4.2.2 Investment Analysis Inputs

The IA phase of the AMS begins with approval of a mission need and iRD and ends with an Investment Decision. There are two stages during the IA phase: the initial IA stage (or the JRC 2a stage) and the final IA stage (or the JRC 2b stage). This section treats the IA phase as a whole, while subsequent sections describe the individual stages. Each stage is described later, along with its separate flow diagrams. Effectively, the outputs of the MA phase represent the inputs to the IA phase.

3.4.2.3 Investment Analysis System Engineering Activities

The core SE processes continue, in an iterative fashion, to produce a design that meets the stakeholder need. The SE elements involved during the IA phase are listed in Figure 3.2-1. Table 3.3-2 lists the AMS/SE work products inputs and outputs for each IA stage (see columns labeled JRC 2a and JRC 2b). Flow diagrams are included later for each IA stage in Figures 3.4-2 and 3.4-3, respectively. The Functional Analysis (Section 4.4) continues to decompose the functions to lower levels. These lower-level functions are used to develop more detailed requirements that are used to bound the next level of functional decomposition. The Specialty Engineering (Section 4.8) feeds this process by providing various Design Analysis Reports to further refine the requirements and manage various risk facets. Requirements generated from this interaction are then validated. Once validated, they are fed into the Synthesis process (Section 4.5), where alternative solutions to meet these requirements are developed and refined. The Trade Studies process (Section 4.6) and the Lifecycle Engineering process (Section 4.13) are both heavily employed during this phase to provide Synthesis in making an informed decision concerning the best solution set. The resulting physical architecture, in conjunction with the functional architecture, is used in Interface Management (Section 4.7) to develop Interface Requirements Documents (IRD) and eventually Interface Control Documents.

3.4.2.4 Investment Analysis Outputs

The primary outputs from the SE efforts in this phase are the functional and physical architectures and associated requirements in the form of IRDs and the fRD. The inputs, outputs, and work products associated with the SE elements that produce them, appear in Figure F-3 and F-4 of Appendix F. Table 3.3-2 showed the products, inputs and outputs required to complete the associated JRC milestones (i.e., initial IA for JRC 2a and final IA for JRC 2b).

3.4.2.5 Initial Investment Analysis Phase

3.4.2.5.1 Initial Investment Analysis Phase Objectives

The key ingredients of the Initial IA phase appear in Figure 3.4-2. The initial IA is the first of two stages in the IA phase. The main objective of this stage is to refine the set of alternative solutions developed during MA in response to the MNS and the requirements contained in the iRD. To accomplish this objective, SE analyzes the high-level requirements so that the needs,

objectives, requirements, and operating scenarios are fully understood and integrated. Because these top-level requirements typically lack the details required to execute a design, it is

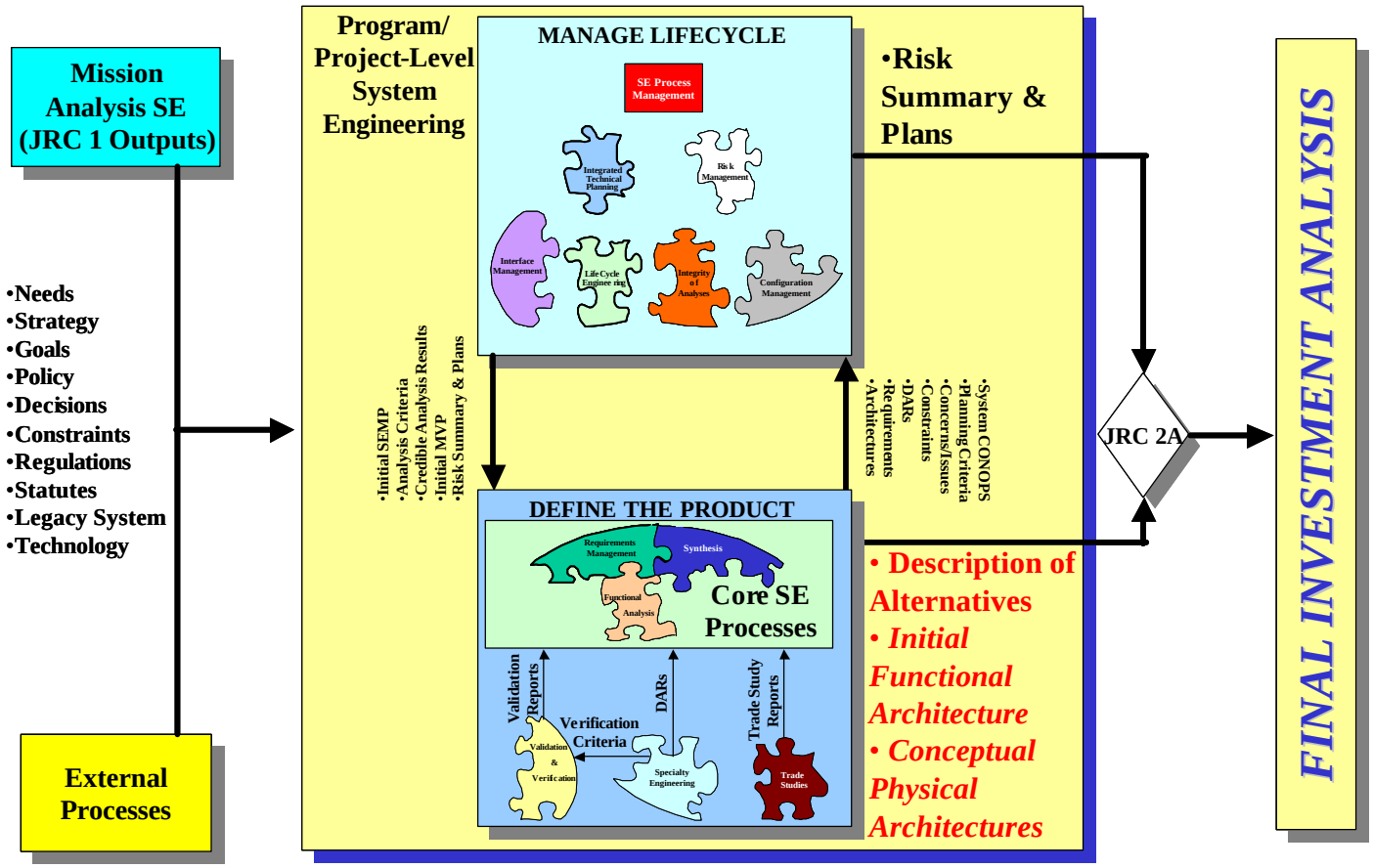


Figure 3.3-2 Initial Investment Analysis System Engineering Inputs and Outputs

important that stakeholders adequately communicate to eliminate gaps in understanding requirements. To this end, the needs, mission(s), and utilization environments are analyzed, interpreted, and coordinated with stakeholders to determine system requirements. This stage also identifies the required disciplines needed to support the effort as well as a review indicating that all stakeholders have been identified.

In this stage, the system functional architecture is expanded. The functions are then transformed into more detailed system requirements that are resolved in the system physical architectures. Higher-level requirements constrain the next lower functional architecture. In addition, the interfaces between the functions, subsystems, and elements that comprise the total system are documented. Functional and performance requirements are allocated to those subsystems and elements. Detailed subsystem and element requirements and constraints are developed, and subsystem and element concepts are traded and selected.

Further development and evaluation of alternative concepts pave the way for selection of the best concept. Each candidate concept is validated to ensure feasibility and that all requirements have been satisfied. Candidate alternative solutions that fail to meet requirements are modified or discarded. More detailed concept development and analyses are then

conducted to characterize each of the concepts to add maturity and facilitate selection of the best alternative. Trade Studies (Section 4.6) are conducted to select from alternative

approaches to satisfy requirements; identify preferred technologies and processes; define support concepts; assess lifecycle cost elements; and quantify program risks. Down-selection criteria are established based on design sensitivities, cost/benefit ratios, schedules, programmatic constraints and requirements, risks, corporate strategies, and other considerations, as applicable.

Of the set of viable alternatives, a single approach is selected before the close of this stage. The cost/benefit analysis that results in selection of the best concept is documented and made a part of the program documentation.

3.4.2.5.2 Initial Investment Analysis Inputs

These criteria include:

- An MND approving continuation of the program to the IA phase
- MA output, including an initial description of alternative solutions and an iRD
- Completion of all work products identified as MA outputs (see column labeled JRC 1 in Table 3.3-2) to the version level specified

Table F-3 in Appendix F lists the inputs and outputs for the Initial IA phase and associates them with the SE element that produces them.

3.4.2.5.3 Initial Investment Analysis System Engineering

In this stage of technical plans development, the following initial drafts of the IPP and the Integrated Lifecycle Plan are developed. In addition, the SEMP and Master Verification Plan (MVP) are created and developed to an initial draft state by the end of this stage. The iRD is developed to the fRD state. The IA process focuses on reviewing the CONOPS, refining the Operational System Environment Description from its initial draft, and further decomposing the next level of functions into sequenced and traceable functional architectures (dependent on the availability and detail of requirements documentation). During the initial IA, conceptual versions of the physical architectures for the set of alternatives are produced, and the description of alternatives are further refined. Activities during this phase include the design analysis of the benefits, strengths, and weaknesses of the alternative concepts against a common set of requirements and selection criteria to determine their relative merits. Design constraints are identified during this analysis. Concept demonstrations may also be conducted to support these activities. The draft IRD is developed during this phase to capture these interfaces. In addition to the tasks identified above, it is recommended that each SE element active during this phase surface concerns and issues that present risk to the program.

3.4.2.5.4 Initial Investment Analysis Outputs

Table 3.3-2 (JRC 2a column) contains the inputs and outputs and work products associated with the initial IA phase that are to be completed before the final IA phase. These outputs include the following:

- Solution selection has been made
- Authorization for the program to proceed to the final IA phase has been given

- All work products identified as initial IA outputs have been completed to the version level specified
- Required disciplines have been identified
- Initial baseline planning has been completed

3.4.2.6 Final Investment Analysis Phase

3.4.2.6.1 Final Investment Analysis Phase Objectives

The key ingredients of the Final IA phase appear in Figure 3.4-3. The main objective of this phase is to establish validated requirements, refine the final alternative solution, and document the complete functional and programmatic baselines for that solution.

During the Final IA Phase, the SEM introduces a new, optional milestone that does not appear in the current AMS. This milestone has been established to give management the option to step back and review the progress of work activities and products that are to be completed by the end of the final IA and before the JRC 2b review. This ISRR milestone, an optional point at which to review program progress, may be added usually 1 to 2 months before JRC 2b. This is not a mandatory AMS milestone, and the review is not conducted by the JRC, but may be used primarily as a means to review and agree upon the final set of system requirements.

Table F-4 in Appendix F lists the inputs and outputs for the Final IA phase and associates them with that SE element that produces the inputs and outputs.

3.4.2.6.2 Final Investment Analysis Phase Inputs

Prerequisites for entering the final IA phase include the following:

- The initial IA decision (JRC 2a) has been made, authorizing the program to proceed to the final IA stage
- Work products from the initial IA stage have been completed to the version level specified
- Solution selection has been made

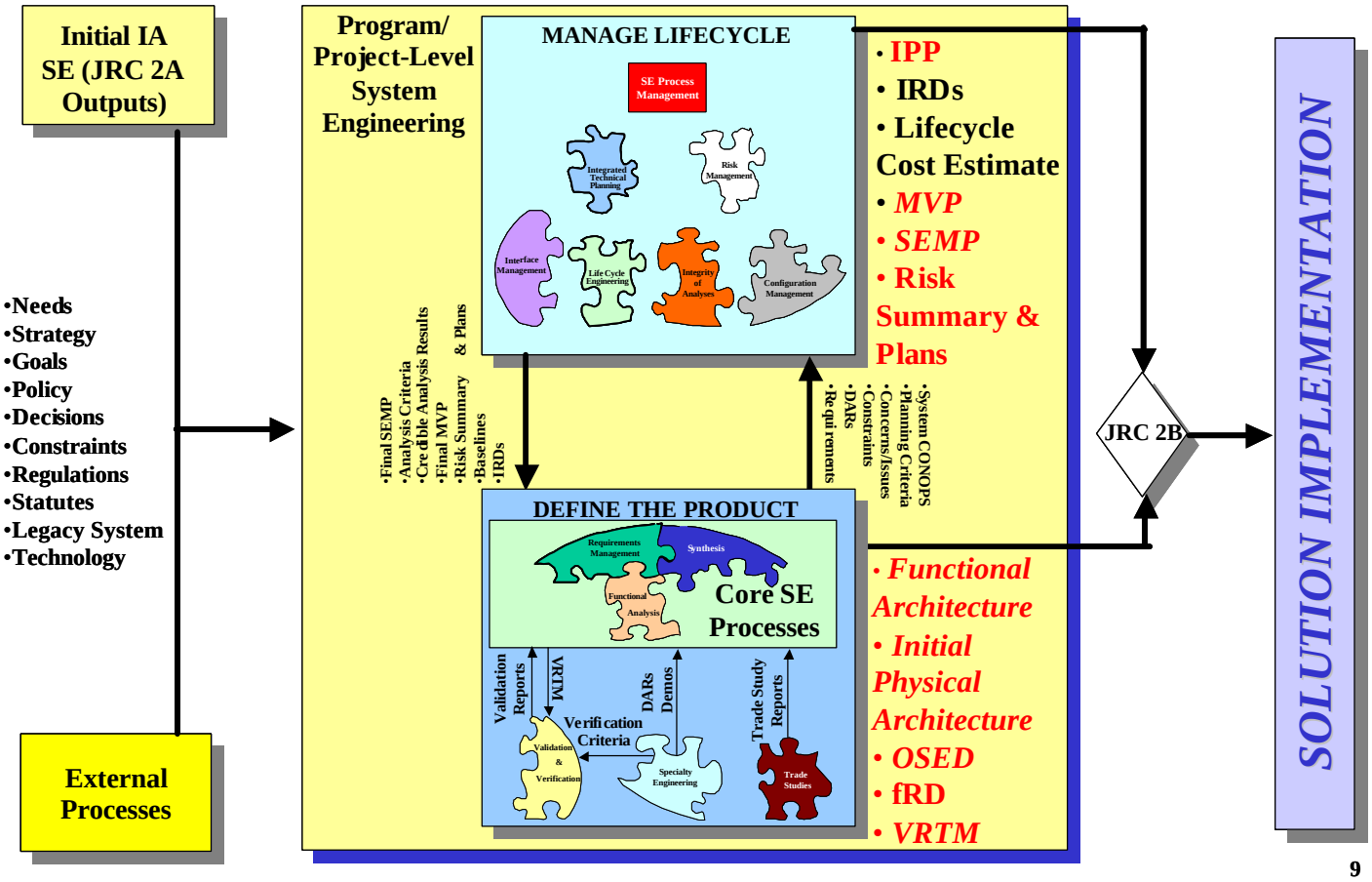


Figure 3.4-3 Final Investment Analysis System Engineering Inputs/Outputs

Table 3.3-2 (column 2b) lists the inputs, outputs, and work products associated with the final IA.

3.4.2.6.2 Final Investment Analysis Systems Engineering

The final IA stage further refines the physical architecture and adds maturity to the documentation. The functional architecture is completed. Selected subsystem and element concepts are expanded with details to verify that they meet high-level requirements and constraints. The interfaces between the elements that comprise the subsystems are documented. Functional and performance requirements and constraints are allocated to those elements, and packages defining development of the elements are created.

A business case is developed that illustrates all stakeholder costs and obligations, providing details of both agency and nonagency resource demands. Program requirements are completed, corrected, and documented in the fRD. The fRD is reviewed at this time in preparation for the JRC 2b. In addition, the interfaces between the components that comprise the elements are documented, and functional and performance requirements are allocated to those components. The planned procurement specifications are listed and the APB is finalized. A successful IA leads to the JRC 2b decision for the program. All work products identified as

ISRR (if option is elected; see “ISRR” column in Table 3.3-2) outputs have been completed to the version level specified. If the option for the ISRR is elected, an ISRR checklist (see Appendix C) may be used in preparing for this review milestone.

3.4.2.6.3 Final Investment Analysis Outputs

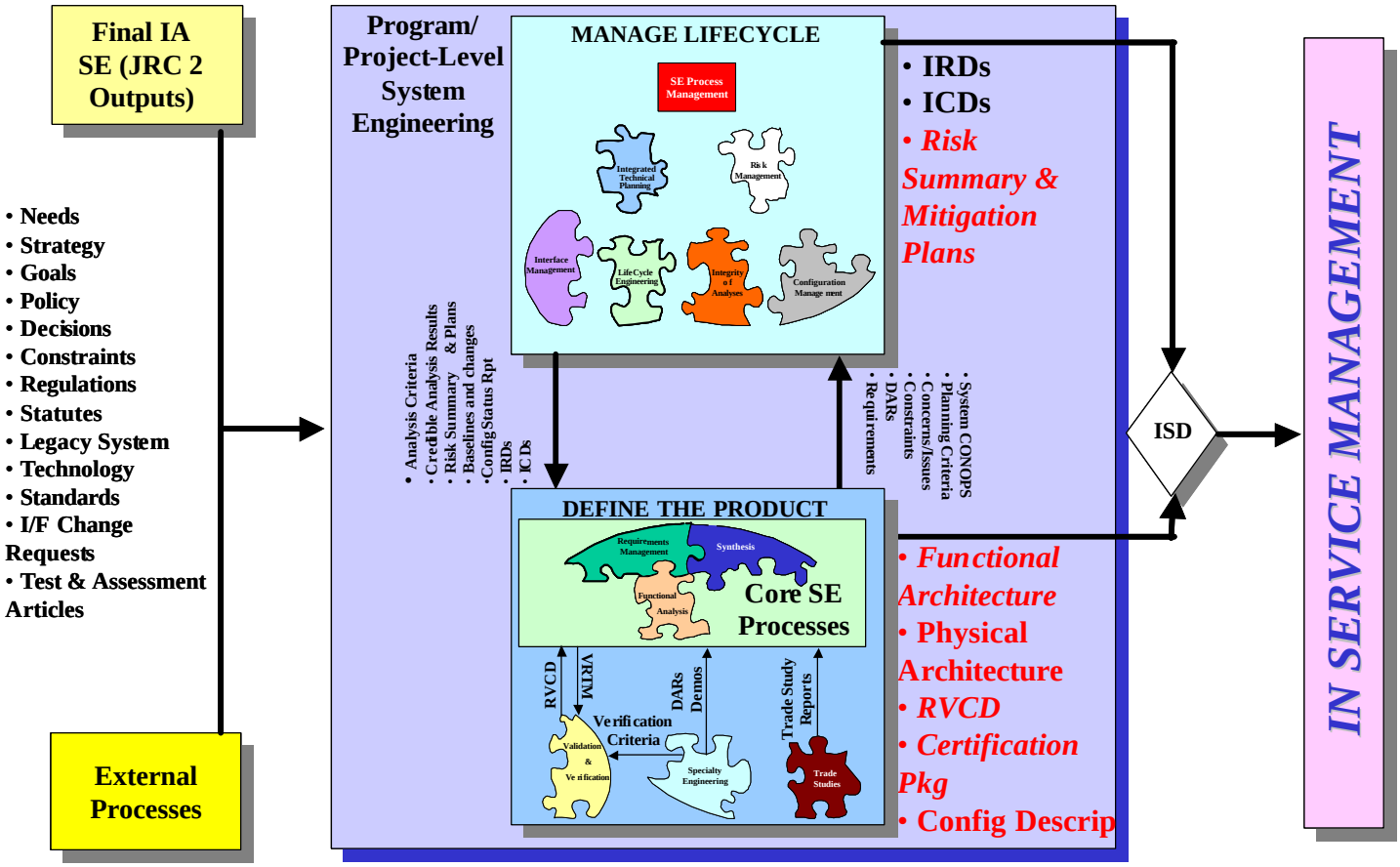
The output criteria for the final IA phase include the following:

- All work products identified as final IA outputs have been completed to the version level specified
- The solution selected during the initial IA phase is defined via a physical architecture with assurance that it meets all system requirements
- The ISSR has been successfully completed if conducted
- If ISRR is conducted, all work products identified as ISRR outputs have been completed to the version level specified
- The final IA decision has been made, authorizing the program to continue into the Solution Implementation (SI) phase

3.4.3 Solution Implementation Phase

3.4.3.1 Solution Implementation Phase Objectives

As shown in Figure 3.4-4, the SI phase begins with the final IA decision at JRC 2b where an acquisition program is established for the solution selected and ends when the new capability goes into service. The flow diagram in Figure 3.4-4 shows the high-level SE inputs and outputs associated with the solution implementation phase. Table 3.3-2 (column labeled JRC 3) contains a more complete listing of all of the inputs, outputs, and work products associated with the AMS milestone JRC 3.



Note: Table 3.3-2 contains acronyms used here.

Figure 3.4-4 Solution Implementation System Engineering Inputs and Outputs

The SE activities conducted during SI vary widely, depending on the nature and scope of the acquisition program. For example, the activities associated with buying and deploying a commercial product typically are much less complex and time-consuming than those for a product requiring full development. However, in each case, it is recommended that products be able to meet stakeholder requirements, be operationally suitable, and compatible with other operational systems within the NAS before the decision is made to place it in service. The main objective of this phase is to successfully complete the necessary actions and activities to obtain the solution and to accept a product or service for operational use.

Table F-5 in Appendix F lists the inputs and outputs for the SI phase and associates the items with the SE element that produces them.

3.4.3.2 Solution Implementation Phase Inputs

The major inputs to the SI phase are:

- Work products from the outputs of the final IA stage have been completed to the version level specified
- The final IPP has been completed
- The final IA decision (JRC 2b) has been made, authorizing the program to continue into SI

Table 3.3-2 (column labeled JRC 3) lists the inputs, outputs and work products associated with SI.

3.4.3.3 Solution Implementation Phase System Engineering Activities

Figure 3.2-1 lists the SE elements activities required to accomplish the SI objectives. While the SE activities vary widely, depending on the program, the interactions of the SE processes remain essentially the same as in the IA phase. Upfront, the activities involve finalizing and baselining the system, its requirements, and the program to support its development and operation. The SE effort then focuses on transforming the accepted concept into a product for deployment. Thus, toward the beginning of the phase, the emphasis remains on the core SE processes, which continue to refine the requirements and bring greater resolution to the design. In the latter portion of this phase, the emphasis shifts to Verification activities (Section 4.12) to verify that the system has been built and integrated according to the requirements. The final set of SI activities consists of installing the product or initiating the service at each site and certifying it for operational use, as appropriate, which typically includes implementation planning, installation and checkout, integration and shakedown, dual operations, and removal and disposal of obsolete equipment.

As in previous stages of SE efforts—in addition to the tasks identified below—it is recommended that each SE element active during this phase surface concerns and issues that present risk to the program.

Various reviews and audits are conducted throughout the SI phase to maintain proper oversight of system development. Integrated Technical Planning (Section 4.2) discusses the following reviews and audits, and they are defined in the glossary:

- System Requirements Review
- System Design Review
- Preliminary Design Review
- Critical Design Review
- Verification Readiness Review
- Functional Configuration Audit
- Physical Configuration Audit

3.4.3.4 Solution Implementation Phase Outputs

The primary output from the SI phase is as follows:

- The In-Service Decision has been made, authorizing the program to deploy and put the developed system into service

Table 3.3-2 (see JRC 3 column) lists the inputs, outputs, and work products associated with SI. As shown in Figure 3.4-4, final forms of the following documents are completed and/or updated by the end of this phase:

- Certification Package
- Interface Control Documents
- Test and Assessment Articles
- Configuration Description
- Functional and Physical Architecture
- Risk Summary and Mitigation Plans
- Requirements Verification Compliance Document

3.4.4 In-Service Management

In-Service Management involves two distinct sets of work activities. The first set monitors and assesses the real-world performance of the system against its requirements and expected benefits in the APB and takes action to optimize performance throughout its operational life. The second set of activities deals with operating and maintaining the system throughout its service life, as well as maintaining the physical and support infrastructure. The various SE elements are employed within both sets of these activities, and the elements appear in Figure 3.2-1. Regarding the latter set of activities, the results of SE efforts are used to support the decision-making process regarding when a new capability or improvement needs to be in place.

In addition to the timing decision, a decision is made regarding whether modifications or improvements are feasible within approved sustainment funding in the APB. If an engineering change to the system within the sustainment funding is unable to be supported, then the shortfall is addressed via the standard AMS lifecycle phases. Thus, the SE efforts for this route are as noted in “Mission Analysis Phase” (Paragraph 3.4.1), “Investment Analysis Phase” (Paragraph 3.4.2), and ‘Solution Implementation Phase” (Paragraph 3.4.3).

If the effort to modify and/or optimize system performance is within the scope of sustaining funds, then the various SE elements are employed much as in the SI phase but on a lesser scale. The specific SE process and associated level of effort depend on the scope of the upgrade. If a modification is made to sustain system operations beyond its planned service life, a new investment decision for a service life extension shall be requested. Again, the SE efforts during this phase are essentially the same as noted in Solution Implementation Phase regarding the pieces of the system that are being modified to extend the life of the system as a whole.

3.4.5 Disposal

SE efforts to support disposal of a system being replaced occur during the new system's SI phase. Lifecycle Engineering (Section 4.12) defines the process for planning and executing disposal activities. The Integrated Technical Planning process (Section 4.2) is used to develop a Disposal Plan under FAA Order 4800.2, Utilization and Disposal of Excess and Surplus Personal Property.

3.5 Reserved

3.6 Reserved

3.7 Guidance for Tailoring of System Engineering

This SEM defines the FAA SE elements along with the work products generated from these elements during each AMS phase. The 12 elements appear in Chapter 1 (Table 1.2-1). A 13th element is included to provide for process management and maintenance of the other 12 elements. These elements that have been defined are elements of better system engineering practices that have been designed to be tailored. Tailoring is deletion or reduction in depth of the application of any of these 12 elements. Tailoring is also the addition of unique or special focus elements or areas provided in organization policies and procedures or in an acquirer-supplier relationship.

3.7.1 Basic Principle of Tailoring of System Engineering

Whether large or small, hardware-intensive or software-intensive, people- or process-concentrated, many if not all of the SE elements apply. The magnitude and nature of the program determines which of the elements that apply and to what depth. Tailoring is determined by the appropriate system engineering management authority designated in the domain (or business unit)-level or IPT-level SEMP. The Chief System Engineer, Program Manager, or other dually authorized authority makes the tailoring decision and captures the rationale for eliminating or reducing the depth of each of the SE elements in the SEMP.

The intent here is not to overburden the lower-than-NAS-level organizations with mandated guidance, but to give them the prerogative to exercise judgment while maintaining awareness of the proven practices in the NAS-level SEM.

This principle does not mean that large, complex programs may be de-scoped, except under the ground rules listed in this section. The following paragraphs give examples of specific aspects of SE and how they are to be treated in a tailoring effort.

3.7.2 Tailoring of Acquisition Management System Process Phase Aspects of System Engineering

"AMS/System Engineering Work Products Inputs and Outputs" (Section 3.3) describes the AMS phases employed on all programs. It is recommended that these phases not be eliminated or combined on any program. However, they may be shorter in duration. Furthermore, it is recommended that the entrance and exit criteria for any phase not be ignored. In addition, it is recommended that the exit reviews associated with the phases not be eliminated. "Tailoring of Review Aspects of System Engineering" (Paragraph 3.7.5) discusses the reviews.

3.7.3 Tailoring of Planning Aspects of System Engineering

It is recommended that all plans pertinent to the program be written; however, some plans may be shortened to a single page or combined in a single document. When combined, the document that comprises the combining for the program contains the rationale and the justification for the combining. The most important plan is the IPP, a result of the SE element Integrated Technical Planning (Section 4.2). The IPP may be reduced to its essential elements, and individual entries may be as short as a single line. It is recommended that these aspects be retained:

- AMS Phases (Section 3.2)
- SE elements (Sections 4.2 through 4.14, as tailored)
- SE specialties to be employed on the program

3.7.4 Tailoring of System Engineering Element Aspects of System Engineering

It is recommended that individual programs tailor the application of processes, tools, and techniques according to program requirements, with implementation of these processes directed by the appropriate SE management authority.

It is recommended that program cost/benefit considerations be the basis for the allocation of appropriate resources, including manpower and schedule, to any process activity. As above, it is also recommended that the basis and rationale for tailoring SE elements be captured in the IPT level, business level or domain-level SEMP.

3.7.5 Tailoring of Review Aspects of System Engineering

Two rules prevail regarding this topic: (1) It is recommended that all major JRC reviews be performed at the end of each of the phases defined in the AMS, and (2) it is recommended that reviews not be combined; but, depending on the nature of the program/acquisition, the duration of time between the Initial IA and the Final IA could be abbreviated if all requirements are met. Additionally, a review may be shortened to an hour for a simple project. The moderator of the review confirms the basic purpose and ground rules of the review to ensure that they have not been compromised. Software reviews are only required if software is selected as a solution to the system requirements (discussed in “Tailoring of Software Aspects of System Engineering” (Paragraph 3.7.10)).

3.7.6 Tailoring of Functional Analysis Aspects of System Engineering

The Functional Analysis process (Section 4.4) is an example of a fundamental process, and it is recommended that its basic principles be maintained on programs of any size. On all programs, it is recommended that Functional Analysis be used to derive requirements in a structured and systematic method. The depth, scope, and tools used in developing the functional architecture may be tailored according to program complexity.

3.7.7 Tailoring of Requirements Management Aspects of System Engineering

The Requirements Management process (Section 4.3) is an example of a fundamental process, and it is recommended that its basic principles be maintained on programs of any size. On all programs, a Requirements Management tool is highly recommended, and the results are loaded into a master requirements database.

3.7.8 Tailoring of Programmatic Risk Management Aspects of System Engineering

It is recommended that the Risk Management process (Section 4.10) be performed on programs of any size and throughout the lifecycle. The example forms provided in Risk Management show that risk to the process is not paper-intensive. On the contrary, the Risk Management process presented is extremely practical and adaptable to programs of any size.

3.7.9 Tailoring of Verification Aspects of System Engineering

The Verification process (Section 4.12) is one of the SE basic principles—it is recommended that all requirements be verified. This is not to say that extensive testing is required, but simply that it is recommended that steps be taken to ensure that the solution satisfies the requirements. A simple analysis often provides that assurance. It is recommended that this principle not be compromised on small programs. Failure to verify requirements may cause small programs to turn unintentionally into large programs.

3.7.10 Tailoring of Software Aspects of System Engineering

Software is a solution to system (i.e., hardware and software) requirements. Hence, if software is not selected as a solution, software reviews and other documentation are not required. If software is required, standard software reviews and documentation are required. However, it is not to be assumed that, if a program is designated as a software program, then the total system aspects of SE might be ignored.

3.7.11 Tailoring of Lifecycle Engineering Aspects of System Engineering (Reserved)

3.7.12 Tailoring of Synthesis Aspects of Systems Engineering

It is recommended that the system engineering organization perform synthesis for the purpose of defining design solutions and identifying subsystems to satisfy the requirements of the verified functional architecture. Synthesis translates the functional architecture into a design architecture that provides an arrangement of system elements, their decomposition, interfaces (internal and external), and design constraints. The activities of synthesis involve selecting a preferred solution or arrangement from a set of alternatives and understanding associated cost, schedule, performance, and risk implications. Depending on the type of acquisition involved (i.e., commercial-of-the-shelf items, nondevelopmental items, commercial hardware/developed software, mix of solution processes, etc.), every aspect of synthesis need not be performed, or the depth of every aspect that is performed need not be extensive.

4 PERFORM SYSTEM ENGINEERING

4.1 System Engineering

The Federal Aviation Administration (FAA) System Engineering (SE) method is robust, iterative, and has extensive interdependencies among the SE elements listed in Table 1.2-1. The process workflow (see Figure 4.1-1) captures the essence of these linkages and provides a high-level view of the various SE processes and how they functionally interact. These functional interfaces only represent the predominant interaction between each process. The interaction between processes at a lower level is much more involved (i.e., Figure 4.1-1 is a simplified view and does not depict all the ways that processes interface). Figure 3.1-2 is an N^2 diagram of SE that shows the actual work products exchanged between the various SE processes shown in Figure 4.1-1.

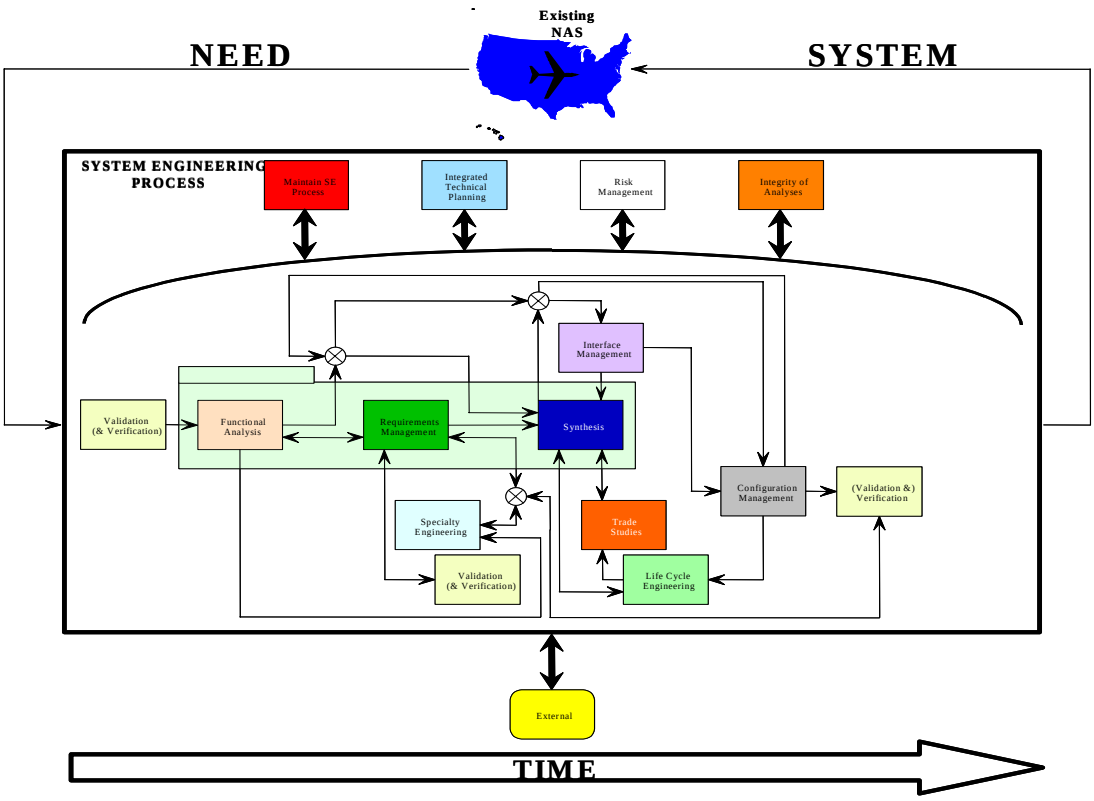


Figure 4.1-1. Functional Flow Diagram of System Engineering

In Figure 4.1-1, each SE process is laid out from left to right to notionally depict when in time each process is employed relative to another. The time arrow is *not* relative to the AMS lifecycle phases. It is recommended to note that overall SE, and many of the interactions at the lower levels, may be iterative in nature; thus, the left to right timeline is notional.

Figure 4.1-1 indicates that SE is initiated when there is a need; that is, a recognized shortfall in capability within the NAS. For example, the stakeholder need may arise as a result of a new service to be provided or with the advent of technological innovations to be leveraged to reap improvements in capacity, security, and/or safety. Once the need is validated, the Functional Analysis process (Section 4.4) is performed to develop a Concept of Operations (CONOPS).

The Requirements Management process (Section 4.3) uses the CONOPS to develop an MNS, which is then fed back to Functional Analysis as input to develop the highest level of functional architecture for the new or modified system. The Requirements Management process uses this high-level functional architecture, as well as inputs from Specialty Engineering analyses, to develop requirements. These requirements are validated via the Validation and Verification process (Section 4.12). The interaction between Functional Analysis and Requirements Management is iterative, as the functional architecture and resulting requirements are decomposed to a level necessary to the appropriate requirements that describe the needed system characteristics. Synthesis (Section 4.5) then develops the physical architecture or design solution to those requirements.

Along with these initial SE activities, three overarching processes that interact with all SE processes are employed. These overarching processes continue throughout the system's lifecycle and are as follows:

- Integrated Technical Planning (Section 4.2)
  - Provides the technical guidance tools required to track and manage program activity
- Risk Management (Section 4.10)
  - Provides an organized, systematic decision-making approach to identify risks that affect achievement of program goals
  - Analyzes identified risks
  - Mitigates risks effectively
  - Tracks the progress of the mitigation efforts
- Integrity of Analyses (Section 4.9)
  - Ensures the provision of credible, useful, and sufficient data/results for program management's decision-making process
  - Ensures the integrity and fidelity of the various analysis tools

Once a valid set of requirements is obtained, the Synthesis process (Section 4.5) is initiated to define system elements and to refine and integrate these elements into a physical architecture. In addition to the requirements input into the Synthesis process, the functional architecture is provided to clarify and bound the system. The Trade Studies process (Section 4.6) and the Lifecycle Engineering process (Section 4.13) supply cost estimates to support the Synthesis process, which ultimately determines the design alternative that best satisfies the identified stakeholder need.

Interface Management (Section 4.7) plays a key role in ensuring that the various internal system pieces are coordinated as well as integrated with external systems. As the total system is decomposed via iterative interaction of Functional Analysis, Requirements Management, and Synthesis, physical and functional interfaces are identified and managed.

The results of these SE activities are continually brought under Configuration Management (Section 4.11). The system is developed according to the baseline design and verified with the Validation and Verification process (Section 4.12). With the system verified as able to meet the identified stakeholder need, it is deployed into the NAS. Although the discussion of this simplified view and description of SE was sequential, SE is truly iterative and employed continuously throughout the lifecycle of the system.

When used properly, SE creates an infrastructure that ensures customer requirements and expectations are effectively and efficiently identified, integrated, and managed. Each SE element is designed to maximize the thoroughness and quality of interaction and cooperation between individuals, teams, suppliers, and stakeholders as each SE element is performed. In addition, each SE element plays various roles throughout the lifecycle phases as shown in Figure 3.2-1. The summary provided below gives an overview of each SE element in terms of objective, definition, and value. Each SE element is extensively documented in the subsequent sections (Sections 4.2 through 4.14), which contain the following details:

- Process-Based Management (PBM) chart (objectives, inputs and associated providing process (providers), outputs and associated receiving process (customers), process tasks, and applicable lifecycle phases)
- Process workflow
- Methods, tools, and detailed descriptions of how each SE element's tasks are accomplished
- Steps to tailor the SE element
- Appendices for terms, acronyms, and work product examples

4.1.1 Summary of System Engineering Areas

The following paragraphs briefly summarize FAA SE and its 13 elements. The subsequent sections of the System Engineering Manual (SEM) further detail each element. The brackets following each subsection heading provide a cross-reference to the applicable section number and the relevant integrated Capability Maturity Model (iCMM) process areas.

4.1.1.1 System Engineering

[SEM 4.1; iCMM PA 01 through 04, 07, 08, 11, 13, 16, 20, and 21]

4.1.1.1.1 Objective

The objective of SE within the FAA is to consistently provide balanced solutions to complex FAA system needs.

4.1.1.1.2 Definition

SE defines how the organization discerns a problem, how it approaches solution development to a problem, and how it implements the plan enabling resolution of the problem. It is a discipline that concentrates on the design and application of the whole (system) as distinct from the parts. It involves looking at a problem in its entirety, taking into account all facets and variables and relating the social aspects to the technical aspects.

4.1.1.1.3 Utilization and Value

While SE process elements support the cycle defined by the Acquisition Management System (AMS), they also provide more granularity. This finer, more detailed breakdown provides better

management visibility into the operation of the program. Risk is reduced through earlier identification of issues and better identification of requirements. Cost is reduced through earlier recognition and correction of problems. Support organizations are able to gauge and plan their work to support each phase.

4.1.1.2 Integrated Technical Planning

[SEM 4.2; iCMM PA 11]

4.1.1.2.1 Objective

The objective of the Integrated Technical Planning element (Section 4.2) is to provide program management with a sound, repeatable method for the execution of a requirements-based and structurally managed program.

4.1.1.2.2 Definition

The Integrated Technical Planning element provides program management with specific guidance and direction on how to plan a program's execution. The technical plans provide stakeholder- and contract-driven tailoring of SE to optimally satisfy program needs. These plans are living documents that are kept current throughout the program's lifecycle.

4.1.1.2.3 Utilization and Value

Various levels of technical and program management use the technical plans that result from Integrated Technical Planning. Expending upfront effort to generate clear, complete, and correct technical plans results in consistent performance across the program. Optimally, miscommunication and misinterpretation of stakeholder and executive expectations by individuals are eliminated. Developing and following properly prepared plans assists in eliminating miscommunication and helps the program to adapt to changes in program environment.

4.1.1.3 Requirements Management

[SEM 4.3; iCMM PA 01 and 02]

4.1.1.3.1 Objective

The objective of the Requirements Management element (Section 4.3) is to identify and develop all requirements and ensure that they are met throughout the product's lifecycle.

4.1.1.3.2 Definition

The Requirements Management element is a series of iterative tasks performed by a multifunction team throughout all AMS phases. The team's focus is to elicit, develop, manage, and control requirements and associated documentation. Once requirements are defined, the team uses a disciplined Requirements Management methodology to manage the requirements through verification, helping to ensure compliance with stakeholder needs and expectations, communication of allocations, and adaptation to/control of changes.

4.1.1.3.3 Utilization and Value

Requirements are the fuel for the design process. They define the needed characteristics of a system at all levels of complexity. They are derived from multiple inputs from internal and external sources that need to be logically and efficiently collected and synthesized in a centralized, accessible decision database(s). The information collected, managed, and controlled is accessed by various teams within the stakeholder and program organizations, associated internal interfaces (e.g., management or operations), and contractors/suppliers. When Requirements Management is performed well, rework and poorly communicated information typically is minimal, if not eliminated entirely. Furthermore, this process is used to surface gaps, redundancies, biases, and/or inconsistencies and resolve, revise, and/or refine them in a consistent, integrated method to the satisfaction and agreement of all the stakeholders. The solid foundation built through Requirements Management provides an ongoing resource for all program stages.

4.1.1.4 Functional Analysis

[SEM 4.4; iCMM PA 03]

4.1.1.4.1 Objective

The objective of the Functional Analysis element (Section 4.4) is to provide a framework for requirements that significantly improves innovation, synthesis, and product integration.

4.1.1.4.2 Definition

The Functional Analysis element takes the stakeholders' needs and translates them into a sequenced and traceable functional architecture. The system is represented as a set of functions defined as tasks, actions, or activities that are performed to achieve specified sequenced and time-based behaviors. Functions are described as what needs to be done, not how. Therefore, each function is written in the verb-noun form (e.g., “read book” and “cook food”). The functions are accomplished by one or more elements, including equipment/hardware, software, firmware, facilities, personnel, and/or procedural data. Each function is hierarchically decomposed until the basic subfunction is reached, and the requirements are fully developed. The functional architecture defines what the system does, including interfaces (both within the system and to the external world).

4.1.1.4.3 Utilization and Value

A logically sequenced and thoroughly functional architecture is critical to the definition of requirements. It surfaces innovative design solutions and sheds light on vague interfaces. It also provides the basis for logical and realistic product integration and synthesis. As the analyses are performed, additional requirements often are flushed out/derived, thereby providing the program with a more detailed list of requirements and an increased understanding of the system. The functional architecture and functional interfaces enable the stakeholders and program management to logically develop requirements down to the lowest level of a system hierarchy.

4.1.1.5 Synthesis

[SEM 4.5; iCMM PA 04]

4.1.1.5.1 Objective

The objective of the Synthesis element (Section 4.5) is to develop (synthesize) balanced solutions to requirements.

4.1.1.5.2 Definition

The Synthesis element develops solutions to problems (as defined by the requirements). This SE element uses scientific/engineering knowledge and methods to derive and document the hows used to solve the whats that are reflected in the requirements. The synthesized design generated is a balanced (i.e., cost, quality, schedule, risk, performance, producible/supportable) solution. The synthesized design is created through the analysis of candidate elements. The candidate elements are preliminarily defined and then iterated until the refinement of the system concept is complete. The final outputs, which also show relationships between candidate elements, are distributed to the groups responsible for building various system elements.

4.1.1.5.3 Utilization and Value

A series of benchmarks for various design performance parameters (e.g., power, data storage, testability, reliability) are generated and used to measure the viability and worth of a candidate design solution. Design performance parameters, ranked by importance, are refined during the design evolution of an affordable, responsive system design. Throughout the evolutionary analyses, credibility and acceptability by the stakeholders shall be ensured. The iterative nature of the candidate element task provides the mechanism for continuous correction of design inadequacies and refinement of the physical allocation process. It also surfaces opportunities for new technologies and innovative ideas to be considered, justified, and integrated. These efforts are used to validate the synthesized design in terms of balance, completeness, understandability, and reflection of the stakeholders' requirements.

4.1.1.6 Trade Studies

[SEM 4.6; iCMM PA 04]

4.1.1.6.1 Objective

The objective of the Trade Studies element (Section 4.6) is to select balanced (i.e., cost, schedule, quality, and risk) solutions from a set of available alternatives based on defined criteria.

4.1.1.6.2 Definition

The Trade Studies element is used by multidisciplinary teams to confirm that the most balanced technical solutions have been identified. The team methodically evaluates a series of design alternatives and recommends the preferred feasible solutions that enhance the value and performance of the overall system and/or functions. The primary assessment methods are the +/- method, the weighted value method, and the cost assessment method. Each assessment is taken to an appropriate level of detail that allows differentiation between alternatives. Recommendations are assembled in a trade study report and forwarded to the appropriate decisionmaker(s) (e.g., program management or stakeholders) for action.

4.1.1.6.3 Utilization and Value

The tasks within the Trade Studies element are designed to assist decisionmakers. The thorough identification and assessment of multiple facets of a problem aids the decisionmaker to relate the whole problem to optimal, feasible solutions by comparing technical, cost, and schedule interactions. The appropriate authority uses this information to make a final decision. The Trade Studies process provides the traceability needed to substantiate design and configuration changes to the baseline product design; it also documents why one alternative was chosen over another during the decisionmaking process.

4.1.1.7 Interface Management

[SEM 4.7; iCMM PA 07]

4.1.1.7.1 Objective

The objective of the Interface Management element (Section 4.7) is to achieve functional and physical compatibility between all interrelated system elements.

4.1.1.7.2 Definition

An interface is any boundary between one area and another. It may be external, internal, functional, or physical. Interfaces occur within the system (internal) as well as between the instant system and another system (external) and may be functional or physical (e.g., mechanical, electrical) in nature. Interface requirements are documented in an Interface Requirements Document (IRD). The Interface Control Document (ICD) contains the final details of how the contractor implements the requirements. An Interface Control Plan describes the management process for IRDs and ICDs. This plan provides the means to identify and resolve interface incompatibilities and to determine the impact of interface design changes.

4.1.1.7.3 Utilization and Value

During the program's life, compatibility and accessibility shall be maintained for the many diverse elements. Compatibility analysis of the interface definition demonstrates completeness of the interface and traceability records (or lack thereof). As changes are made, an authoritative means of controlling the design of interfaces shall be managed with appropriate documentation, thereby avoiding the situation in which hardware/software, when integrated into the system, fails to function as part of the system, as intended. Ensuring that all system pieces work together is a complex task that involves teams, stakeholders, contractors, and program management from the end of the initial concept definition stage through the operations and support stage.

4.1.1.8 Specialty Engineering

[SEM 4.8; iCMM PA N/A]

4.1.1.8.1 Objective

The objective of the Specialty Engineering element (Section 4.8) is twofold: (1) to integrate specific system attributes and disciplines into the acquisition process; and (2) to assess and confirm various system attributes (Specialty Engineering).

4.1.1.8.2 Definition

The Specialty Engineering element includes System Safety Engineering (SSE); Reliability, Maintainability, and Availability (RMA); Human Engineering (human factors); Electromagnetic Environmental Effects (E^3); Quality Engineering; Information Security Engineering; and Hazardous Materials Management/Environmental Engineering. Specialty Engineering analyses describe technical details of the design from a particular perspective and often require specialized skills. These analyses help the program to define requirements and design features and/or describe characteristics of the design and related operations in support of Validation and Verification (Section 4.12), requirements, Trade Studies (Section 4.6), Synthesis (Section 4.5), and Functional Analysis (Section 4.4). These analyses are performed throughout the product's lifecycle. At minimum, analysis results shall be available at standard design milestones, including the preliminary and critical design reviews. Table 4.1-1 provides a general description of the specialty engineering disciplines.

Table 4.1-1. Specialty Engineering Disciplines

Specialty Engineering Discipline	Description
SSE	Evaluation and management of the safety risk associated with a system using measures of safety risk identified in various hazard analyses, fault tree analyses, safety risk assessments, and hazard tracking and control.
RMA	Quantitative and qualitative analyses of the attributes of the system to perform reliably. Quantitative assessments are in the form of probabilistic, mean, and/or distribution assessments. Qualitative analyses are in the form of failure mode assessments. Evaluation of the design's ability to meet operational readiness requirements through preventive and corrective maintenance.
Human Factors Engineering	Human factors is a multidisciplinary effort to generate and compile information about human capabilities and limitations and apply that information to: – equipment, systems, facilities – procedures, jobs, environments – staffing – training – personnel and organizational management for safe, comfortable, and effective human performance.

Specialty Engineering Discipline	Description
E^3	Analysis of the system for susceptibility and/or vulnerability to electromagnetic fields or capability to generate such fields that might interfere with other systems, identify sources of interference, and means for correction within the levels prescribed by law, program requirements, spectrum management, or recognized standards. E^3 is composed of Electromagnetic Interference (EMI) and Electromagnetic Compatibility (EMC)
Quality Engineering	Evaluation of a system's ability to meet its requirements and to mitigate product defects.
Information Security Engineering	Evaluation of the vulnerability of the system to unauthorized access and use, or susceptibility to sabotage. Assessment of the ability of the system to survive a security threat in the expected operational environment.
Hazardous Materials Management/Environmental Engineering	Determination of environmental impacts at deployment sites and during operations, including both environmental impacts on the system and system impacts on the environment during all phases of the product life.

4.1.1.8.3 Utilization and Value

These analyses are used to support functional analysis, define and allocate requirements, contribute to the design, and to evaluate design progress, technical soundness, and risk. They are also needed by the stakeholders to ensure that the product performs as intended, as well as by engineering, operations, and product support personnel to accomplish their responsibilities in product development and operation.

4.1.1.9 Integrity of Analyses

[SEM 4.9; iCMM PA N/A]

4.1.1.9.1 Objective

The objective of the Integrity of Analyses element (Section 4.9) is to ensure that analyses provide the required level of fidelity and accuracy in a timely manner.

4.1.1.9.2 Definition

Throughout SE and the program's lifecycle, analyses are constantly being performed. These analyses range from simple to complex, quantitative to qualitative, top-down to bottom-up, and basic formulas to sophisticated simulations. In order to ensure credible, useful, and sufficient data/results for program management's decisionmaking process, the integrity and fidelity of the various analysis tools shall be understood and validated. This validation takes several forms: the attributes of the tool suite, validity of the input data, and proficiency and workmanship of the

analyst. An Analysis Management Plan is generated that outlines the details of the various analysis methods and tools. It is recommended that this plan also reflect the program's constraints in terms of technical capabilities, schedule requirements, and cost requirements.

4.1.1.9.3 Utilization and Value

The initial selection of the method, tools, or model to be used in an analysis focuses on determining a practical tool that provides the most visibility into the problem with the least complexity. Because this process is iterative, there is an ongoing need to use the best approach to select the right method, tool, or model, considering the preferences of the stakeholders, other teams' previous experience with different tools, and the limitations of budgets, technology, and schedule. The bottom line is to have analyses in place that guard against mistakes and embed a consistent level of confidence in the integrity of the analysis. The analysis, in turn, contributes significantly to the success of the decisionmaking processes of program management, teams, stakeholders, and contract managers.

4.1.1.10 Risk Management

[SEM 4.10; iCMM PA 13]

4.1.1.10.1 Objective

The objective of the Risk Management element (Section 4.10) is to identify and analyze the uncertainties of achieving program objectives and develop plans to reduce the likelihood and/or consequences of those uncertainties.

4.1.1.10.2 Definition

The Risk Management element is an organized, systematic decisionmaking SE process element used by all disciplines and program teams to identify risks regarding achieving program goals, analyze these risks, and effectively mitigate these risks. Risk is defined as an event or situation with a realistic uncertainty of occurrence and an unfavorable consequence if the risk occurs. Risk Management is applied at all levels, from small projects to large programs. Risks are identified (what might go wrong), impacts are analyzed (how big is the risk), mitigation plans are defined (how to reduce the risk), and risk status is continuously tracked and monitored (how the mitigation efforts are progressing). Identifying risks begins when a program is initiated and continues throughout the program's life. A risk watchlist, which compiles the most significant risk items into a single composite document, is generated. The watchlists are used to continuously monitor and track the overall risk status within team meetings and program management reviews.

4.1.1.10.3 Utilization and Value

Understanding the levels of likelihood and consequences of risk occurring increases the program manager's and program team's ability to anticipate and control the impacts of internal and/or external events on their programs. These impacts include, but are not limited to, cost, quality, schedule, and stakeholder satisfaction trends. The comprehensiveness of the analysis drives the thoroughness of what resources are required to mitigate the risk (e.g., budgets, requirements changes, stakeholder interfaces). Risk identification worksheets, tools, and terminology ensure a consistent approach that generates an analysis in which subjectivity is minimized, and confidence in the analysis is maximized.

4.1.1.11 Configuration Management

[SEM 4.11; iCMM PA 16]

4.1.1.11.1 Objective

The objective of the Configuration Management element (Section 4.11) is to establish and maintain consistency of a product's performance, functional, and physical attributes with its requirements, design, and operational information throughout its life.

4.1.1.11.2 Definition

The Configuration Management element is an orderly identification, documentation, and maintenance of a product's functional performance and physical attributes. The tasks are focused on consistency of requirements, design, and operational information throughout the product’s life. Once baselined as defined by stakeholder requirements, changes are systematically approved and managed to ensure that traceability/accountability is maintained throughout myriad levels of documentation. The scope of this process element begins with planning the Configuration Management process for the context and environment in which it is to be performed. It ends when the configuration and its associated changes are verified and audited for accuracy and completeness. Throughout the entire Configuration Management effort, a status check provides accurate and timely information concerning the product and its associated data. Support tasks within Configuration Management include developing training plans, defining performance-based management measurements, and assessing methods and trends to effect process improvements.

4.1.1.11.3 Utilization and Value

Configuration Management benefits the program, stakeholders, and contractors/suppliers. As product attributes are defined, measurable performance parameters may be established for the product’s acquisition and use. As changes are made, Configuration Management provides correct and current information to the decisionmaking process. When configurations are managed, product repeatability is enhanced, guesswork and downstream surprises are avoided, cost and schedule savings are realized, erratic changes are minimized, proper replacement and repairs are ensured, and maintenance costs are reduced. The overall effect is the establishment of a high level of confidence in the product information.

4.1.1.12 Validation and Verification

[SEM 4.12; iCMM PA 08]

4.1.1.12.1 Objective

The objective of the Validation and Verification element (Section 4.12) is to determine that the system and process requirements are correct and have been met.

4.1.1.12.2 Definition

The Validation and Verification element ensures that all system requirements are correct and have been met. The Validation process proves requirements are correct. The Verification process proves that requirements are met. Requirements may not be verified by test alone.

The majority of requirements are verified by a combination of test and assessment, which comprise the two categories of verification. Test is the disciplined and controlled subjection of the system to conditions that replicate operations in a real or simulated environment as defined by the requirements. It involves examination, observation, and evaluation of measurable parameters of a system element. Assessment, the second category of verification, includes analysis, demonstration, inspection, verification by similarity, validation of records, simulation, and review of design documentation. It is a basic principle of SE that all requirements shall be verified.

4.1.1.12.3 Utilization and Value

The Validation process eliminates poor or unnecessary requirements, ensuring that the FAA obtains a set of requirements that are necessary and sufficient to meet the needs of the stakeholders. The Verification process ensures that the product satisfies the validated requirements, and thus meets the stakeholders' needs.

4.1.1.13 Lifecycle Engineering

[SEM 4.13; iCMM PA N/A]

4.1.1.13.1 Objective

The objective of the Lifecycle Engineering element (Section 4.13) is to assess and confirm system attributes (Lifecycle Engineering).

4.1.1.13.2 Definition

The Lifecycle Engineering analyses supplement the program to define requirements and design features or describe characteristics of the design and related operations. These analyses provide technical details of the design from a particular perspective and are performed throughout the product's lifecycle. At minimum, analysis results shall be available at standard design milestones, including the preliminary and critical design reviews.

4.1.1.13.3 Utilization and Value

These analyses are used to evaluate design progress, technical soundness, and risk. They are also needed by the stakeholders to ensure that the product performs as intended, as well as by engineering, operations, and product support personnel to accomplish their responsibilities in product development and operation.

4.1.1.14 System Engineering Process Management

[SEM 4.14; iCMM PA 20 & 21]

4.1.1.14.1 Objective

The System Engineering Process Management element (Section 4.14) has two objectives. The first is to manage and maintain the SE processes in order to satisfy the FAA's goals. This objective is accomplished by maintaining technical awareness, inserting new technology into SE, maintaining the SE support environment, and monitoring the SE support environment for improvement opportunities. The second is to gain agencywide skill and process consistency by

continuously improving the effectiveness and efficiency of the SE processes. This objective is accomplished by analyzing the processes and explicitly planning and deploying improvements to those processes.

4.1.1.14.2 Definition

System Engineering Process Management provides support and balance for the 12 other SE process elements. It also covers activities to measure and improve the SE process elements, which involves designing, developing, improving, and maintaining definitions of SE activities, work, products, methods, techniques, practices, and tools. It additionally provides the technology environment needed to develop systems and perform SE.

4.1.1.14.3 Utilization and Value

This process provides the details and data required to ensure and improve the efficiency and effectiveness of overall SE. In turn, the purpose of improved SE is to reduce cost and schedule, while improving the efficiency and safety of the National Airspace System.

4.2 Integrated Technical Planning (Satisfies Criteria of EIA/IS731 FA 2.1 & iCMM PA 11)

4.2.1 Introduction to Integrated Technical Planning

Integrated Technical Planning is the tactical and strategic means of defining problems, forecasting conditions, and coordinating program elements to maximize program focus on providing superior products and services. The Integrated Technical Planning process provides the guidance and tools required to track and manage program activity, as well as the program-specific process tailoring required to optimally satisfy program needs. This System Engineering (SE) element has been subdivided into two primary areas: plans and reviews. The plans include the Integrated Program Plan (IPP) and supporting technical plans such as the System Engineering Management Plan (SEMP), Master Verification Plan (MVP), the System Safety Management Plan, etc. The review section contains both design reviews and audits. This section includes all planning documents; specific development details are in Appendix E. Perform tailoring only by deleting planning requirements; provide a rationale for each deletion. The only allowable additions are those unique to the program and formally required by the stakeholders. The size, complexity, and visibility of a program determine which SE elements need to be supported by more detailed planning documents. Integrated Technical Planning applies to all programs/projects regardless of size, whether or not they are new programs or changed or derivative projects. The size and scope of planning may change to meet program needs. A change to a program with an existing IPP, SEMP, or other plans only requires documentation that existing plans still apply. On any existing program, it is recommended that the current plans be referenced in all new plans developed.

4.2.1.1 Integrated Technical Planning Objective

The objective of the Integrated Technical Planning process is to provide program management with a sound, repeatable method for executing requirements-based and structurally managed programs.

4.2.1.2 Process-Based Management

The Process-Based Management (PBM) chart appears in Figure 4.2-1.

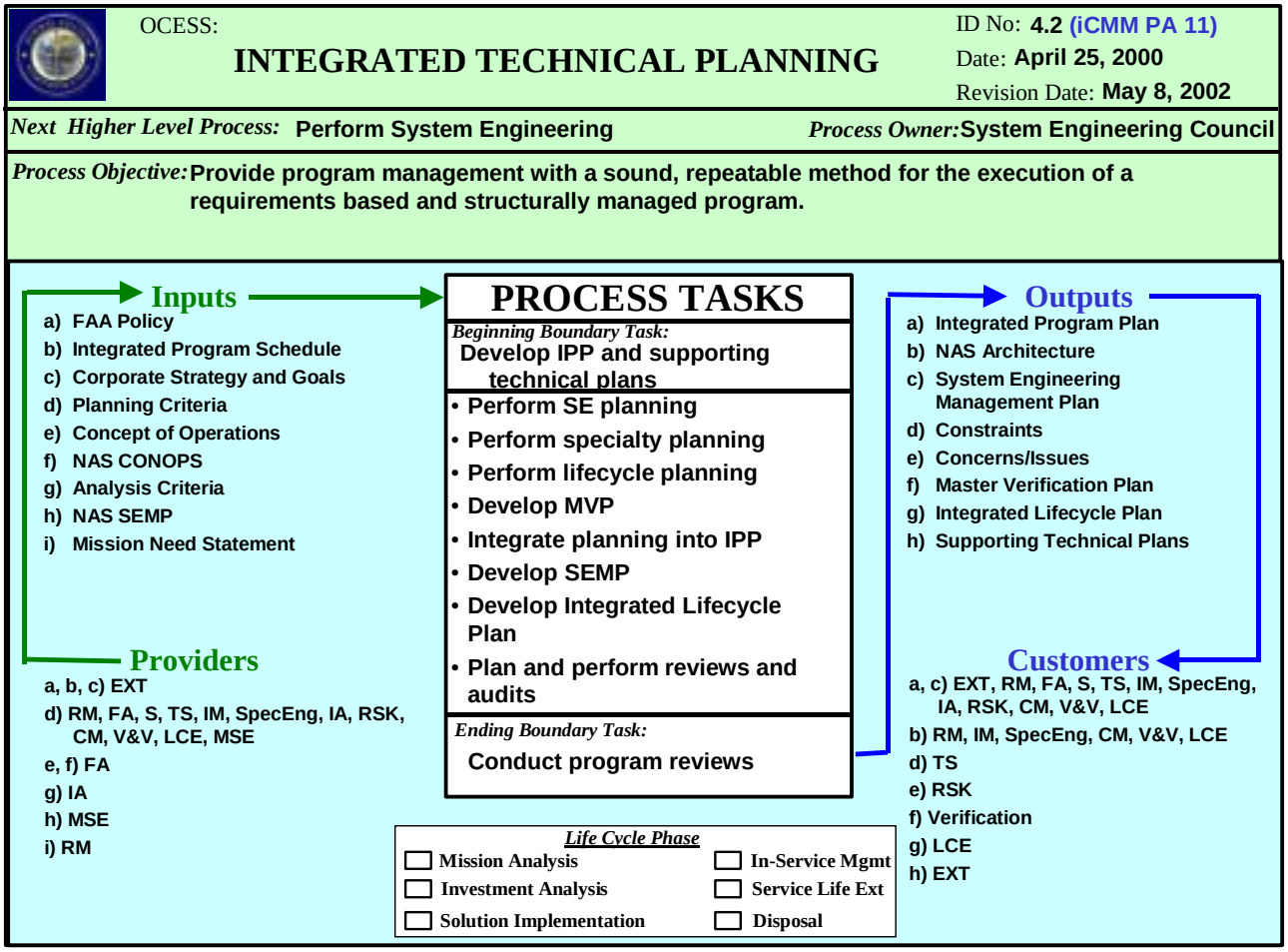


Figure 4.2-1. Integrated Technical Planning Process-Based Management Chart

4.2.1.3 Inputs to Integrated Technical Planning

The inputs to the process at this level appear in the PBM chart. Some of these inputs provide requirements, while others impose constraints.

4.2.1.4 Integrated Technical Planning Process Tasks

The process tasks are shown on the PBM.

4.2.1.5 Outputs of Integrated Technical Planning

The output from this process constitutes most of the "Manage To" package, as well as a part of the "Design To" package. A summary of the output for this process is shown on the PBM chart above. Details of the outputs are documented later in this chapter.

4.2.1.6 Integrated Technical Planning Process Metrics

The metrics for performance of the Integrated Technical Planning process are the sum of the metrics on lower-level processes.

4.2.1.7 Integrated Technical Planning Tools

Integrated Technical Planning requires word processing, display, and scheduling tools.

4.2.1.8 Key Decisions

Key decisions required for this process are:

- Request by the stakeholder and/or program manager for Integrated Technical Planning (usually included in the IPP and SEMP)
- Identification of necessary planning elements by the program system engineer and the project team
- Program manager acceptance that the identified planning elements are necessary
- Baseline plan accepted by the program manager, stakeholders, and the Joint Resources Council (JRC)
- Program manager's approval of the IPP, MVP, SEMP and any other supporting technical plans

4.2.1.9 Key Process Interfaces

Integrated Technical Planning interfaces with all other SE processes, either receiving inputs from them or providing outputs to them.

4.2.1.10 Acquisition Management System Process Interface

The Acquisition Management System (AMS) process interface is described in Chapter 3. AMS process activities that most strongly interact with the SE shall be taken into account in the Integrated Technical Planning process. All plans are living documents and are subject to continuous review and update to satisfy program needs and changes. It is recommended that all available plans be reviewed at each AMS milestone and as part of subsequent system baseline modifications throughout the program lifecycle.

4.2.2 Integrated Program Plan

4.2.2.1 Introduction to the Integrated Program Plan

The IPP is the primary document within the AMS for planning the actions and activities needed to execute the program within the cost schedule, benefits, and performance baselines in the approved Acquisition Program Baseline. An approved IPP is required for the Final Investment Decision (JRC 2b). IPP development is initiated when the Mission Needs Review has been completed and when the Concept of Operations has been developed. The IPP is reviewed and updated at all subsequent phase exit reviews and reflects changes throughout the program's lifecycle. The IPP reflects contractual requirements and unique programmatic requirements.

The IPP is the recognized plan used to manage a project and contains the Integrated Program Schedule, which encompasses milestones (events), accomplishments, and criteria. The IPP relates accomplishments to program events and demonstrates a logical, event-driven sequence of effort. It is directly traceable to the Work Breakdown Structure (WBS) and Statement of Work (SOW). The IPP provides vertical and horizontal integration traceability through its task statements and numbering system and identifies task relationships. It facilitates resource planning and provides time-phased tasks, a tool for measuring progress against planned efforts, problem identification, and a framework to develop recovery and workaround plans. Table 4.2-1 lists the sections of an IPP.

Table 4.2-1. Integrated Program Plan Table of Contents

Integrated Program Plan Table of Contents	
1	BACKGROUND
1.1	Mission Need
1.2	Status
2	OVERVIEW
2.1	Program Scope
2.2	Products
3	INTEGRATED PROGRAM FUNDING
4	INTEGRATED PROGRAM SCHEDULE
5	PERFORMANCE
5.1	Core Work Activities
5.2	Program Management Work Activities
5.3	Procurement Work Activities
6	BENEFITS
7	PHYSICAL INTEGRATION
8	FUNCTIONAL INTEGRATION
9	HUMAN INTEGRATION
10	SECURITY
11	IN-SERVICE SUPPORT
12	VERIFICATION (INCLUDES TEST AND EVALUATION)
13	IMPLEMENTATION AND TRANSITION
14	QUALITY ASSURANCE
15	CONFIGURATION MANAGEMENT
16	IN-SERVICE MANAGEMENT

4.2.2.2 Inputs to the Integrated Program Plan

The following inputs are necessary to develop the IPP:

- Program objective as reflected in the stakeholder-provided, top-level Mission Need Statement (MNS) and requirements documents, which detail the operational environments in which the system is expected to operate
- Program-specific guidelines

- Top-level program constraints and assumptions, including program-specific organizational constraints and assumptions to be used on the program
- Program-specific schedule constraints and events
- Concept approach, including top-level conceptual alternatives, functional analyses, design support alternatives, and initial system evaluations
- Any specified government or external standards to be employed on the program
- Any other supporting technical plans (e.g., MVP, SEMP) to be presented at the JRC 2b, either in a draft or baseline stage

4.2.2.3 Integrated Program Plan Steps

An IPP is the responsibility of program management, which often delegates the writing and coordinating to SE. The IPP is developed using the following steps.

4.2.2.3.1 Step 1: Collect Inputs

All program elements, both technical and nontechnical, are responsible for providing IPP inputs. The stakeholders provide the inputs for every technical and nontechnical discipline involved. Inputs are also gathered from the Request for Proposal (RFP), SOW, WBS, organizational charts, Contract Data Requirements List (CDRL), and schedule information.

4.2.2.3.2 Step 2: Prepare Integrated Program Plan

The IPP is prepared in accordance with the format described within the AMS. IPP tools shall be selected and a timetable for implementation prepared. The draft IPP includes accomplishments and criteria for each event, responsibility for each accomplishment, entrance and exit criteria, milestone linkages, and supporting narratives. “System Engineering in the Acquisition Management System Program Lifecycle” (Chapter 3) provides some guidelines on the timing for developing various IPP drafts, with the final approved IPP required for the Final Investment Decision (JRC 2b). The AMS Federal Aviation Administration Acquisition System Toolset (FAST) contains the IPP template.

4.2.2.3.3 Step 3: Coordinate and Baseline

The internal and external IPP stakeholders are provided drafts of the IPP for review. Once concurrence is obtained from the stakeholders, the IPP is approved at the JRC 2b and becomes the baseline IPP. SE coordinates IPP impacts and develops workaround strategies.

4.2.2.3.4 Step 4: Maintain Plan

The program progress is monitored continually throughout the life of the program. Changes in the program are reflected in the IPP, which is then coordinated for approval of the modifications.

4.2.2.3.5 Step 5: Provide Current Plan

The IPP is provided to all stakeholders.

4.2.2.4 Outputs of the Integrated Program Plan

There are five basic types of data in the IPP:

- **Data Type 1: Event.** This may be major program review—especially the AMS phase exit reviews—or they are sub-events.
- **Data Type 2: Accomplishment.** An accomplishment is the end goal of any program task tied to the event. The accomplishment may be the development of a deliverable or conduct of an analysis or test.
- **Data Type 3: Success Criteria.** A success criterion is the measure of whether the accomplishment was met or not. The criterion may be completion of the task, delivery of a report, or completion of the test. Success criteria may also include quality measures, such as the success of a test or the approval of a report.
- **Data Type 4: Task.** A task is the activity required to accomplish the objectives tied to the event. It is recommended that the task statement reference the applicable WBS and SOW elements.
- **Data Type 5: Subtask.** A subtask is a subdivision of the task described in the major task.

4.2.2.5 Integrated Program Plan Metrics

The primary IPP metric is publication and approval of the IPP at each AMS milestone. The IPP itself is a metric to evaluate the conduct of the program. The performance and conduct of the events, accomplishments, success criteria, tasks, and subtasks are program metrics.

4.2.2.6 Integrated Program Plan Tools

The primary IPP tool is a generic template for any project using the SE elements and is contained in the FAST Toolset under “Required Planning Documents”. Specific projects may tailor this template to provide information pertaining to specific deliverables, tasks, and tools.

4.2.2.7 Integrated Technical Planning Inputs to the Integrated Program Plan

The Integrated Program Plan and System Engineering. SE planning directly relates to elements of the SE process and is included as sections of the IPP. It describes how the SE process is applied to the given program or project at a summary level with detailed SE implementation activities discussed in supporting technical plans (e.g., SEMP, MVP, etc). These planning sections become the tailored process. All IPP sections apply to every program; however, stakeholder direction or the nature of the program may dictate elimination of a planning section. As an example, a program without any avionics interfaces does not require a certification planning section. The program system engineer documents the rationale for eliminating any IPP sections or tailoring any process, and the program manager approves these actions. Table 4.2-2 lists the sections of an IPP and the SE elements from the SEMP that provide summary level inputs to the applicable IPP sections.

Table 4.2-2. SE Inputs To The Integrated Program Plan

Integrated Program Plan		
1	BACKGROUND	
1.1	Mission Need	Integrated Technical Planning (ITP)
1.2	Status	ITP
2	OVERVIEW	
2.1	Program Scope	ITP
2.2	Products	ITP
3	INTEGRATED PROGRAM FUNDING	ITP
	INTEGRATED PROGRAM SCHEDULE	ITP
5	PERFORMANCE	
5.1	Core Work Activities	ITP; Functional Analysis (FA); Synthesis (Syn); Trade Studies (TS); Interface Management (IM); Integrity of Analyses (IA); Specialty Engineering (SpecEng – Reliability, Maintainability and Availability – RMA)
5.2	Program Management Work Activities	Requirements Management (RM); SpecEng (System Safety); Risk Management (RSK)
5.3	Procurement Work Activities	ITP
6	BENEFITS	RM
7	PHYSICAL INTEGRATION	Lifecycle Engineering (LCE – real property; deployment and transition); SpecEng (Hazardous Materials Management/Environmental Engineering; Electromagnetic Environmental Effects E^3)
8	FUNCTIONAL INTEGRATION	IM
9	HUMAN INTEGRATION	SpecEng (Human Factors Engineering)
10	SECURITY	SpecEng (Information Security Engineering)
11	IN-SERVICE SUPPORT	LCE (Integrated Logistics Support; Sustainment/Technology Evolution)
12	VALIDATION (INCLUDES TEST AND EVALUATION)	Validation and Verification (VV)
13	IMPLEMENTATION AND TRANSITION	LCE (Deployment and Transition;

Integrated Program Plan		
		Disposal)
14	QUALITY ASSURANCE	SpecEng (Quality Engineering)
15	CONFIGURATION MANAGEMENT	Configuration Management (CM)
16	IN-SERVICE MANAGEMENT	LCE (ILS; Sustainment/Technology Evolution)

The following describes which SE element is the source of information for each section of the IPP. The IPP summarizes the SE activities while the SEMP and other supporting technical plans describe the implementation detail.

4.2.2.7.1 Background

Integrated Technical Planning is the source of information for summarizing the mission need and status of the program.

4.2.2.7.2 Overview

Integrated Technical Planning is the source of information about the scope of the program and the primary deliverables.

4.2.2.7.3 Integrated Program Funding

Integrated Technical Planning is the source for WBS, level of effort and schedule/duration information in sufficient detail to allow cost estimators to identify funding requirements.

4.2.2.7.4 Integrated Program Schedule

Integrated Technical Planning is the source for WBS, milestone and SE activity information to allow for a logical networking of program activities to achieve program objectives.

4.2.2.7.5 Performance

Within the “Core Work Activities” section, SE elements that are not specifically broken out as separate work activities are described here. SE elements—such as Integrated Technical Planning, Functional Analysis, Synthesis, Trade Studies, Interface Management, Integrity of Analyses, and Specialty Engineering sub-elements such as Electromagnetic Environmental Effects (E^3) and Reliability, Maintainability, and Availability (RMA)—may be addressed to the extent that they apply.

Within the “Program Management Work Activities” section, specific SE elements such as Requirements Management, Specialty Engineering (System Safety) and Risk Management are identified as work activities requiring discussion. Program metrics are also described in this section with Integrated Technical Planning as the source.

Within the “Procurement Work Activity” section, those SE resources required to support Screening Information Request release, RFP development, proposal evaluations, and contractor requirements definition are identified.

4.2.2.7.6 Benefits

Requirements Management is the source for technical or performance benefits.

4.2.2.7.7 Physical Integration

SE inputs to this section of the IPP to identify space, facility, environment, power, and hazardous materials activities that require planning.

4.2.2.7.8 Functional Integration—Reserved

4.2.2.7.9 Human Integration—Reserved

4.2.2.7.10 Security—Reserved

4.2.2.7.11 In-Service Support—Reserved

4.2.2.7.12 Verification—Reserved (See MVP and SEMP)

4.2.2.7.13 Implementation and Transition—Reserved

4.2.2.7.14 Quality Assurance—Reserved

4.2.2.7.15 Configuration Management—Reserved

4.2.2.7.16 In-Service Management—Reserved

It is recommended that, as part of the IPP, these planning sections be reviewed and changed whenever dictated by a change in the program or discovery of a discrepancy in the IPP. It is also recommended that changes to any these planning sections be coordinated with the SEMP, MVP, and other associated plans. All plans shall be reviewed at each phase exit review through the review following the last action required by the plan. After any plan is created following this manual, it is recommended that the plan be provided as reference material for future plan developers. It is recommended this be done through SE. It is also recommended that, along with the plan to be achieved, comments are provided to continue improvement of the plan development process.

4.2.3 System Engineering Management Plan

4.2.3.1 Introduction to the System Engineering Management Plan

The SEMP is the only implementing document that integrates all SE activities. The SEMP unambiguously ties together the organization, direction and control mechanisms, and personnel to be used to attain program/project cost, performance, and schedule objectives. Prepared by the SE manager, this tool identifies and ensures control of the overall SE process and provides greater SE implementation detail than does the higher- level IPP. The preliminary issue of the SEMP typically occurs in Mission Analysis; a final version is released in the first phase of Investment Analysis for JRC 2a, and a scheduled update occurs in the later phase of Investment Analysis, with additional updates as necessary to reflect changing input conditions throughout the program/project.

4.2.3.2 Inputs to System Engineering Management Plan

The SEMP relates the technical requirements to program requirements, providing the structure to guide and control the integration of engineering activities needed to achieve the SE objectives consistent with a top-level management plan for the program. The SEMP includes more detailed planning for all SE elements to be executed as part of the program. Organizing to execute the system development involves defining the entire organizational structure (such as teams, work groups, and programs); establishing the responsibilities, authority, and accountability of each; and clearly defining structural interfaces. It is recommended that this be an iterative process.

Information and data necessary to begin creation of a SEMP include the following:

- Knowledge of corporate strategy and goals
- Description and understanding of the overall program/project, usually found in an IPP or draft IPP
- Identification of top-level program/project requirements, usually from the MNS, final Requirements Document, change request, or one of the outputs developed during Mission Analysis Structure of engineering and other organizations, both internal (e.g., stakeholder) and external (e.g., supplier)
- Contract documents
- Any restrictions or constraints

4.2.3.3 System Engineering Management Plan Steps

The following steps shall be employed to write a SEMP.

4.2.3.3.1 Step 1: Collect Inputs

4.2.3.3.2 Step 2: Analyze Inputs

To determine the SE effort required and committed to by program management, review the IPP, which is based on the nature and magnitude of the program/project.

- Large and complex system developments demand full System Engineering application to insure success
- Small-scale projects may be run under a subset process
- SE shall coordinate with IPT teams and program management, as their concurrence ensures the project team shall refer to and comply with the SEMP

4.2.3.3.3 Step 3: Define Activities and Efforts

After evaluating all inputs, establish how the SE manager integrates them. It is recommended that decisions made involve the following:

- Tailoring the SE process
- Selecting an approach to ensure integration of engineering specialties

- How program team members are to interact and communicate to execute technical program planning and control
- Identifying the explicit SE responsibilities to be assigned to each individual and organization, which, in total, are to account for all such tasks planned
- The structure of the comprehensive SE Master Schedule (integrated with the IPP) for scheduled tasks
- Explicit guidance regarding development of each task for optimal inclusion, as program team members employs the SEMP as a handbook and reference source for essential information

4.2.3.3.4 Step 4: Baseline

Prepare a draft SEMP for review and comment, using input from all affected engineering, engineering specialty, and program/project management organizations and, when appropriate, the stakeholders. The draft may also include contractual SEMP requirements, such as a CDRL Item and/or Data Item Description, with which all affected parties shall comply.

4.2.3.3.5 Step 5: Interface With Other Processes/Plans

In addition to employing the IPP as an input during development, the SEMP interfaces with and forms a roadmap to other SE and engineering specialty plans (e.g., Master Verification Plan). The SEMP addresses all of the SE elements:

- Integrated Technical Planning (Section 4.2)
- Requirements Management (Section 4.3)
- Functional Analysis (Section 4.4)
- Synthesis (Section 4.5)
- Trade Studies (Section 4.6)
- Interface Management (Section 4.7)
- Specialty Engineering (Section 4.8)
- Integrity of Analyses (Section 4.9)
- Risk Management (Section 4.10)
- Configuration Management (Section 4.11)
- Validation and Verification (Section 4.12)
- Lifecycle Engineering (Section 4.13)
- Maintain System Engineering (Section 4.14)

4.2.3.3.6 Step 6: Update and Maintain the Plan

It is recommended that throughout the program/project, the SE manager monitor inputs (especially the IPP). When there is a significant change in one or more inputs, it is recommended that the SEMP be revised (by repeating the creation steps above).

4.2.3.4 Output of System Engineering Management Plan

Table 4.2-3 is a SEMP outline.

Table 4.2-3. System Engineering Management Plan Outline

System Engineering Management Plan Outline	
SECTION 1	INTRODUCTION
1.1	Scope
1.2	Purpose of the System Engineering Management Plan
1.3	Organization of the System Engineering Management Plan
1.4	SEMP Overview
1.5	*Program/Project name* System Description
1.6	Program Organization
1.7	System Engineering Responsibility Assignments
1.8	System Engineering Environment and Tools
1.9	System Engineering Metrics
SECTION 2	SYSTEM ENGINEERING
2.1	System Engineering Process
2.2	Integrated Technical Planning
2.3	Requirements Management
2.4	Functional Analysis
2.5	Synthesis
2.6	Trade Studies
2.7	Interface Management (may refer to IPP section 7)
2.8	Specialty Engineering
2.8.1	System Safety Engineering
2.8.2	Human Factors Engineering (may refer to IPP section 9)
2.8.3	Quality Engineering (may refer to IPP section 14)
2.8.4	Reliability, Maintainability and Availability
2.8.5	Electromagnetic Environmental Effects (E^3)
2.8.6	Hazardous Materials Management/Environmental Engineering
2.9	Integrity of Analysis

System Engineering Management Plan Outline	
2.10	Risk Management
2.11	Configuration Management (may refer to IPP section 15)
2.12	Validation and Verification (may refer to IPP section 12)
2.13	Lifecycle Engineering
2.13.1	Real Property Management
2.13.2	Deployment and Transition
2.13.3	Integrated Logistics Support
2.13.3.1	Maintenance Planning
2.13.3.2	Maintenance Support Facility
2.13.3.3	Direct-Work Maintenance Staffing
2.13.3.4	Supply Support
2.13.3.5	Support Equipment
2.13.3.6	Training, Training Support, and Personnel Skills
2.13.3.7	Technical Data
2.13.3.8	Packaging, Handling, Storage, and Transportation
2.13.3.9	Computer Resources Support
2.13.4	Sustainment/Technology Evolution
2.13.5	Disposal
2.14	Maintain System Engineering
SECTION 3	
3.1	System Engineering Master Schedule

Appendix E contains more detailed input and format information for the planning associated with all of the SE elements discussed in Section 2 of the SEMP.

4.2.3.5 Requirements Management Planning—See Appendix E for Details

This planning specifies the tasks, products, responsibilities, and schedule for managing requirements throughout product development. The planning is baselined at the JRC 2b in the IPP and is updated as necessary at subsequent exit reviews.

The planning section details the total effort in managing requirements. The work includes identifying and capturing requirements (Paragraph 4.3.2.1), analyzing and decomposing requirements (Paragraph 4.3.2.2), and allocating requirements (Paragraph 4.3.2.3).

4.2.3.6 Functional Analysis Planning—See Appendix E for Details

The Functional Analysis planning section of the SEMP specifies the tasks, products, responsibilities, and schedule for functional analysis throughout development of the product. Because there is no program level SEMP in the early phases of the program (i.e., Mission Analysis and Investment Analysis), Functional Analysis in these phases is guided by the National Airspace System (NAS)-level SEMP. When the IPP is developed, the Functional

Analyses is guided by the program's tailored SEMP. The planning section is baselined at the JRC 2b and is updated as necessary at subsequent exit reviews. This planning section details the total effort for managing functional analysis. This work includes analysis of the concept of operations and environment, the decomposition of functions into subfunctions, decomposing and allocating requirements to functions, evaluating alternative decompositions, defining functional sequences and timelines, defining functional interfaces, and documenting the functional baseline. These tasks are described in Functional Analysis (Section 4.4).

4.2.3.7 Synthesis Planning—Reserved

4.2.3.8 Trade Study Planning—See Appendix E for Details

The Trade Study planning documents the formal management planning regarding how alternative solutions to a problem or design issue associated with a program/project product development is to be assessed in a fair and impartial manner.

Trade study planning:

- Provides the formats for how trade study results and information are to be presented to management at design reviews
- Identifies the organization or person designated to be the trade study leader
- Identifies any tools that are to be used in performing of the trade study (i.e., cost models, computer simulations, test articles and fixtures, analytical tools)
- Provides the criteria (including constraints) under which the trade study is to be conducted
- Provides instructions on where trade study results and data are to be stored for future reference and which organization is responsible for maintaining the data

4.2.3.9 Interface Management Planning—See Appendix E for Details

Interface management (IM) planning ensures establishment of the formal management system of interface (I/F) controls that enable physical and functional compatibility between interfacing hardware, software, personnel, and facilities. This planning:

- Provides the means for identifying, defining, documenting, and controlling the interfaces at all levels of the system
- Provides the means for changing the interfaces as required by the evolution of the design and for resolving interface incompatibilities
- Guides management, control, and documentation of all system functional and physical interfaces
- Establishes the Interface Working Group (IWG) and its policies and procedures
- Contains requirements and templates for preparing, revising, and processing the interface documentation; identifies products
- Establishes the participants of the I/F control process and their responsibilities
- Establishes the interface management schedule

The IWG Chair drafts the IM planning policies and procedures in the early phase of Investment Analysis concurrent with the SEMP and the SE Schedule. The IWG Chair updates and reviews the interface control planning section of the IPP to reflect the system functional and physical architectures developed in later phase of Investment Analysis.

4.2.3.10 Specialty Engineering Planning—Reserved

4.2.3.10.1 System Safety Management Planning

System safety is the application of engineering and management principles, criteria, and techniques to optimize safety within constraints of operational effectiveness, time, and cost throughout all program lifecycle stages. The NAS Modernization System Safety Management Plan (SSMP) governs system safety efforts conducted in the AMS. The SSMP requires each program to develop, as part of the IPP, an Integrated System Safety Program (ISSP) tailored to the program's safety needs. The ISSP calls for contractors or vendors to develop and maintain a System Safety Program Plan (SSPP) that details the planned safety activities. The SSPP describes safety assessments, tasks, and activities of system safety management and system safety engineering required to support the design process and to identify, evaluate, and eliminate or control hazards throughout the system lifecycle.

4.2.3.10.2 RMA Planning—Reserved

4.2.3.10.3 Human Integration Planning—See AMS

4.2.3.10.4 Security Planning—See AMS

4.2.3.10.5 Quality Assurance Planning—See AMS

4.2.3.10.6 Hazardous Material Management Planning—Reserved

4.2.3.10.7 Electromagnetic Interference/Electromagnetic Compatibility and Environmental Planning—Reserved

4.2.3.11 Analysis Management Planning—See Appendix E for Details

The Analysis Management planning section of the IPP is compiled following JRC 1 approval. It supports the objective of that process: "to create high likelihood that the program's analyses are credible, useful, and sufficient." Analysis Management planning defines the analyses to be performed throughout the program and the operational criteria for the analytic tools to be used, as well as the users and the requirements for verifying that the results are correct and sufficient. As a part of the IPP, this section is reviewed with any other plans at the JRC 2b.

4.2.3.12 Risk Management Planning—See Appendix E for Details

Risk is inherent in every program. Stakeholders know this and expect contractors to address risks in program plans. SE addresses three facets of risk: technical, schedule, and cost. Technical risks include all events that may prevent the program from satisfying contractual requirements, including performance, supportability, maintainability, and regulatory requirements. Schedule risks are events that may prevent timely execution of tasks identified in the IPP. Cost risks are events that may cause actual expenditures to exceed estimated costs.

Risk management is a key process within SE. The program and functional managers implement it by ensuring appropriate resources are applied to reduce risk to acceptable levels. Risk management consists of five essential components: identify risks, analyze risks, identify mitigation options, implement risk-reduction plan, and monitor risks.

The risk management planning section describes the approach, methods, procedures, and criteria for risk management and its integration into the program decision process. It is continually updated throughout the program life with the IPP.

4.2.3.13 Configuration Management Planning—See Appendix E for Details

Configuration Management planning documents the formal management system of CM to ensure that the integrity and continuity of the design, engineering, and cost tradeoff decisions made between technical performance, producibility, operability, testability, and supportability are recorded, communicated, and controlled by program and functional managers. CM planning provides the means for the:

- Configuration Identification process that identifies the functional and physical characteristics of selected system components, designated as configuration items (CI), during the system's acquisition lifecycle
- Configuration Control process that controls the changes to CIs during the system's acquisition lifecycle
- Configuration Status Accounting process that records/reports change processing and implementation status
- Configuration Audits process that supplies current descriptions of developing hardware configuration items, computer software configuration items, and the system itself

4.2.3.14 Validation and Verification Planning—See Appendix E for Details

4.2.4 Master Verification Plan (Includes Test and Evaluation Planning) (MVP)—See Appendix E for Details

The MVP contains both validation and verification planning. Validation is the process of proving that the right system is being built (i.e., that the system requirements are unambiguous, correct, complete, consistent, traceable to needs, operationally and technically feasible, and verifiable). The validation planning process is conducted to demonstrate that the requirements for a system are clearly understood and that it is possible to satisfy them through design work using available state-of-the-art technology, funding, and schedule. Verification is the process (tasks, actions and activities) of confirming that evolving system solutions comply with functional, performance, and design requirements that spell out stakeholder (internal and external) expectations of capabilities, as well as performance and characteristics of the developed system. Product verification may occur during any phase of a product development cycle, but is more likely to occur after the product Preliminary Design Review. Verification is the process that ensures that system requirements have been met by the design solution and that the system is ready for use in its operational environment. This means that a verified system may demonstrate that it complies with mission need and meets functional, performance, allocated, derived, and interface requirements, as well as design and allocated constraints that achieve customer needs. The MVP objective is to define all verification activities that demonstrate the system's capability to meet the specification requirements.

4.2.5 Integrated Lifecycle Planning—Reserved

4.2.5.1 Real Property Management—Reserved

4.2.5.2 Deployment and Transition—Reserved

4.2.5.3 Integrated Logistics Support—Reserved

4.2.5.4 Sustainment/Technology Evolution—Reserved

4.2.5.5 Disposal—Reserved

4.2.6 Reviews and Audits

4.2.6.1 Technical Reviews

4.2.15.1.1 Joint Resources Council 1 Review

4.2.15.1.2 Joint Resources Council 2a Review

4.2.15.1.3 Initial System Requirements Review

4.2.15.1.4 Joint Resources Council 2b Review

4.2.15.1.5 Preliminary Design Review

4.2.15.1.6 Critical Design Review

4.2.15.1.7 Joint Resources Council 3 Review

4.2.6.2 Audits

4.2.15.2.1 Functional Configuration Audit

4.2.15.2.2 Physical Configuration Audit

4.3 Requirements Management

4.3.1 Introduction to Requirements Management

The Requirements Management process, an element of System Engineering (SE), is an activity that spans the program's entire lifecycle. It is associated with iterative identification and refinement, to successively lower levels, of the top-level requirements, functional baselines and architectures, and synthesis of solutions established for the preferred system concept. For the purposes of Requirements Management, a system or a product shall mean any physical product being designed, developed, and/or produced, or any intangible product such as the development of a process or service-based product.

The Requirements Management process defines, collects, documents, and manages all requirements, including the complete requirements set consisting of the Mission Need Statement (MNS), the initial Requirements Document (iRD) and final Requirements Document (fRD), and the system and procurement specifications. A requirement is defined as a condition or capability that shall be met or exceeded by a system or a component to satisfy a contract, standard, specification, or other formally imposed document. Executing this process results in the authorized, organized, and baselined set of requirements for the product. These requirements are presented as requirements sets, usually in the form of requirements documents, to all other applicable SE and Federal Aviation Administration (FAA) processes. To effectively develop and manage system requirements, all requirements shall be developed through this process.

4.3.1.1 Process Description

4.3.1.1.1 Purpose

Requirements Management's purpose is to establish a layered approach that defines the necessary and sufficient attributes of the lower-level system components required for the product's successful development, production, deployment, operation, and disposal. Successful completion of this process is measured by the acceptable transformation of stakeholder needs into discrete, verifiable, low-level requirements. The process identifies, clarifies, balances, and manages the entire requirements set through interactive dialogue with all stakeholders. The top-level process appears in Figure 4.3-1.

4.3.1.1.2 Requirements Management Objectives

Requirements Management is an iterative process that:

- Identifies and captures the requirements applicable to the system
- Analyzes and decomposes the requirements into clear, unambiguous, traceable, and verifiable requirements
- Allocates the requirements to the appropriate component within the system hierarchy and/or to the appropriate organizational entities
- Derives lower-level requirements from higher-level requirements in the system hierarchy
- Establishes the method of verification for each requirement
- Ensures that the product complies with the requirements

- Manages, documents, and controls the requirements and changes to them in a traceable manner

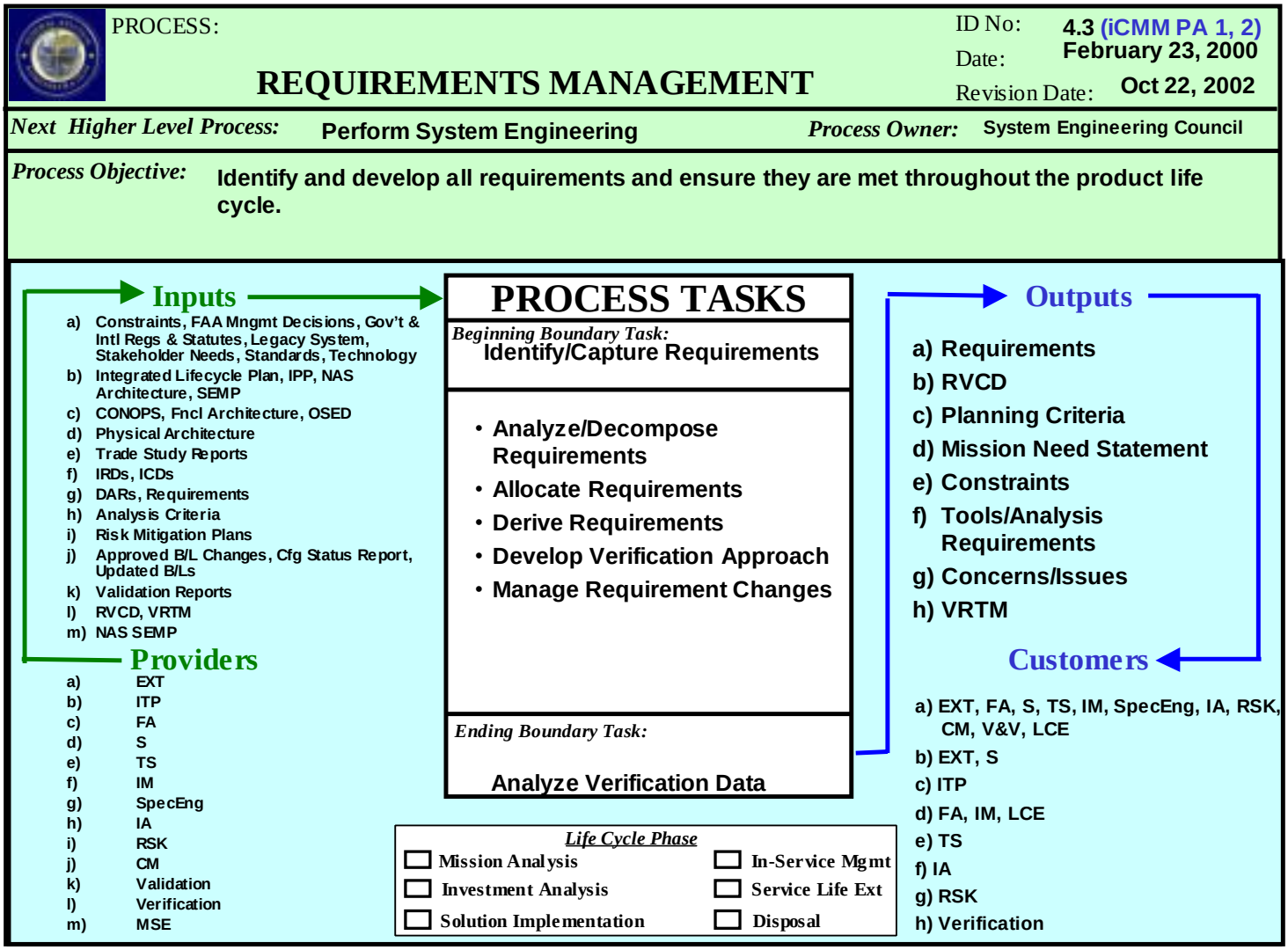


Figure 4.3-1. Requirements Management Process-Based Management Chart

4.3.1.2 Management

The Requirements Management process bridges integrated product development system stages. The products of this process are baselined in accordance with the milestones established in the Integrated Program Plan (IPP) for the applicable project. Prerequisites for successful performance of the process are:

- Empowering a requirements analysis team with the authority and mission to execute the process
- Assigning an experienced team leader knowledgeable in SE principles and committed to the standard SE methods documented herein

- Assigning team members that are experienced and knowledgeable in relevant engineering, manufacturing, operational, specialty engineering, and support disciplines
- Establishing the criteria for decisionmaking and any supporting tools
- Completing the relevant training of team members in using this process and relevant tools
- Defining the formats of the output deliverables from this activity

4.3.2 Inputs to Requirements Management

An input to the Requirements Management process is defined as information received during the process. Inputs are classified according to their source (i.e., external or internal). External inputs come from sources outside SE. Internal inputs come from other SE processes as described in this manual. Typical inputs include Stakeholder Needs and objectives, missions, measures of effectiveness (MOE) and measures of suitability, environments, key performance parameters, technology base, output requirements from prior application of SE, and program decision requirements. Input requirements shall be comprehensive and defined for both system products and system processes, including the eight lifecycle functions of development, manufacturing, verification, deployment, operations, support, training, and disposal.

Requirements Management is an iterative process that flows from a high level to a low level of requirements. Therefore, some of the inputs described in the following paragraphs may be inputs to one stage of the requirements development process and outputs of other stages. All requirements sources described were, at one point in the process, inputs and shall be captured. The inputs to the Requirements Management process are as follows.

4.3.2.1 External Inputs

External inputs come from outside SE's boundaries.

4.3.2.1.1 Constraints

A Constraint is a boundary condition within which the system remains while satisfying the aggregate system requirements.

4.3.2.1.1.1 External Constraints

External constraints, including guidelines and assumptions, shall be identified. External constraints are imposed from outside the project or system boundaries. External conditions under which the mission is to be performed and systems developed are described. The conditions may include cost, schedule, performance, technology, use of infrastructure, labor/management agreements, and programmatic constraints. Additional assumptions concerning programmatics, technology, and environments that may be required are captured.

4.3.2.1.1.2 Internal Constraints

Internal constraints, including assumptions, guidelines, and program-specific constraints, shall be identified. Internal constraints are imposed from within the project or system boundaries but outside of the SE process boundary. Program-specific conditions under which the mission is to be performed and systems developed are described. The conditions may include cost, schedule, performance, technology, use of infrastructure, and programmatic constraints.

Additional assumptions concerning programmatics, technology, and environments that may be required are captured.

4.3.2.1.1.3 Program-Specific Constraints

Program-specific organizational constraints and assumptions are captured, as well as program-specific needs, schedule constraints, and events.

4.3.2.1.1.4 Technology Constraints

Technology availability or technology constraints are captured. Technology necessary to satisfy requirements and the resulting derived requirements are described. Constraints identify the envelope of the technology operation. These inputs may include identifying key technologies, performance, maturity, cost, and risks; they may also include technology breakthroughs and forecasts.

4.3.2.1.2 Standards, Specifications, and Handbooks

Specified government standards, external standards, and general specifications or handbooks to be employed on the program are identified. The most common standards, specifications, and handbooks used in FAA requirements documents appear in Appendix A.

4.3.2.1.2.1 Standards

A standard is a document that establishes engineering and technical requirements for processes, procedures, practices, and methods that have been adopted as standard. Standards may also establish requirements for selection, application, and design criteria for material. The FAA, Department of Defense (DoD), other U.S. Government agencies, the RTCA, international organizations, and commercial standards organizations publish standards.

4.3.2.1.2.1.1 RTCA Standards

The RTCA publishes standards as Minimum Operational Performance Standards (MOPS) and Minimum Aviation System Performance Standards (MASPS).

4.3.2.1.2.1.1.1 Minimum Operational Performance Standards

The MOPS contain performance requirements for avionics. The standards describe typical equipment applications and operational goals and establish the basis for required performance and test procedures for verification under a common set of standards. Definitions and assumptions essential to proper understanding are provided, as well as installed equipment tests and operational performance characteristics for equipment installations. The MOPS also provide information that explains the rationale for equipment characteristics and stated requirements.

4.3.2.1.2.1.1.2 Minimum Aviation System Performance Standards

The MASPS address the user-level service requirements used to qualify the system for operational acceptance and to allocate requirements for the subsystems (including avionics). The standards provide information that explains the rationale for system characteristics, operational goals, requirements, and typical applications.

4.3.2.1.2.2 Specifications

A specification is a document prepared specifically to support an acquisition that clearly and accurately describes the essential technical requirements for purchased material or products and the criteria for determining whether the requirements are satisfied. The FAA, DoD, other U.S. Government agencies, international organizations, and commercial standards organizations publish specifications.

4.3.2.1.2.3 Handbooks

A handbook is a guidance document that contains information or guidelines for use in design, engineering, production, acquisition, and/or supply management operations. These documents present information, procedural and technical use data, or design information related to processes, practices, services, or commodities. Handbooks provide industry with reference materials that help to standardize FAA assets. Use of handbooks is optional unless required by a specification or contract document. The FAA, DoD, other U.S. Government agencies, international organizations, and commercial standards organizations publish handbooks.

4.3.2.1.2.4 Federal Aviation Administration Orders

An FAA order is a permanent directive on individual subjects or programs that apply to the FAA. It directs action or conduct using action verbs. Orders also prescribe policy, delegate authority, and empower and/or assign responsibility for compliance with stated requirements or direction. Orders empower or direct only FAA personnel and carry no weight with contractors. Thus, orders shall not be used in contract documents. They are not referenced in requirements documents but are used as inputs with the potential to generate requirements.

4.3.2.1.2.5 National Airspace System Management Directives

NAS-MD-001, “National Airspace System Master Configuration Index,” lists all baselined equipment and software currently operational or under procurement for the National Airspace System (NAS) with current approved baseline documentation. FAA and contractor personnel use NAS-MD-001 to identify configuration items and documentation requiring NAS Change Proposals (NCP).

4.3.2.1.3 Federal Aviation Administration Management Decisions

Management decisions that are imposed on the system from the national, department, or agency level are captured.

4.3.2.1.4 Government Policy

4.3.2.1.4.1 Government Regulations and Statues

Government statutes and military and civilian regulations impacting the system are identified, including requirements incorporated into legislation (e.g., safety or security requirements). These requirements also include government standards that have been mandated as part of a contract.

4.3.2.1.4.2 International Policy

The International Civil Aviation Organization (ICAO) develops and publishes international Standards and Recommended Practices (SARP). A standard is any specification for physical characteristics, configuration, material performance, personnel, or procedure that is applied uniformly for the safety or regularity of international air navigation and to which the international aviation community conforms. A recommended practice is identical to a standard except that it is not considered necessary—only desirable.

4.3.2.1.4.3 Federal Aviation Administration Policy

This category covers all FAA agency-wide management decisions and policy requirements imposed by FAA agency-wide mandate. The category may include technical, operational, acquisition, financial, and other requirements. FAA policy is invoked using the FAA Directives System, as described in FAA Order 1320.1, “FAA Directives System.”

4.3.2.1.4.4 Acquisition Management System Limitations

New or revised directions and limitations established by the Acquisition Management System (AMS) are identified.

4.3.2.1.5 Legacy Systems

Requirements from past and current systems are captured and analyzed for applicability.

4.3.2.1.6 Stakeholder Needs

4.3.2.1.6.1 National Airspace System Concepts of Operations Document

The NAS Concepts of Operations (CONOPS) document provides a CONOPS from the perspectives of NAS users and service providers. It is the basis for an incremental benefits-driven approach toward NAS evolution. The document is arranged in a phases-of-flight approach, including Flight Planning, Surface, Arrival/Departure, En Route, and NAS Management. It is the source document for all NAS operational requirements.

4.3.2.1.6.2 Mission Need Statement

The MNS is the first document to translate the NAS CONOPS into the needs and requirements of the users and service providers. It identifies the decision factors relevant to a capability shortfall or a technological opportunity to satisfy a mission more efficiently or effectively. The MNS justifies, in rigorous analytical terms, the need to resolve a shortfall in services required by its users and service providers or to explore a technological opportunity for more efficient and effective mission performance. The MNS identifies the mission area, needed capability, current capability, capability shortfall, impact to users and service providers if the shortfall is not resolved, benefits, timeframe for resolving the shortfall, criticality of the mission, and resource estimate.

4.3.2.1.6.3 Operational Scenarios

Operational scenarios provided by the user describe how the CONOPS is implemented. They may be incorporated into the MNS or provided as a separate document.

4.3.2.1.6.4 Requirements Document

The requirements document establishes the operational framework and performance baseline, traces Functional Analysis to the NAS CONOPS and the MNS, and is the primary source document for the system requirements. This document is the principal force driving the search for a realistic and affordable solution to the mission need. The iRD is developed early in the process by the sponsoring organization. It translates the need in the MNS into initial top-level requirements that address concerns such as performance, supportability, physical and functional integration, human integration, security, test and evaluation, implementation and transition, quality assurance, configuration management, and in-service management. The iRD does not describe a specific solution to a mission need. It is recommended that the iRD not preclude leasing, commercial, or non-development solutions. The fRD defines exactly the operational concept and requirements that are to be achieved and is the basis for evaluating the readiness of resultant products and services to become operational.

4.3.2.1.7 External Interface Studies

System external interface studies and analyses that characterize and define the interfaces between the system and external environment are reviewed or conducted. These studies identify functional and physical characteristics between two or more elements that are provided by different agencies, as well as resolve problems. Topics include issues, option assessments, impact assessments, interfaces and connections, interferences, and configuration options.

4.3.2.1.8 National Airspace System Architecture

The NAS Architecture is a strategic and evolutionary plan for modernizing the NAS that supports investment analysis tradeoffs. It focuses on defining and delivering the services that meet aviation industry and public needs, which it accomplishes by decomposing the services into capabilities that are the functions and activities necessary to deliver a service. Each capability is defined by the implementations steps required to deliver the capabilities. Each implementation step is defined in terms of the mechanisms required to provide each step. Finally, each mechanism is defined in terms of the people, systems, and support activities provided by the procuring office. The NAS Architecture presents a comprehensive design that shows each major mechanism within the NAS, including interfaces and data flows. Use of a documented design, complete with traceable requirements, as the foundation for the architecture not only provides a complete picture of the NAS but also provides a roadmap for implementing future enhancements.

4.3.2.1.9 National Airspace System System Engineering Management Plan

The NAS System Engineering Management Plan (NAS SEMP) defines the relationship between the NAS SE levels, including requirements management, and the roles and responsibilities of each level. The SE levels are defined in the NAS SEMP and include the Enterprise, Domain, and Functional levels.

4.3.2.1.10 National Airspace System Requirements

4.3.2.1.10.1 **NAS Systems Requirements Specification (NAS-SR-1000)**

This FAA document defines the operational requirements and is the approved document for operational requirements for the NAS. The document serves as a basis to perform studies and

analysis and to identify engineering concepts to satisfy operational requirements. It also serves as a source document for system specification preparation.

4.3.2.1.10.2 NAS Design Specification (NAS-DD-1000).

This FAA document defines the functional architecture, including basic NAS elements, sub-elements, subsystems, and their interrelationships.

4.3.2.1.10.3 NAS System Specification (NAS-SS-1000).

This FAA document defines functional, performance, design, construction, logistics, personnel and training, documentation, verification, and interface requirements for the NAS.

4.3.2.2 Internal Inputs

Internal inputs come from inside SE's boundaries.

4.3.2.2.1 Technical Planning

4.3.2.2.1.1 Integrated Program Plan

The Requirements Management planning section of the IPP (Integrated Technical Planning (Section 4.2)) specifies the tasks, products, responsibilities, and schedules needed to manage requirements throughout product development. It details the total work effort for managing requirements. This work includes "Task 1: Identify and Capture Requirements" (Paragraph 4.3.3.1); "Task 2: Analyze and Decompose Requirements" (Paragraph 4.3.3.2); "Task 3: Allocate Requirements" (Paragraph 4.3.3.3); "Task 4: Derive Requirements" (Paragraph 4.3.3.4); and "Task 6: Manage Requirements Changes" (Paragraph 4.3.3.6).

4.3.2.2.2 Functional Analysis

4.3.2.2.2.1 Concept of Operations

A Concept of Operations (CONOPS), which is a user-oriented document that describes a proposed system's functional requirements from the user's viewpoint, is obtained from the Functional Analysis process (Section 4.4). The CONOPS document is written to communicate overall quantitative and qualitative system characteristics to the user, buyer, developer, and other organizational elements. The CONOPS aids in requirements capture and communicates the need to the developing organization. The CONOPS describes the existing system, current environment, users, interactions among users and the system, and organizational impacts. A CONOPS is essentially a top-level narrative Functional Analysis and is the basis for developing the MNS.

4.3.2.2.2.2 Functional Architecture

Every function required to satisfy a system's operational needs shall be identified and defined. Once defined, the functions are used to define system requirements, and a Functional Architecture is developed based on the identified requirements. The process is then taken to a greater level of detail, as the identified functions are further decomposed into subfunctions, and the Functional Architecture and requirements associated with those functions are each decomposed as well. This process is iterated until the system has been completely

decomposed into basic subfunctions, and each subfunction at the lowest level is completely, simply, and uniquely defined by its requirements. In this process, the interfaces between each of the functions and subfunctions are fully defined, as are the interfaces within the environment and external systems. The functions and subfunctions are arrayed in a Functional Architecture to show their relationships and internal and external interfaces.

The Functional Architecture includes a definition of the functions that the system needs to perform and is developed into Primitive Requirements Statements (PRS). "Task 2: Analyze and Decompose Requirements" (Paragraph 4.3.3.2) of the Requirements Management process develops these PRSs into Mature Requirements Statements (MRS).

4.3.2.2.2.3 Operational Services and Environmental Description

The Operational Services and Environmental Description (OSED) is a complete system description that includes information on all known hardware, software, people, procedures, and ambient and operational environments in the system. It consists of everything inside and outside the system that affects system performance and that is affected by system operation or both.

The OSED is used as a source to derive lower-level requirements. It describes many system characteristics that are nonfunctional, such as environments, and that are not described in the Functional Architecture. Nonfunctional requirements are derived from the OSED in "Task 4: Derive Requirements" (Paragraph 4.3.3.4).

4.3.2.2.3 Synthesis

4.3.2.2.3.1 Physical Architecture

The Physical Architecture allocates requirements to the physical hardware and/or software during the Synthesis process (Section 4.5). If requirements conflicts are discovered during the development of the Physical Architecture, those requirements are cycled back through the Requirements Management process for evaluation, which may result in conducting a Trade Study (Section 4.6), reallocating the requirement, or deriving lower-level requirements.

4.3.2.2.4 Trade Studies

Trade Studies (Section 4.6) may be conducted within and across functions to support decisions during any stage of the system's lifecycle. They quantify through metrics the consequences of opting for various system alternatives, traceable to stakeholder requirements that may be imposed by the requirements development process. They support allocating performance requirements and determining requirements or Design Constraints; they are also used in evaluating alternatives. Trade Studies usually result in derived requirements that are developed into MRSs in "Task 2: Analyze and Decompose Requirements" (Paragraph 4.3.3.2).

4.3.2.2.4.1 Trade Study Reports

Trade Study Reports identify requirements that are affected by the results of each Trade Study (Section 4.6). The new, changed, or derived requirements flow through the entire Requirements Management process and may result in changes to the requirements baseline.

4.3.2.2.4.2 Feasibility Assessments

The Feasibility Assessment may be conducted to assess the difficulty in achieving program goals within the Constraints. Assessment results consider various aspects, such as technical, cost, and schedule, across the lifecycle. It provides information on the expectations for success, considering identified technology development needs in view of program and mission schedule and cost constraints. It also assesses the range of costs and benefits associated with several alternatives for solving a problem.

4.3.2.2.4.3 Derived Requirements

Derived requirements ("Task 4: Derive Requirements" (Paragraph 4.3.3.4)) may be developed through Trade Studies (Section 4.6) and not provided by external sources, such as the user, service provider, or government agencies.

4.3.2.2.5 Interface Management

The inputs from Interface Management (Section 4.7) identify, describe, and define interface requirements to ensure compatibility between interrelated systems and between system elements.

4.3.2.2.5.1 Interface Requirements Document

The Interface Requirements Document (IRD) defines requirements associated with external physical and functional interfaces between the particular system and other associated system(s).

4.3.2.2.5.2 Interface Control Document

The Interface Control Document (ICD) is a design document that describes the detailed, as-built implementation of the functional requirements contained in the IRD.

4.3.2.2.6 Specialty Engineering

Specialty Engineering (Section 4.8) defines and evaluates a system's specific areas, features, or characteristics. Specialty Engineering supplements the design process by defining these characteristics and assessing their impact on the program. Specialty Engineering studies often find characteristics that create a need for new or different requirements or a conflict between two or more requirements. The Specialty Engineering process develops the new or changed requirements, which become inputs to the Requirements Management process.

4.3.2.2.6.1 Design Analysis Reports

Design Analysis Reports (DAR), which document the results of a specific Specialty Engineering analysis with rationale, are inputs to the Requirements Management process. Each DAR contains a description of the system's special characteristics, a list of existing requirements that have undergone the Validation and Verification process (Section 4.12), residual risks, and candidate requirements found as a result of the analysis.

The rationale supplementing the DARs includes the scope, ground rules, assumptions, constraints, methods, and tools applicable to the analysis.

4.3.2.2.6.2 Derived Requirements

The Specialty Engineering process (Section 4.8) provides analysis that typically defines, validates, or verifies requirements. Occasionally, the analysis discovers system characteristics that are not adequately specified in the existing specification or requirements documents. When such discoveries occur, Specialty Engineering defines the necessary requirements that are consistent with the area of Specialty Engineering and the requirements standards described in Requirements Management.

4.3.2.2.7 Integrity of Analysis

4.3.2.2.7.1 Analysis Criteria

If the Requirements Management process requires an analysis or selection of a tool, Analysis Criteria for that analysis or selection are captured. The Analysis Criteria for conducting a required analysis is contained within the Analysis Management Plan.

4.3.2.2.8 Risk Management

4.3.2.2.8.1 Risk Mitigation Plans

Concerns/Issues identified by any SE process are analyzed in the Risk Management process (Section 4.10). Risk Mitigation Plans that result from risk analysis become inputs to the Requirements Management process. Requirements that present a risk are processed through the Requirements Management process for reanalysis, reallocation, and rederivation, as needed.

4.3.2.2.9 Configuration Management

4.3.2.2.9.1 Approved Baseline Changes

Approved changes to the baselined requirements set are captured from the Configuration Management process (Section 4.11). “Step 6: Manage Requirements Changes” (Paragraph 4.3.3.6) inserts the Approved Baseline Changes into the requirements set.

4.3.2.2.9.2 Configuration Status Reports

Configuration Status Reports are captured from the Configuration Management process (Section 4.11). “Step 6: Manage Requirements Changes” (Paragraph 4.3.3.6) uses these reports to maintain a status accounting of all requirements.

4.3.2.2.9.3 Updated Baselines

Updated Baselines are captured from the Configuration Management process (Section 4.11). “Step 6: Manage Requirements Changes” (Paragraph 4.3.3.6) controls the updated baseline configuration.

4.3.2.2.10 Validation

The Validation process (Section 4.12) determines if the requirements produced by the Requirements Management process are sufficiently correct and complete. Requirements that are not validated are captured and resubmitted to the Requirements Management process.

4.3.2.2.10.1 Validation Report

The Validation Report summarizes the results of the Validation process (Section 4.12) and communicates the Validation Table to the Requirements Management process.

The Validation Report contains:

- Summary of validation results
- Description of the system and program
- Validation methodology used
- Unvalidated requirements
  - List of nonconforming requirements
  - Recommendations for correction of nonconforming requirements
- Validation Table
- Discussion of trends and patterns of failure, evidence of systemic failings, and emerging threats to system services.

4.3.2.2.10.2 Validation Table

The Validation Table is a listing of all requirements that describes if a requirement has been validated, where the requirement may be found, source of validation, corrective action to be taken if necessary, and the corrective action owner. Table 4.12-1 in Validation and Verification (Section 4.12) is an example of a Validation Table. The completed Validation Table is included in the requirements document and is the basis for the Verification process.

4.3.2.2.11 Verification

The Verification process (Section 4.12) determines that applicable requirements are satisfied by the design solution.

4.3.2.2.11.1 Verification Requirements Traceability Matrix

The Validation Table from the Validation process (Section 4.12) is further refined into a Verification Requirements Traceability Matrix (VRTM), the heart of the Verification process. The strategy or method used to verify each requirement is specified in a Verification Requirement, and the Verification Requirements are listed in the VRTM. The VRTM defines how each requirement (functional, performance, and design) is to be verified, the stage in which verification is to occur, and the applicable verification levels. The VRTM establishes the basis for the verification program. The VRTM is initiated by the Requirements Management process, which sends it to the Verification process, which returns it to Requirements Management when verification has been completed.

4.3.2.2.11.2 Requirements Verification Compliance Document

The Requirements Verification Compliance Document (RVCD) provides evidence of compliance for each requirement at all levels and to each VRTM requirement. The flowdown from the requirements documents to the VRTM completes the full requirements traceability. Compliance with all requirements ensures that the system-level requirements have been met. The RVCD

defines, for each requirement, the verification methods and corresponding compliance information. The results of the Verification process (Section 4.12), including evidence of completion, are recorded and documented in the RVCD. It is recommended that the RVCD contain information regarding the results of each verification activity, as well as a description and disposition of conformance, nonconformance, conclusions, and recommendations. Compliance information provides either the actual data or a reference to the location of the actual data that shows compliance with the requirement. The document also includes a section that details any noncompliance. It is recommended that this section also specify appropriate reverification procedures. The Requirements Management process captures noncompliant requirements, leading to a decision on disposition of the noncompliant requirement.

4.3.3 Requirements Management Process Tasks

The following tasks are necessary to perform this process:

- Identify and Capture Requirements
- Analyze and Decompose Requirements
- Allocate Requirements
- Derive Requirements
- Establish Requirements Verification Methods
- Manage Requirements

4.3.3.1 Task 1: Identify and Capture Requirements

4.3.3.1.1 Description

The Identify and Capture Requirements activity identifies, prioritizes, and extracts all written directives, including documented stakeholder negotiations/discussions, and internally derived requirements that are relevant to the particular stage of the system lifecycle. This activity is performed on the entire system, including any requirements that are known at this stage about how the system shall perform during its lifecycle and any constraints imposed on the system design/production by stakeholders and internal functions (i.e., manufacturing, product support, agency-level policies, suppliers). There are many different types, or categories, of requirements, as identified and defined in Paragraph 4.3.3.2.1.4.3. Requirements are typically categorized by the stage of the system lifecycle in which the requirement is obtained and by the function/user that generates the requirement. The primary objective is to consolidate baseline or approved system requirements so that they may serve as a foundation for later refinement and/or revision by subsequent functions in SE. This consolidation also allows an unambiguous and traceable flowdown of source requirements throughout the NAS Architecture as well as the product hierarchy. It is also important to negotiate with both external and internal stakeholders to reach agreement on which documents and to what level requirements need to be traced. This activity helps to ensure that the visibility stakeholders expect to obtain from requirements traceability may be achieved. This foundation needs to be as complete and accurate as possible and shall be fully traceable to the requirements source documentation.

4.3.3.1.2 Scope

The scope of the requirements set shall include sufficient specification of all the system functions and all the external interfacing systems, including the system environment. This task

may require considering a wider domain than the immediate physical boundary of the product and its components. Different boundaries may need to be defined for different states, modes, and capabilities. Refinement of these boundary definitions is an iterative process that occurs as more information is discovered about the true nature of the required system functions and performance (Interface Management (Section 4.7)). In this process, hardware, software, and system requirements are analyzed and refined to ensure that they are consistent, clear, valid, feasible, compatible, complete, and verifiable and that they do not include detail design information.

4.3.3.1.3 Result

The result of performing this activity shall be a baseline set of requirements. The requirements shall be captured in an organized fashion. It is recommended the that information be readily accessible for reference by other program personnel as needed. This activity is the basis for discovering and successively refining the requirements to be recorded and maintained over the product's lifecycle.

4.3.3.1.4 Compatibility

The selected requirements methodology shall be compatible with other methodologies applied across the FAA, and the analysis methodology supported with the necessary tools, as required by the Integrity of Analysis process (Section 4.9).

4.3.3.1.5 Detailed Task 1 Description

Figure 4.3-2 describes the flow of the Identify and Capture Requirements task.

4.3.3.1.5.1 Task 1.1: Define Stakeholder Expectations

Stakeholder expectations are defined and quantified, and stakeholder expectations in the FAA come from the operational stakeholder in the form of:

- CONOPS
- MNS
- iRD or fRD

They are transformed into baselined requirements sets at a successively lower level through iteration of the Requirements Management process. It is recommended that the definition of stakeholder expectations be balanced with an analysis of their effects on the overall system design and performance as well as on human engineering; knowledge, skills, and abilities; availability; reliability; safety; and training requirements of the humans required to support lifecycle processes. Stakeholder expectations include:

- What the system is to accomplish (functional requirements)
- How well each function is to be performed (performance requirements)
- The operational and ambient environment in which the system is to be operated
- Constraints under which the system is to be developed or operated (e.g., funding, cost or price objectives, schedule, technology, nondevelopmental and reusable items, physical characteristics, and hours of operation per day)

4.3.3.1.5.2 Task 1.2: Define Project and Corporate Constraints

Project and corporate constraints that impact design solutions shall be identified and defined. The NAS Architecture may also impose long-range planning constraints through the approved capabilities and implementation steps.

4.3.3.1.5.2.1 Project Constraints

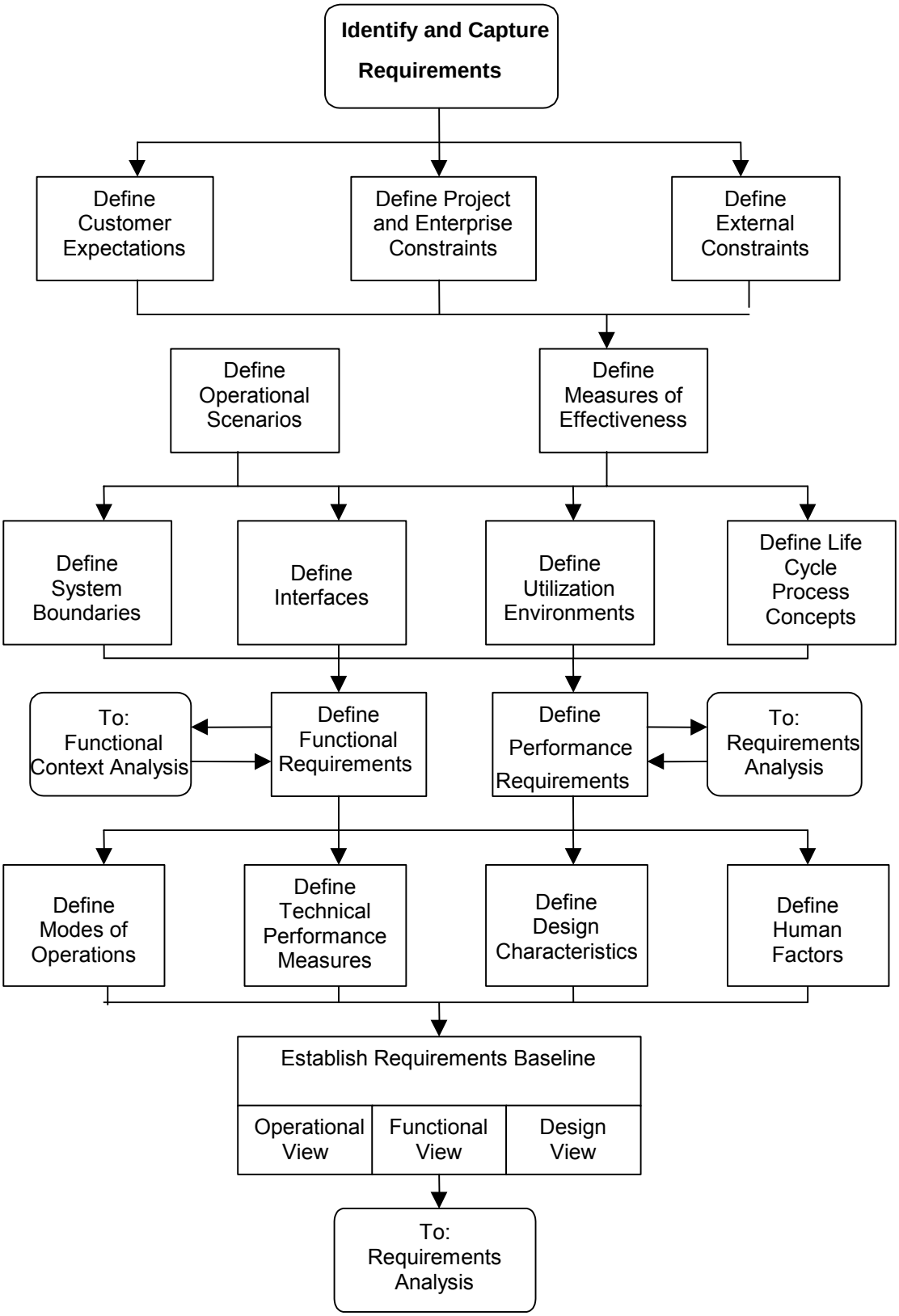
Project constraints include:

- Existing approved specifications and baselines
- Updated NAS Architecture implementation steps
- Updated NAS Architecture segments and mechanisms
- Availability of automated tools
- Required metrics for measuring technical progress

4.3.3.1.5.2.2 Corporate Constraints

Corporate constraints include:

- Management decisions from the Joint Resources Council or other management review
- FAA-wide general specifications, standards, handbooks, and guidelines
- FAA policy directives
- Established lifecycle processes
- Physical, financial, and human project resources



525 **Figure 4.3-2. Identify and Capture Requirements Flow**

4.3.3.1.5.3 Task 1.3: Define External Constraints

External constraints that impact design solutions or implementation of SE activities shall be identified and defined. These include:

- U.S. Government and international laws and regulations
- Industry, international, and other general specifications, standards, and guidelines
- ICAO SARPs
- RTCA MOPS and MASPS
- Human-related specifications, standards, and guidelines
- The technology base
- Interfacing systems

4.3.3.1.5.4 Task 1.4: Define Operational Scenarios

Operational scenarios that define the range of the anticipated system uses shall be identified and defined. For each operational scenario, expected interactions with the environment and other systems, human tasks and task sequences, and physical interconnections with interfacing systems and platforms shall be defined.

Data for this step comes from the CONOPS, iRDs and fRDs, and the NAS Architecture.

4.3.3.1.5.5 Task 1.5: Define Measures of Effectiveness

System effectiveness measures that reflect overall stakeholder expectations and satisfaction are defined. Key MOEs may include performance, safety, operability, usability, reliability, maintainability, time and cost to train, workload, human performance requirements, or other factors. Data for this step comes from the CONOPS, iRDs and fRDs, the NAS Architecture, the NAS Requirements, and operational scenarios.

4.3.3.1.5.6 Task 1.6: Define System Boundaries

System boundaries are defined as follows:

- System elements that are under design control and elements that are not
- Expected interactions among system elements under design control and external and/or higher-level and interacting systems outside the system boundary

Data for this step is obtained from any internal, external, policy, or technology constraints; CONOPS; MNS; iRDs and fRDs; and Functional Analysis.

4.3.3.1.5.7 Task 1.7: Define Interfaces

The functional and physical interfaces are defined to external or higher-level and interacting systems, platforms, and/or products in quantitative terms. Functional and physical interfaces may include mechanical, electrical, thermal, data, communication procedural, human-machine, and other interactions required. Interfaces may also be considered from an internal/external perspective. Internal interfaces address elements inside the boundaries established for the

system; they are generally identified and controlled by the contractor responsible for developing the system. External interfaces involve entity relationships outside the established system boundaries.

Data for this step is in IRDs, ICDs, Functional Analysis, MNS, and iRDs and fRDs.

4.3.3.1.5.8 Task 1.8: Define Utilization Environments

Utilization environments for each of the operational scenarios shall be defined. All environmental factors, operational and ambient, that may impact system performance need to be identified and defined. Also identified are factors that ensure that the system minimizes the potential for human or machine errors or for failures that cause accidents or death and that impart minimal risk of death, injury, or acute chronic illness, disability, and/or reduced job performance of the humans who support the system lifecycle. Specifically, weather conditions (e.g., rain, snow, sun, wind, ice, dust, and fog); temperature ranges; topologies (e.g., ocean, mountains, deserts, plains, and vegetation); biological factors (e.g., animal, insects, birds, and fungi); time (e.g., day, night, and dusk); induced factors (e.g., vibration, electromagnetic acoustic, x-ray, and chemical), or other environmental factors are defined for possible locations and conditions conducive to system operation. It is recommended that effects on hardware, software, and humans be assessed for impact on system performance and lifecycle processes.

Data for this step is contained in the OSED, Trade Studies, Specialty Engineering analysis, and FAA and Military Standards, Specifications, and Handbooks.

4.3.3.1.5.9 Task 1.9: Define Lifecycle Process Concepts

The outputs of Tasks 1.1 through 1.8 are analyzed to define lifecycle process requirements necessary to develop, produce, test, distribute, operate, support, train, and dispose of system products being procured.

4.3.3.1.5.9.1 Manpower

The required job tasks and associated workload used to determine the number and mix of humans who support the system lifecycle processes shall be identified and defined.

4.3.3.1.5.9.2 Personnel

The experiences, aptitudes, knowledge, skills, and abilities required to perform the job tasks that are associated with the humans who support the system lifecycle shall be identified and defined.

4.3.3.1.5.9.3 Training

The instruction education and on-the-job or team training necessary to provide humans and teams with knowledge and job skills needed to support the system lifecycle processes at the specified levels of performance are to be identified and developed.

4.3.3.1.5.9.4 Human Engineering

Human cognitive, physical, and sensory characteristics that directly contribute to or constrain lifecycle system performance and that impact human-machine interfaces shall be identified.

4.3.3.1.5.9.5 Safety

The System Safety Engineering analysis derives and identifies requirements that are designed to control the risk of identified safety hazards.

4.3.3.1.5.10 Task 1.10: Define Functional Requirements

Functional requirements for each function of the system as determined by the Functional Analysis process (Section 4.4) shall be defined, describing what the system may be able to do. The functions identified are used in Paragraph 4.3.3.1.5.11 to define how well the functions shall be performed and to establish the performance requirements. The functions identified through Functional Analysis shall be further decomposed during functional decomposition to provide a basis for identifying and assessing design alternatives. All system requirements shall involve a functional and performance aspect, which views system requirements as having both functional and performance aspects that ensure that requirements are complete, consistent, and verifiable.

4.3.3.1.5.11 Task 1.11: Define Performance Requirements

Performance requirements for each system function shall be defined. Performance requirements describe how well functional requirements shall be performed to satisfy the MOEs. These performance requirements are the MOPS that are allocated to subfunctions during functional decomposition analysis and that are the criteria against which design solutions (derived from Synthesis (Section 4.5)) are measured. There are typically several MOPS for each MOE, which bound the acceptable performance envelope.

4.3.3.1.5.12 Task 1.12: Define Modes of Operation

The system modes of operation (e.g., full system, emergency, training, and maintenance) are defined for the system being procured. The conditions (e.g., environmental, configuration, and operation) that determine the modes of operation are defined.

Data for this step shall come from the NAS or system-level CONOPS, MNS, OSED, or Functional Analysis.

4.3.3.1.5.13 Task 1.13: Define Technical Performance Measures

Technical Performance Measures (TPM) are defined that describe the key indicators of system performance. It is recommended that selection of TPMs be limited to critical MOPs that, if not met, put the project at cost, schedule, or performance risk. Specific TPM activities are integrated into the System Engineering Master Schedule to periodically determine achievement to date and to measure progress against a planned value profile.

Data for this step comes from the CONOPS or the MNS.

4.3.3.1.5.14 Task 1.14: Define Design Characteristics

Required design characteristics (e.g., color, texture, size, anthropometrical limitations, weight, and buoyancy) are identified and defined for the system being procured. Design characteristics that are constraints and which may be changed based on tradeoff analysis (Synthesis (Section 4.5)) are identified.

Data for this step comes from the CONOPS, MNS, OSED, Functional Analysis, Tradeoff Studies, and FAA and Military Standards, Specifications, and Handbooks.

4.3.3.1.5.15 Task 1.15: Define Human Factors

Human factor considerations (e.g., design space limits, climatic limits, eye movement, reach ergonomics, cognitive limits, and usability) are identified and defined that affect operation of the system being procured. Human factors that are constraints and may be changed based on tradeoff analysis are identified.

Data for this step comes from the CONOPS, MNS, OSED, Functional Analysis, Tradeoff Studies, Specialty Engineering analysis, and FAA and Military Standards, Specifications, and Handbooks.

4.3.3.1.5.16 Task 1.16: Establish Requirements Baseline

The output of Tasks 1.1 through 1.15 forms a requirements baseline that establishes the characteristics of the system problem to be solved. Three views—operational, functional, and design—are used to define the baseline. The Operational View describes how the system products serve users. It establishes who operates and supports the system and its lifecycle processes and how well and under what conditions the system is to be used. The Functional View describes what the system does to produce the desired behavior described in the Operational View and provides a description of the methodology used to develop the view and decision rationale. The Design View describes the design consideration of the system development and established requirements for technologies and for design interfaces among equipment and among humans and equipment. The content of these views may include the information discussed in the following paragraphs.

4.3.3.1.5.16.1 Operational View

The Operational View addresses how the system serves its users. It is useful when requirements are being established that describe how well and under what condition the system is to be used. It is recommended that Operational View information be documented in an operational concept document that identifies:

- Operational need description
- Results of system operational analyses
- Operational sequences/scenarios, including utilization environments and MOEs and how the system may be used
- Conditions/events to which system products need to respond
- Operational constraints, including MOEs
- Human roles, including job tasks and skill requirements
- Training requirements, including how humans are trained to be a part of the system and support system lifecycle processes through formal, informal, embedded, on-the-job, or other forms of training
- What operations are required to ensure safety
- The security threats that the system shall be protected against

- Lifecycle process concepts, including MOEs, critical MOPS, and already existing products and services
- Operational interfaces with other systems, platforms, humans, and/or products
- System boundaries

4.3.3.1.5.16.2 Functional View

The Functional View focuses on what the system shall do to produce the required operational behavior. It includes required inputs, outputs, states, and transformation rules. The Functional View and the Operational View are the primary sources for the MNS and the requirements documents. The functional requirements, coupled with the design requirements, described in Design View below, are the primary sources of the requirements that may eventually be reflected in the system specification. Functional View information includes:

- Functional requirements that describe what system products and lifecycle processes shall do or accomplish
- Performance requirements, including qualitative (how well), quantitative (how much, capacity), and timeliness or periodicity (how long, how often) requirements
- Functional sequences for accomplishing system objectives
- TPM criteria
- Functional interface requirements with external, higher-level, or interacting systems, platforms, humans, and/or products
- Modes of operations
- Functional capabilities for planned evolutionary growth
- Verification requirements, including inspection, analysis/simulation, demonstration, and test

4.3.3.1.5.16.3 Design View

The Design View focuses on how the system is constructed. It is key to establishing the physical interfaces among operators and equipment and technology requirements. Design View information includes:

- Previously approved specifications and baselines
- Design interfaces with other systems, platforms, humans, and/or products
- Human SE elements, including safety, training, knowledge, skills, and abilities required to accomplish system functions, and characteristics of information displays and operator controls
- Characterization of operator(s) and support personnel, including special design requirements and applicable movement or visual or workload limitations
- Characterization of information displays and operator controls
- System characteristics, including design limitation (e.g., capacity, power, size, weight); technology limitations (e.g., precision, data rates, frequency, language); inherent human limitations (e.g., physical and cognitive workload, perceptual abilities, and reach and

anthropometric limitations); and standardized end items, nondevelopmental items (NDI), and reusability requirements

- Design constraints, including project, corporate, and external constraints, that limit design solutions and/or developmental procedures
- Design capabilities and capacities for planned evolutionary growth

4.3.3.2 Task 2: Analyze and Decompose Requirements

The Functional Architecture developed in Functional Analysis (Section 4.4) is translated into Primitive Requirements Statements (PRS) that, in turn, are translated into Mature Requirements Statements (MRS) in this task.

4.3.3.2.1 Analyze Requirements

The Functional Architecture is the primary input to the Requirements Management process. A Functional Architecture describes "what" a system shall accomplish. The Functional Architecture is composed of functional flow diagrams (FFD), timeline sequence diagrams, and functional N^2 charts described in Functional Analysis (Section 4.4). The Functional Architecture is a living document that increases in level of detail along with the decomposition of requirements. It is recommended that there be a level of Functional Analysis and corresponding Functional Architecture for every level of requirements (Table 4.3-1). The Requirements Management process uses the Functional Architecture to derive PRSs.

The Requirements Management process starts with recognition of a need or shortfall in system capability and progresses in increasing detail, as shown in Table 4.3-1.

Table 4.3-1. Functional Architecture to Requirements Traceability Hierarchy

Functional Architecture	Requirements
CONOPS →	Mission Need Statement
Functional Analysis 1 →	Initial Requirements Document
Functional Analysis 2 →	Final Requirements Document
Functional Analysis 3 →	System Requirements
Functional Analysis N →	System Specification to N level

4.3.3.2.1.1 Function to Requirements Transformation

The objective of function transformation is to transform functions into the functional and performance PRSs that describe the system attributes that achieve customers' needs.

A Functional Architecture (from Functional Analysis (Section 4.4)) is transformed into PRSs through two fundamental methods: (1) a structured analysis methodology called System Functional Requirements Analysis (SFRA) and (2) Functional Architecture Referencing (FAR).

Regardless of the method used, the result is a set of PRSs associated with the system functions.

4.3.3.2.1.1.1 System Functional Requirements Analysis

SFRA is a structured methodology for developing requirements from a Functional Architecture. It requires building a matrix of functions and system characteristics then assigning a PRS to each function/characteristic pair if one is needed. The following steps produce a list of functions for which PRSs shall be developed.

4.3.3.2.1.1.1.1 List Functions

From the Functional Architecture, the functions are listed on the vertical axis of a table, such as the example included in Table 4.3-2. A tree diagram may be used to assist creation of the function list.

4.3.3.2.1.1.1.1.1 Tree Diagrams

A tree diagram is constructed from the top down. Each subfunction is shown as a branch of the tree. Using the FFD in Figure 4.4-23 as an example, the tree diagram in Figure 4.3-3 was developed as an incomplete example of what the tree diagram might look like. A completed diagram might result in a family tree hierarchy of functions.

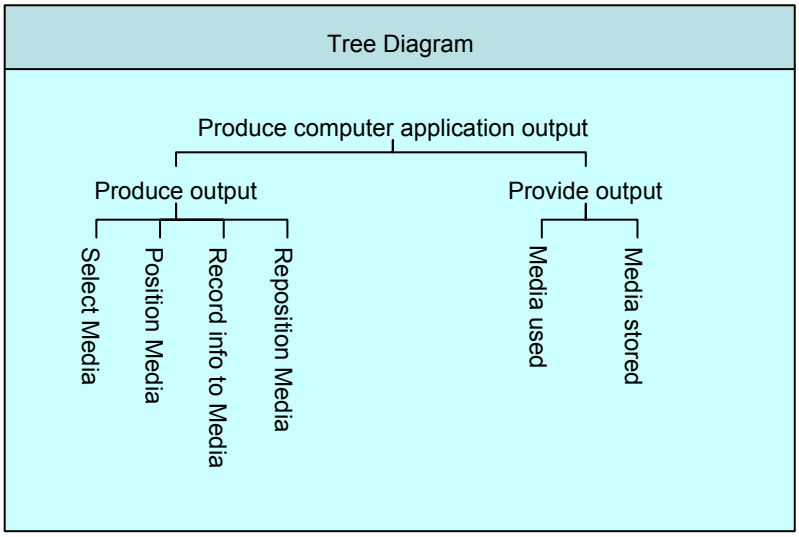


Figure 4.3-3. Tree Diagram Example

4.3.3.2.1.1.1.2 List System Characteristics

System characteristics are developed by identifying all measurable product characteristics perceived as related to meeting customer requirements. These characteristics come from (1) the external inputs described in Paragraph 4.3.2.1 and (2) analyses conducted in Specialty Engineering (Section 4.8). The characteristics include specialty requirements, constraints, standards, handbooks, management decisions, policies, and legacy requirements. The system characteristics are listed on the horizontal axis of Table 4.3-2. The specific categories and characteristics are unique to and change with each system. The material shown is for illustration only.

4.3.3.2.1.1.1.3 Determine Intersections

The purpose of this step is to determine if a need exists to translate a particular function into a PRS. If there is a significant relationship between the function and the characteristic, a PRS number is placed in that cell. “Significant” means that it was determined, using engineering judgment, that the function shall have one or more of the related characteristics in order to meet the customer’s need. Wherever there is a number, a unique PRS is required to describe that relationship. The number is associated with the unique PRS that describes the function-characteristic combination.

If it is determined that a function-characteristic combination is not significant or nonexistent, then a PRS is **not** written for that intersection.

4.3.3.2.1.1.1.4 Develop Primitive Requirements Statements

A PRS for each intersection in the table is developed in accordance with the procedure in Paragraph 4.3.3.2.1.1.3.

4.3.3.2.1.1.2 Functional Architecture Reference

This method generates PRSs from the standards, handbooks, and Specialty Engineering analyses. The functional PRSs are developed by referencing the Functional Architecture. Because of the risk of missing critical requirements, it is recommended that this method be used only when there is not enough time to perform SFRA.

4.3.3.2.1.1.2.1 Derive Primitive Requirements Statement From Standard Sources

A list of PRSs is developed. The PRSs are derived by using the sources described in Specialty Engineering (Section 4.8) and the inputs listed in Paragraph 4.3.3. The PRSs shall be developed in accordance with 4.3.3.2.1.2.

For example, assume that a reliability analysis derived a requirement that states: “Transmitter MTBF greater than 5000 op hours.” The PRS is listed as a requirement in this list. Table 4.3-3 provides an example.

Table 4.3-2. System Characteristic Matrix

Functions	Characteristics	Performance		Specialty Engineering				Environment		
		Accuracy	Thermal	Reliability	Safety	Spectrum	Oprtr workload	Radiation	Lightning	Precipitation
Detect ac state vector	Determine aircraft horizontal location	2	1		3	N	N	N	N	N
	Determine aircraft vertical location	N	N		N	N	N	N	N	N
	Determine aircraft velocity vector	N	N		N		N			
Transmit voice RF	Convert sound to high frequency (RF) signal	N	N	N		N	N	N	N	N
	Convert signal to EM wave	N	N	N	N	N		N		N
	Propagate wave through space-time					N		N	N	N
Distribute NOTAM	Encode NOTAM	N	N		N		N			
	Determine scope	N	N		N		N			
	Transmit NOTAM	N	N		N	N	N	N	N	N

Note: N = a PRS number for the specific intersection.

Table 4.3-3. Primitive Requirement Statements List

PRS Number	Primitive Requirement Statement	Functional Reference
Assign a unique number to the PRS	This is the derived PRS	Assign the PRS to a function in the Functional Architecture
126	Transmitter MTBF greater than 5000 op hours	F.3.2.1.1

4.3.3.2.1.1.2.2 Relate Primitive Requirements Statement to Functional Architecture

The Functional Architecture and existing PRSs are reviewed, and each PRS is assigned to a function in the Functional Architecture. Each requirement shall be assigned to a function, and it is recommended that each function have one or more requirements assigned to it.

4.3.3.2.1.1.2.3 Sort the Primitive Requirements Statements by Functional Reference

The list of PRSs developed in 4.3.3.2.1.1.2.2 shall be sorted or grouped so that grouped and sorted requirements allocated to an individual function are together. Table 4.3-4 is an example.

Table 4.3-4. Primitive Requirement Statements List

PRS Number	Primitive Requirement Statement	Functional Reference
126	Transmitter MTBF greater than 5000 op hours	F.3.2.1.1
34	Transmitter EMI hardened greater than 50000 volt-meters	F.3.2.1.1
212	Transmitter power less than 10 watts	F.3.2.1.2
6	Transmitted power less than or equal to table 4.3 in HERP standard 6.	F.3.2.1.2
57	Transmitted power less than or equal to table 2.1 in HERF standard 4.4.	F.3.2.1.2

4.3.3.2.1.1.2.4 Write the Functional Primitive Requirements Statement

Once requirements are sorted to functions, the functional PRSs are derived. First, the Functional Architecture used shall be appended to the requirements document. Then, for each group of PRSs, a functional PRS shall be defined in the following manner:

[Element] functions + as defined in + [Functional Reference (include page and figure number)]

For the above example table, two functional PRSs are added as shown in Table 4.3-5.

Table 4.3-5. Grouped and Sorted Primitive Requirement Statements List

PRS Number	Primitive Requirement Statement	Functional Reference
126	Transmitter MTBF greater than 5000 op hours	F.3.2.1.1
34	Transmitter EMI hardened greater than 50000 volt-meters	F.3.2.1.1
220	Transmitter functions as defined in F.3.2.1.1, page A-26, figure A.2.2.	F.3.2.1.1
212	Transmitter power less than 10 watts	F.3.2.1.2
6	Transmitted power less than or equal to table 4.3 in HERP standard 6.	F.3.2.1.2
57	Transmitted power less than or equal to table 2.1 in HERF standard 4.4.	F.3.2.1.2
221	Transmitter functions as defined in F.3.2.1.2, page A-28, figure A.2.4.	F.3.2.1.2

4.3.3.2.1.1.3 Develop Mature Requirements Statements

Once the list of PRSs is developed using either SFRA or FAR, they are transformed to MRSs in accordance with Paragraph 4.3.3.2.1.3.

4.3.3.2.1.2 Primitive Requirements Statements

Requirements are first captured as a list of PRSs. A PRS is a primitive form of a requirement statement that has no punctuation or formal sentence structure and is not written in a formal specification style. The PRS form is used at this stage to improve the early requirements identification capability by removing the rigor of writing MRSs from the early concept development and to remove the considerable cost of forming mature requirements. Each PRS is uniquely numbered and follows a simple three-part format:

Name + Relation + Value

The name describes the characteristic or attribute to control; the relation details the connection between the attribute and its control value; and the value sets a quantifiable number with units or defines a standard. Numerical requirements use one of six possible relations: less than, greater than, equal to, less than or equal to, greater than or equal to, or between a range of values. For nonnumerical requirements, words such as “is,” “be,” and “conforms to” are used as the relation.

4.3.3.2.1.3 Mature Requirements Statement

Once the PRSs at any level are identified, they shall be synthesized into MRSs that satisfy the characteristics and attributes of good requirements. Requirements characteristics are the principal properties of the MRS. Characteristics may apply to individual requirements or to an aggregate of requirements. A well-defined set of MRSs needs to exhibit certain individual and aggregate characteristics. The result of performing this activity shall be a baseline set of

requirements that satisfy all of the characteristics described herein and that is recorded and maintained over the lifecycle of the product, as well as accessible to all parties.

The basics of well-defined requirements are clarity, conciseness, and simplicity; elegant, entertaining prose is not needed and is undesirable. This activity describes (1) how to build requirements and (2) the essential characteristics of well-defined requirements.

An MRS is a written statement of a requirement in one or more complete sentences in a familiar language (normally English) using the idiom of a particular business sector, such as air traffic control or avionics. Normal specification standards require that the content of a specification document include complete sentences organized in a particular way. Each requirement statement shall (1) be written in proper grammar, (2) make appropriate use of standard constructs, (3) possess the characteristics and attributes of good requirements, and (4) comply to a specified standard format.

Each PRS shall be converted to specification text. A specification for a system is a published set of requirements that has been properly refined and formatted into more precise language than used for the PRSs. Usually, each PRS becomes a short paragraph when converted into specification text. A primitive requirement is connected into specification text by adding the characteristics described in the following paragraphs.

4.3.3.2.1.3.1 Paragraph Number

The type of requirements is identified, and a paragraph number is assigned according to the required format. The numbering format may be ad hoc for some requirements documents or shall adhere to a rigid format, such as a Federal Aviation Administration Acquisition System Toolset (FAST) template or FAA-STD-005 or MIL-STD-961.

4.3.3.2.1.3.2 Paragraph Title

A paragraph title is identified that is linked to the named or controlled PRS attribute.

4.3.3.2.1.3.3 Subject

The subject of the requirements is the main topic of the sentence and is linked to the named or controlled PRS attribute.

4.3.3.2.1.3.4 Directive Verb

The directive verb in the requirement sentence directs the action required and shall relate the named or controlled attribute to the value. See Paragraph 4.3.3.2.1.1.5.1.

4.3.3.2.1.3.5 Sentence Ending

The requirements sentence is ended with a period with a commonly used word or phrase that provides a reference to a standard or specification. See Paragraph 4.3.3.2.1.1.5.2.

4.3.3.2.1.3.6 Explanatory information

Explanatory, defining, or clarifying information is added after the requirements sentence if necessary to ensure understanding and avoid ambiguity.

4.3.3.2.1.3.7 Standard Constructs

Standard constructs are used to record requirements so that they possess the characteristics of good requirements.

4.3.3.2.1.3.7.1 Directive Verbs

All requirements documents shall have directive verbs that denote action, as follows:

- Use the verb “shall” to denote compulsory or mandatory action that the person being directed is obliged to take. (For example: The contractor shall furnish all facilities and equipment necessary for the tests specified herein.)
- Use the verb “may” to denote permission or an option that is not obligatory. (For example: For instruction books of 50 pages or less, multi-ring binding may be employed in lieu of saddle stitching.)
- Use the verb “will” to denote a declaration of purpose on the part of the government. (For example: The Contracting Officer will furnish shipping instructions upon request.)
- The verb “should” is not used in requirements documents. Although the word “should” is used to denote action that is recommended but not obligatory, it may imply duty or obligation in legal usage.

4.3.3.2.1.3.7.2 Commonly Used Words and Phrasings

Certain words and phrases are frequently used in requirements documents. The following rules shall apply:

- Referenced documents requirements are to be written as follows:
  - “ …in accordance with Specification (or Standard)…”
  - “…shall be as specified in Specification (or Standard)…”
  - “…shall conform to…
  - “…conforming to Specification (or Standard)…”
- The phase “unless otherwise specified” shall be used to indicate an alternate course of action. The phrase shall come at the beginning of the sentence and, if possible, at the beginning of the paragraph. This phrase shall be limited in its application and used sparingly.
- The term “and/or” shall not be used in requirements documents. The following example conveys the desired meaning: “The panel shall be supported on brackets, pillars, or both.”
- Do not use “minimum” and “maximum” to state limits. Use “no less than” or “no greater than.” This standard construct avoids the ambiguity associated with the limiting values. This does not mean that the words “minimum” and “maximum” may not be used at all, just not to state limits.

4.3.3.2.1.3.7.3 Words and Phrases To Avoid

It is recommended that specific words and phases be avoided because they are vague, ambiguous, and general, such as “flexible,” “fault tolerant,” “high fidelity,” “adaptable,” “rapid” or “fast,” “adequate,” “user-friendly,” “support,” “maximize,” “minimize,” and “shall have the capability to.”

4.3.3.2.1.4 Characteristics of Individual Requirements

Characteristics of individual requirements may be used for requirements development as well as in requirements reviews and audits for assessing the quality of requirements. These characteristics are described below with synonyms in parenthesis.

4.3.3.2.1.4.1 Necessary

The stated requirement is an essential capability, characteristic, or quality factor of the product or process. If removed or deleted, it may cause a deficiency that is unable to be fulfilled by other capabilities of the product or process.

This is a primary characteristic, and it shall be exhibited in the requirements statement to effect a well-defined requirement. There is no room in a specification for unnecessary requirements because they add cost to the product. If a necessary requirement is deleted from the specification, a major need may not be met, even if all other requirements are satisfied.

One good test of necessity is traceability to higher-level documentation. In the case of a system specification, traceability may be verified to user documentation, such as the Operational Requirements Document. If there is no parent requirement, the requirement may not be necessary.

4.3.3.2.1.4.2 Concise (Minimal, Understandable)

The requirements statement includes only one requirement that simply and clearly states only what shall be done, making it is easy to read and understand. To be concise, the requirements statements shall not contain any explanations, rationale, definitions, or descriptions of system use, which are used in text analysis and trade study reports, operational concept documents, user manuals, or glossaries. A link may be maintained between the requirements text and the supporting analyses and trade studies in a requirements database so that the rationale and explanations may be referenced.

Determining what constitutes one requirement is a constant struggle in developing requirements and often requires engineering judgment. An example is the requirement in FAA automation systems for a Minimum Safe Altitude Warning/Conflict Alert alarm. This alarm requires an aural alarm and a visual alarm to warn the controller about potential unsafe conditions. Therefore, the question is: Is this one requirement, or does a requirement need to be written for each condition? Multiple requirements in one paragraph are undesirable, as is the proliferation of the number of requirements without reason. Each requirement needs to be managed and verified, and as such, has an associated cost.

One decision-making approach to the question is to determine how the requirement is to be verified. In the alarm example, it is recommended to verify that the alarms work together;

therefore, any test to verify the alarms shall include both the aural and visual alarms, thus combining the aural and visual alarms into one requirement.

4.3.3.2.1.4.3 Implementation-Free

The requirement states what is required, not how the requirement needs to be met. It is recommended that the requirement state the desired result in functional and performance terms, not in terms of a solution set. It is also recommended that a requirements statement not reflect a design or implementation nor describe an operation. However, the treatment of interface requirements is generally an exception.

This characteristic of a requirement is perhaps the hardest to judge and implement. At the system level, requirements may be truly abstract or implementation-free. The system requirements have to be synthesized by a system design solution. After a trade study has been conducted between alternatives and a candidate solution has been selected, the system requirements have to be allocated to the elements defined by the system design. This incremental procedure of allocating requirements to the next lower-level elements, which is dependent on system design, leads to the observation that one level of design is the requirement at the next lower level. The conclusion is that a requirement is implementation-free at the level that it is being specified, but is a result of the design activity at the level above it.

Interface requirements are usually an exception to the implementation-free rule. Interface requirements are specified in IRDs that describe a specific design or an interface or mating part. The interface requirement shall provide complete information so that the two sides of the interface may be designed to work as specified when connected to each other.

4.3.3.2.1.4.4 Attainable (Achievable or Feasible)

The stated requirement may be achieved by one or more developed system concepts at a definable cost. This implies that at least a high-level conceptual design has been completed and cost tradeoff studies have been conducted.

This characteristic is a test of practicality of the numerical value or values set forth in a requirement. It signifies that adequate analyses, studies, and trades have been performed to show that the requirement may be satisfied by one or more concepts and that the technology cost associated with the concept(s) are reasonable within program cost constraints.

4.3.3.2.1.4.5 Complete (Standalone)

The stated requirement is complete and does not need further amplification and provides sufficient capability.

This characteristic specifies that each requirement be stated simply using complete sentences. It is recommended that each paragraph state everything required on the topic and that the requirement be capable of standing alone when separated from other requirements.

4.3.3.2.1.4.6 Consistent

The stated requirement does not contradict other requirements and is not a duplicate of another requirement. The same term is used for the same item in all requirements.

This characteristic of well-defined requirements is usually well understood and does not cause much discussion. However, in a large set of requirements that are not well organized by some clearly defined categories, it may be hard to spot duplications and inconsistencies. Therefore, organizing requirements in accordance with a standard or template is important so that inconsistencies may be identified. It is also important to maintain a glossary of program terms because the meaning of some words is domain-dependent.

4.3.3.2.1.4.7 Traceable

It is recommended that each stated requirement be developed in a way that allows it to be traced back to its source. A requirement also needs to identify related requirements (i.e., parents, children, peers) and requirements that might be impacted by changes to it.

This characteristic contributes to completeness by verifying that all requirements have a source or are allocated. It also helps to eliminate unnecessary or missing requirements.

4.3.3.2.1.4.8 Unambiguous

Each requirement shall have one, and only one, interpretation. Language used in the statement shall leave no doubt as to the intended descriptive or numeric value.

This characteristic is difficult to achieve because the English language may be unstructured and, in some cases, the same sentence may mean different things to different people. It is helpful to use standard specification language constructs and commonly used words and phases and to avoid using the commonly used words and phrases cited in Paragraph 4.3.3.2.1.1.5.3.

4.3.3.2.1.4.9 Verifiable

Each requirement shall have an identified means by which to verify that it meets the characteristics established above.

The stated requirement is not vague or general but is quantified in a manner that may be verified by one of the verification methods described in Validation and Verification (Section 4.12).

The characteristic of verifiability needs to be considered at the same time that a requirement is being defined. A requirement that is not verifiable is a problem because it involves the acceptability of the system. To be verifiable, a requirement shall be stated in measurable terms.

4.3.3.2.1.4.10 Allocatable

It is recommended that the stated requirement be allocated to component(s) within the requirements hierarchy or assigned to an organization.

This characteristic is important because it helps to eliminate requirements that are not complete, concise, and clear. If a requirement is not allocatable to the Physical Architecture, it is probably not necessary.

4.3.3.2.1.5 Characteristics of Aggregate Requirements

Aggregate requirements are a set of requirements for a system or element that specifies its characteristics in totality. Usually, these aggregates are found in specifications or Statements of Work (SOW). Characteristics of individual requirements also are applicable to aggregates.

4.3.3.2.1.5.1 Complete

The set of requirements is complete and does not need further amplification. The set of requirements has addressed all categories (Paragraph 4.3.3.2.1.4.3) of requirements and covers all allocations from higher levels.

This characteristic addresses the difficult problem of identifying requirements that are necessary but are missing from the requirements set. One approach to identify missing requirements is to walk through the Operational Concept and its associated scenarios from start to finish, then walk through the same set of scenarios and ask “what if” questions. This approach usually uncovers a new set of requirements. A second approach is to develop a checklist of topics or areas, such as a specification outline, and verify that requirements exist in each topic area or, if they do not exist, that there is a good reason for it. A third approach is to check the aggregate requirements set against a higher-level document (if one exists) to verify that all allocated requirements have been included in the set.

4.3.3.2.1.5.2 Consistent

The set of requirements has no individual requirements that are contradictory. Requirements are not duplicated, and the same term is used for the same item in all requirements.

This characteristic addresses the problem of identifying unnecessary or conflicting requirements that are inadvertently included in the set. Assigning program-unique identification to each requirement and conducting thorough reviews are ways to eliminate these requirements.

4.3.3.2.1.6 Attributes of Requirements

This section describes secondary properties or attributes of individual requirements that provide supplementary information about the requirement and its relationship to other requirements and source documents. The properties or attributes also assist in requirements management. However, these attributes are not essential in all cases.

4.3.3.2.1.6.1 Requirement Identification

Each requirement is assigned a program-unique identifier (PUI) for identification and tracking purposes. The PUI may be either numeric or alphanumeric and assigned automatically if a requirements management tool is used. The requirement identifier assists in identifying the requirement, maintaining change history, and providing traceability.

4.3.3.2.1.6.2 Level

This attribute indicates the level at which the specific requirement is applicable in the system hierarchy or Work Breakdown Structure (WBS). A level I requirement may indicate a top- or system-level requirement; a level II requirement may be a segment- or component-level requirement.

4.3.3.2.1.6.3 Requirements Category

Two categories are used to classify requirements: program and technical.

4.3.3.2.1.6.3.1 Program Requirements

Program requirements are stakeholder or user requirements imposed on vendors through contractual vehicles other than specifications, including the contract or contract SOW. Program requirements include:

- Compliance with Federal, State, or local laws, including environmental laws
- Administrative requirements (e.g., security); stakeholder/vendor relationship requirements (e.g., directives to use government facilities for specific types of work such as test); and specific work directives (e.g., directives included in the SOW and Contract Data Requirements List (CDRL))

Program requirements may also be imposed on a program by agency policy, directives, or practice.

Program requirements are different from technical requirements: They are not imposed on the system or product to be delivered but on the process to be followed by the program. Program requirements, which are managed similarly to technical requirements, need to be necessary, concise, attainable, complete, consistent, and unambiguous in the same manner as technical requirements.

4.3.3.2.1.6.3.2 Technical Requirements

Technical requirements are applicable to the system or service to be procured. Technical requirements are described in requirement documents, system specifications, and interface documentation. Types of technical requirements are described in the following paragraphs.

4.3.3.2.1.6.3.2.1 Stakeholder Requirements

Stakeholder requirements are associated with the stakeholder's intended operating practices, maintenance concepts, and desired features.

4.3.3.2.1.6.3.2.2 Operational Requirements

Operational requirements define the interfaces between the end-user and each functional system, maintenance concept and each system, and various other support and related functions or equipment.

4.3.3.2.1.6.3.2.3 Performance Requirement

Performance requirements define how well the product performs its intended function (e.g., accuracy, fidelity, range, resolution, and response times).

4.3.3.2.1.6.3.2.4 Functional Requirements

Functional requirements identify what the system may do, not how the system accomplishes it. They are based on Functional Analysis (Section 4.4).

4.3.3.2.1.6.3.2.5 Interface Requirements

Interface requirements are the physical and functional requirements associated with the product interfaces (boundary conditions). Interface development is described in Interface Management (Section 4.7).

4.3.3.2.1.6.3.2.6 Constraint Requirements

Constraint requirements are limitations or restrictions that bound the solution set.

4.3.3.2.1.6.3.2.7 Regulatory Requirements

Regulatory requirements are imposed by statutes or regulations (e.g., FARs, Occupational Safety and Health Administration (OSHA) regulations, and Environmental Protection Agency (EPA) directives).

4.3.3.2.1.6.3.2.8 Reliability, Maintainability, and Availability/Supportability

Reliability, maintainability, and availability/supportability requirements are based on the user's system readiness and mission performance requirements, physical environments, and resources (e.g., personnel, training, and facilities) available to support the mission.

4.3.3.2.1.6.3.2.9 Safety Requirements

These requirements are defined to control the effects of failure conditions, hazards, and/or safety-related functions.

4.3.3.2.1.6.3.2.10 Health Hazard Requirements

These requirements are defined to control the effects of failure conditions, hazards and health related functions.

4.3.3.2.1.6.3.2.11 Human Engineering Requirements

Human requirements define the human system interface(s).

4.3.3.2.1.6.3.2.12 Producibility Requirements

Producibility requirements define the producibility of a product that involve identifying materials, special tools, test equipment, facilities, personnel, and procedures. They identify the manufacturing technology needs, availability of critical materials, long-lead procurement requirements, and manufacturing test requirements, among other aspects.

4.3.3.2.1.6.3.2.13 Cost Requirements

Cost requirements define product budget constraints.

4.3.3.2.2 Decompose Requirements

The requirements may be decomposed to the lowest level and partitioned in such a way that integrating the partitioned requirements shall satisfy the higher-level requirement.

4.3.3.2.3 Checklist for Writing and Evaluating Requirements

The following guidelines for writing and evaluating requirements contain representative questions; however, the list is not intended to be complete and comprehensive.

4.3.3.2.3.1 Technical Considerations

- Does the requirement state a valid need?
- Is the requirement verifiable?
- Has the verification approach been identified?
- Are the necessary interface requirements stated?
- Are appropriate data (e.g., tables, figures) included?
- Are the stated references clearly applicable to the requirement?
- Is the requirement within the span of knowledge of the requirement owner?
- Does the requirement have stated values for quantities?
- Are words that imply a design avoided?

4.3.3.2.3.2 Traceability Considerations

- Are the applicable parent, child, and peer requirements identified?
- Are the source and rationale for the existence of the requirement documented?
- Is the basis for allocation identified?

4.3.3.2.3.3 Writing Considerations

- Is the requirement stated as a requirement?
- Is the requirement stated clearly and concisely?
- Does the requirement represent only one thought?
- Is the requirement stated positively?
- Is the requirement void of ambiguous terminology?
- Is the requirement grammatically correct?
- Is the requirement punctuated correctly?
- Is excessive punctuation avoided?

4.3.3.3 Task 3: Allocate Requirements

4.3.3.3.1 Allocation

The Allocate Requirements activity allocates or assigns requirements to system, personnel, or support activity components and/or appropriate organizational entities. This process verifies that the performance and verification requirements are correct and complete at each level before further allocation and decomposition, and it verifies them regarding feasibility and top-level design concept before allocation to software. The allocated requirements consist of all requirements, including the breakdown/decomposition of physical characteristics, functions,

cost, schedule, reliability/maintainability parameters, and performance parameters. Mapping of these requirements identifies the owner that has Responsibility, Authority, and Accountability (RAA) for the respective requirement.

4.3.3.3.2 Application

The Allocate Requirements activity is applied iteratively when new, changed, or derived requirements are generated. One cycle through the Allocate Requirements activity is complete when the currently identified requirements have been accurately allocated to the appropriate system, personnel, or support activity component(s). Subsequent analyses, requirement decomposition, and trade studies may produce additional requirements that define the most balanced requirements allocation for the product. When a system-level requirement is allocated to more than one configuration item, the allocation process ensures that the lower-level requirements, when taken together, satisfy the system requirements.

4.3.3.3.3 Allocation Hierarchy

Typically, the requirements are allocated to components of the system hierarchy defined in the Physical Architecture provided by the Synthesis process (Section 4.5). System requirements (including test and verification requirements) are analyzed, refined, and decomposed to ensure complete functional allocation to system, personnel, or support activity components. When a system-level requirement is allocated to more than one configuration item, a process is used to ensure that the lower-level requirements, when taken together, satisfy the system-level requirement. Early allocations only designate high-level product components, as a complete design may not have been determined. As the product design matures, the identified requirements may be allocated to lower-level components in the Physical Architecture. The requirements documents below the system level are simply documents containing the requirements that have been allocated to particular product component(s). As requirements are identified and allocated at different levels of the product hierarchy, the requirements documents may be produced and formatted to fit the need at that particular level. As the requirements and system hierarchy are iteratively defined to lower levels, each requirement ultimately shall be allocated to the lowest possible level of the system component. The results of the allocation process are documented in the Requirements Allocation Matrix (RAM) described in Paragraph 4.3.4.1.1.3.

4.3.3.3.4 Hardware/Software Allocation

The requirements allocation process allocates design requirements to hardware and software. Software, hardware, and interface specifications are analyzed and refined to ensure that all requirements allocated to software and hardware are adequately addressed and that they do not include inappropriate levels of design details. Occasionally, requirements are derived from software requirements; these requirements are documented and maintained. In addition to allocating requirements to system elements, the process allocates requirements to incremental blocks and builds. The process establishes functional, performance, and verification requirements for each incremental system or software block or build.

4.3.3.3.5 Allocation Program Responsibility

Although SE does not establish program organization, the program organization shall contain elements responsible for allocating requirements and deriving design from the system specification to the software and hardware configuration items.

4.3.3.4 Task 4: Derive Requirements

4.3.3.4.1 Identify Derived Requirements

The objective of requirements derivation is to identify and express requirements that result from considering functional analysis, higher-level requirements, constraints, or processes. This results in additional clarification or amplification of higher-level requirements. These derived requirements need to be stated in measurable parameters at increasingly lower levels within the product hierarchy. Derived requirements may result from, but are not limited to:

- Regulatory policies, program policies, agency practices, and supplier capabilities.
- Environmental and safety constraints; the process translates and traces safety-specific system requirements into the software and hardware requirements baseline. Safety program requirements are also reflected in organizational standards and procedures. The process translates and traces safety-specific requirements into the system (hardware and software) baseline. The process assesses system safety program requirement tasks for applicability and incorporation into organizational standards and procedures.
- Architecture choices for performing specific system functions.
- Design decisions.
- Hardware-software interfaces not already specified in the baseline interface documentation.
- Establishment of detailed requirement values and tolerances (i.e., minimum, maximum, goal, threshold).

Impacts of derived requirements need to be analyzed progressively in all directions (parent, child, and peer) until it is determined that no additional impact is propagated. During this process, the hardware and software architecture design is reviewed for flexibility to adapt to new system requirements.

4.3.3.4.2 Capture Derived Requirements

Derived requirements are captured and treated in a manner consistent with other requirements applicable during the development stage. This activity, like overall SE, is an iterative operation, constantly refining and identifying new requirements as the product concept develops and additional details are defined. As part of the requirements derivation process, areas of the system with volatile requirements are monitored, and requirements specifications are reviewed for ambiguities with the potential of causing software sizing and timing instability and other program impacts.

4.3.3.5 Task 5: Establish Verification Methodology

In this step, a verification approach is developed for each requirement documented in the Validation Table, and the Validation Table is transformed into a VRTM. The strategy or method used to verify each requirement is specified in a Verification Requirement, and the Verification Requirements are listed in the VRTM. The VRTM defines how each requirement is to be verified, the stage in which verification is to occur, and the applicable verification levels. The verification approaches are:

- Inspection
- Analysis
- Demonstration
- Test

These methods are discussed in Validation and Verification (Section 4.12). Figure 4.12-2 is an example of a VRTM. Specific guidelines for the VRTM are included in the Test and Evaluation section of the FAST (http://fast.faa.gov/toolsets/index.htm).

4.3.3.6 Task 6: Manage Requirements Changes

This activity manages and controls requirements throughout the product's lifecycle (before and after instituting formal configuration control) by means of a defined change process. The activity identifies and controls all issues and decisions, action items, formal and informal stakeholder/program management desires/directives, and any other real or potential changes to the requirements. The activity is invoked when a new requirement is identified or a change occurs during any other activity within the Requirements Management process. The activity is a project-wide, approved approach that documents and controls the identified requirement, its appropriate attributes, its relationship(s) to other requirements, and allocation to the product of functional and/or verification hierarchies. The activity ensures that all involved stakeholders concur with the baselined requirements and any changes. The change process controls the allocation of requirements between hardware and software. This activity shall be conducted in conjunction with the Configuration Management process (Section 4.11).

This process accounts for changes to Government-Furnished Equipment (GFE) and Contractor-Furnished Equipment (CFE) safety critical items that impact development efforts. The process also accounts for changes resulting from the Verification process (Section 4.12). That is, if a test or other form of verification determines that a change in requirements is necessary, the process ensures that the change process is initiated to accomplish that change. The steps described in the following paragraphs are performed.

4.3.3.6.1 Identification

A new requirement or a change to an existing requirement is identified. The originator documents the new requirement or change to an existing requirement by providing, at minimum, the following information to the requirements analysis team:

- Statement of the requirement.
- Justification/rationale (e.g., trade study, documentation).
- Traceability, if applicable, to the parent child and/or peer requirements(s). Two-way traceability between the software requirements and the system requirements is established and maintained.
- List of other elements (e.g., physical or functional hierarchies) impacted. For example, whenever requirements change, there is a review of and an update to the hardware and software architecture design. This process ensures that the software impact for each proposed change is addressed. Software artifacts (e.g., requirements, design, code, and documentation), for example, are revised as changes to the requirements are

incorporated. In addition, software development plans and program baselines (e.g., cost and schedule) are reviewed and modified if necessary.

- Change requests and problem reports for all configuration items or units are initiated, recorded, reviewed, approved, and tracked.

4.3.3.6.2 Control

The requirements analysis team prepares and disseminates a requirements change notification as follows:

- Assign due date
- Collect and resolve conflicting responses—if not received, assume acceptance
- Place on decision authority agenda
- Present to appropriate decision authority and record the disposition

Multiple approval levels may be established, depending on management methodology, size, or project phase. If concurrence is not reached, the requirement shall be elevated to the next higher-level review board or decision authority; that is:

- Project Configuration Control Board (CCB)—Changes that impact only the project products
- Program CCB—Changes that impact projects outside of individual projects
- NAS CCB—Changes that are NAS-wide in scope or affect NAS-level requirements or architecture

4.3.3.6.3 Status Accounting

The disposition is recorded and the decision is disseminated to the involved stakeholders. At the program and NAS level, a Configuration Control Decision shall be issued. Otherwise, the project issues new/revised requirements document(s), Specification Change Notices (SCN), requirements verification document(s), and compliance report(s), as appropriate.

4.3.4 Outputs of Requirements Management

4.3.4.1 External Outputs

4.3.4.1.1 Requirements

4.3.4.1.1.1 Requirements Documents

The term “requirements documents” refers to any media that record requirements, either in hard copy or electronic form. It is a basic rule that all requirements shall be recorded, including internally generated requirements as well as those generated external to the project. The process does not allow verbal or unwritten requirements.

4.3.4.1.1.1.1 Stakeholder Requirements Documents

Standard requirements documents from an FAA stakeholder include the MNS, the iRD, and the fRD. Other organizations use the Operational Requirements Document (ORD) to communicate requirements. Stakeholders convey requirements through memoranda and other media.

4.3.4.1.1.1.2 Specifications

Specifications are a standard form of requirements documents. The technical requirements for a system and its elements are documented through a series of specifications as described in this manual. FAA-STD-005e, "Preparation of Specifications, Standards and Handbooks," describes the requirements for preparing FAA specifications, standards, and handbooks. MIL-STD-961 is the current standard format for FAA specifications required by FAA-STD-005e. FAA specifications were prepared in the MIL-STD-490 format until recently, and some legacy specifications remain in that format. However, MIL-STD-490 specifications may continue to be used for reference. Newly prepared specifications shall be prepared in accordance with FAA-STD-005e.

4.3.4.1.1.1.2.1 Types of Specifications

The System Specification (Type A) is the single most important engineering design document, defining the system functional baseline and including the results from the needs analysis, feasibility analysis, operational requirements and the maintenance concept, top-level functional analysis, and the critical TPMs. This top-level specification leads to one or more subordinate specifications covering applicable subsystems, configuration items, equipment, software, and other system components. Although the individual specifications for a given program may assume a different set of designations, a generic approach is used here.

4.3.4.1.1.1.2.1.1 System Specification (Type A)

Type A Specification includes the technical, performance, operational, and support characteristics for the system as an entity. It includes allocation of requirements of functional areas, and it defines the various functional-area interfaces. The information derived from the feasibility analysis, operational requirements, maintenance concept, and functional analysis is covered. The Type A specification is the FAA-E-XXXX specification described in FAA-STD-005e.

The System Specification shall provide the technical baseline for the system as an entity, shall be written in performance-related terms, and shall describe design requirements in terms of "whats," including the functions that the system is to perform and the associated metrics.

The System Specification is the requirements document used by the FAA to procure most systems. It is placed under configuration management before the system Request for Proposal (RFP) is issued.

4.3.4.1.1.1.2.1.2 Development Specification (Type B)

Type B Specification includes the technical requirements for any item below the system level where research, design, and development are accomplished. This may cover an equipment item, assembly, computer program, facility, or critical item of support. Each specification shall

include the performance, effectiveness, and support characteristics that are required in evolving design from the system level down.

The Development Specification is usually produced by a system vendor in response to the FAA-developed System Specification. It is placed under configuration management at completion of the Preliminary Design Review (PDR).

4.3.4.1.1.1.2.1.3 Product Specification (Type C)

Type C Specification includes the technical requirements for any item below the top system level that is currently in the inventory and may be procured off the shelf. This may cover standard system components (e.g., equipment, assemblies, units, cables), a specific computer program, a spare part, or a tool. The Product Specification is usually produced by a system vendor in response to the FAA-developed System Specification or to a vendor-developed Development Specification. It is placed under configuration management at completion of the PDR.

4.3.4.1.1.1.2.1.4 Process Specification (Type D) (Rarely Used in Federal Aviation Administration Procurements)

Type D Specification includes the technical requirements that cover a service that is performed on any component of the system (e.g., machining, bending, welding, plating, heat treating, sanding, marking packing, and processing).

The Process Specification is usually produced by a system vendor in response to the FAA-developed System Specification. It is created by the vendor and is rarely used in FAA procurements.

4.3.4.1.1.1.2.1.5 Material Specification (Type E) (Rarely Used in Federal Aviation Administration Procurements)

Type E Specification includes the technical requirements that pertain to raw materials, mixtures (e.g., paints, chemical compounds), or semi-fabricated materials (e.g., electrical cable, piping) that are used in the fabrication of a product.

The Material Specification is usually produced by a system vendor in response to the FAA-developed System Specification. It is created by the vendor and is rarely used in FAA procurements.

4.3.4.1.1.2 Requirements Change Notices

An SCN is a formal document specifying that a baselined document has been changed.

4.3.4.1.1.3 Requirements Allocation Matrix

The RAM allocates requirements to components and assigns responsibilities to organizations. Normally, a requirements management tool, such as Dynamic Object-Oriented Requirement System (DOORS), is used for this purpose. A RAM contains the following data:

- Text-based requirement.
- Detailed source of the requirement (i.e., person, document and paragraph number).

- Assigned team(s).
- Traceable parent and/or child requirements. Two-way traceability between the design and the requirements is established and maintained. In addition, when software is reviewed against the design, two-way traceability between the software code and design is established and maintained. Two-way requirements traceability is maintained from system specification to hardware and software configuration item specifications.
- Date of inclusion or deletion.
- Reference WBS number.
- Requirements verification method (i.e., test, analysis, inspection, demonstration).
- Allocated cost estimate, if any.
- Any CDRL item(s) associated with the requirement.

4.3.4.1.1.4 Requirements Database

Although requirements are normally provided in the hard-copy formats described above, they are also available in the original electronic format in automated tools such as DOORS.

4.3.4.1.2 Requirements Verification Compliance Document

The RVCD is output to program and project management for program control activities.

4.3.4.1.3 Verification Requirements Traceability Matrix

The VRTM is included as a part of every requirement and specification document. It provides information on the verification and traceability from a requirement to a higher-level requirement or to its ultimate source. Validation and Verification (Section 4.12) provides more information on this topic.

4.3.4.2 Internal Outputs

Internal outputs are products that are provided to other SE processes.

4.3.4.2.1 Technical Planning

4.3.4.2.1.1 Planning Criteria

Planning criteria describing planned activities for the Requirements Management process are output to the Integrated Technical Planning process (Section 4.2).

4.3.4.2.2 Functional Analysis

4.3.4.2.2.1 Mission Need Statement

The MNS is output to Functional Analysis (Section 4.4) for use as the baseline for developing the next lower-level Functional Architecture that is then used by the Requirements Management process to develop the next lower-level requirements.

4.3.4.2.2.2 Requirements

The requirements set at any stage in the requirements development process are output to the Functional Analysis process (Section 4.4) for developing the next lower-level functional analysis.

4.3.4.2.3 Synthesis

4.3.4.2.3.1 Requirements

The requirements set below the MNS are output to the Synthesis process (Section 4.5), which allocates requirements to the Physical Architecture.

4.3.4.2.4 Trade Studies

4.3.4.2.4.1 Requirements

During the Requirements Development process, alternative solutions may be proposed that require analysis by conducting trade studies. The Requirements Management process provides output requirements for analysis to the Trades Studies process (Section 4.6).

4.3.4.2.4.2 Constraints

Constraints that are developed during the Identify and Capture Requirements task may be used in a trade study and are output to the Trade Studies process (Section 4.6) in addition to requirements.

4.3.4.2.5 Interface Management

4.3.4.2.5.1 Mission Need Statement

The MNS is provided to the Interface Management process (Section 4.7) so that functional and physical interfaces may be identified and placed under management.

4.3.4.2.5.2 Requirements

Requirements are provided to the Interface Management process (Section 4.7) at all stages of requirements development so that interfaces are identified and controlled.

4.3.4.2.6 Specialty Engineering

4.3.4.2.6.1 Requirements

To perform Specialty Engineering analyses, the system under study shall be described. Requirements are a key component of any description, and they are an output to Specialty Engineering (Section 4.8).

4.3.4.2.7 Integrity of Analysis

4.3.4.2.7.1 Tools/Analysis Requirements

Requirements for tools or analysis that are needed during the Requirements Management process are output to the Integrity of Analysis process (Section 4.9) so that Analysis Criteria may be developed.

4.3.4.2.7.2 Requirements

Requirements are output to the Integrity of Analysis process (Section 4.9).

4.3.4.2.8 Risk Management

4.3.4.2.8.1 Concerns and Issues

Concerns and Issues related to accomplishing the mission objectives and satisfying Stakeholder Needs that are discovered during the Requirements Management process are provided to the Risk Management process (Section 4.10) for review and resolution.

The cumulative status of requirements as a result of previous requirements reviews regarding coverage, balance, mutual conflicts, induced constraints, and so forth are analyzed, and Concerns and Issues are identified.

In the course of performing SE, it is possible that potential requirements management problems may surface in the form of Concerns and Issues. These Concerns and Issues may take many forms, but, for the most part, they may be potential risks to the program.

4.3.4.2.8.2 Requirements

The Requirements Management process identifies requirements to Risk Management (Section 4.10) that are to be analyzed for potential risk.

4.3.4.2.9 Configuration Management

4.3.4.2.9.1 Requirements

The Requirements Management process identifies requirements to the Configuration Management process (Section 4.11) that are to be controlled.

4.3.4.2.10 Validation

4.3.4.2.10.1 Requirements

Requirements developed through the Requirements Management process are to be submitted to the Validation process (Section 4.12) to determine if they are complete, concise, and necessary.

4.3.4.2.11 Verification

4.3.4.2.11.1 Verification Requirements Traceability Matrix

The Requirements Management process expands the Validation Table into a VRTM with assigned verification methods and submits the VRTM to the Verification process (Section 4.12).

4.3.4.2.11.2 Requirements

The Requirements Management process submits requirements to be verified to the Verification process (Section 4.12).

4.3.5 Requirements Management Process Metrics

Performance of this process is measured and recorded on a regular basis. The following metrics, at minimum, may be used to evaluate process performance:

- Number of requirements, including both stakeholder-specified and project-derived
- Number of changed requirements, including both stakeholder or project-initiated
- Technology requirements, including proven, to be defined, and unknown technology
- Unclear, undefined, or ambiguous requirements
- Cycle time from requirement change initiation to decision
- Cycle time from change decision to baseline incorporation
- Percent of validated requirements to total proposed requirements

4.3.6 Automated Tools for Requirements Management

Use of an automated requirements tool for documenting requirements and related information depends on a variety of factors (e.g., size and complexity of the program, number of requirements, budget). There are multiple automated software tools in the marketplace that adequately store and retrieve the requirements and their traceability. A program's tool shall be capable of maintaining two-way traceability, from system specifications to hardware and software configuration item specifications. It shall be capable of being integrated into an overall SE tool suite so that data are seamlessly portable between applications.

For small programs, a spreadsheet may be more than adequate to document and control the requirements set. As a program grows and becomes more complex, a tool designed for requirements management may be necessary. The primary requirements tool used by the FAA and many of the FAA's systems vendors is DOORS.

4.3.6.1 Requirements Database Accessibility

The requirements information shall be accessible by all program personnel. This may be accomplished by allowing user access to the database itself or by providing availability to the documentation out of the database. A program decision shall be made concerning the availability and changeability of the requirements data. All personnel may be trained in using the requirements management tool or database, or a select group may manipulate the database and use a distribution media (e.g., intranet Web site, paper) to disseminate the information and collect comments and changes.

4.3.6.2 Requirements Tool Characteristics

It is recommended that the database be capable of identifying (i.e., in the form of attributes and relationships) and presenting (e.g., internal queries, standard and project-unique reports) the following types of information:

- **Requirements documentation**—statements of the requirements, status, requirement type, rationale, and history (including data configuration control) regarding each requirement, and the ability to present the requirements in an appropriate user-defined format (e.g., requirement documents, specifications)
- **Traceability**—linking requirements to their parent, child, and peer requirements, resulting in user-defined requirement traceability matrices
- **Allocation**—linking requirements to the product hierarchy, resulting in user-defined requirements allocation documents
- **Verification**—linking the requirement to specific verification approach attributes, resulting in requirements verification and compliance documents
- **Traceability Impact Assessment**—ability to assess the impact of proposed changes to the requirement, product, and verification hierarchies
- **Compatibility**—ability to communicate (minimum of import and export capabilities) with other automated tools

4.3.7 References

1. Blanchard, B. "System Engineering Management." (2nd ed.). John Wiley & Sons, Inc: New York, NY.
2. Defense Systems Management College. "Systems Engineering Fundamentals." Defense Systems Management College Press: Fort Belvoir, VA, 1999.
3. Grady, Jeffrey. "System Requirements Analysis." McGraw Hill: New York, NY, 1993.
4. Hooks, Ivy. "Guide for Managing and Writing Requirements." Compliance Automation, Inc: Houston, TX.
5. "IEEE Standard for Application and Management of the Systems Engineering Process." The Institute of Electrical and Electronic Engineers, New York, NY.
6. Kar, Philip, and Bailey, Michelle. "Characteristics of Good Requirements." Compliance Automation, Inc: Houston, TX.
7. MIL-STD-961D. 22 March 1995. "Department of Defense Standard Practice for Defense Specifications."
8. Mission Needs Statement.
9. National Airspace System Architecture.
10. National Airspace System Concept of Operations. Version 2.
11. Requirements Documents.
12. Sage, A., and Rouse, W. "Handbook of Systems Engineering and Management." John Wiley & Sons, Inc: New York, NY.
13. Young, R. "Effective Requirements Practices." Addison-Wesley: New York, NY.

4.4. Functional Analysis *(Satisfies EIA/IS 731 FA 1.2 and iCMM PA 4)*

Functional Analysis details the use of functional flow diagramming as a representative structured analysis process that is the preferred approach of the Federal Aviation Administration (FAA). In addition, this section covers several alternative approaches, as FAA system engineers come in contact with organizations that apply techniques other than functional flow diagramming. Therefore, it is necessary that the engineers be able to communicate with members of those organizations and integrate their results with the work performed by other organizations. The following paragraphs detail functional flow diagramming; alternative approaches appropriate for systems and hardware; alternative models for problems to be solved with computer software; and references that cover these techniques in more depth.

4.4.1. Introduction to Functional Analysis

The process of analyzing functions provides System Engineering (SE) with a functional system description that becomes a framework for developing requirements and physical architectures. Utilizing the Functional Analysis process significantly improves synthesis of design, innovation, requirements development, and integration. The Functional Analysis process provides two key benefits to SE: (1) it discourages single-point solutions, and (2) it describes the behaviors that lead to requirements and physical architectures. The essential elements of Functional Analysis are illustrated in Figure 4.4-1, which lists the key inputs necessary to initiate the task, providers, process tasks, outputs required, and customers of process outputs. The beginning and ending boundary tasks, as well as the intermediate tasks, are described in later paragraphs.

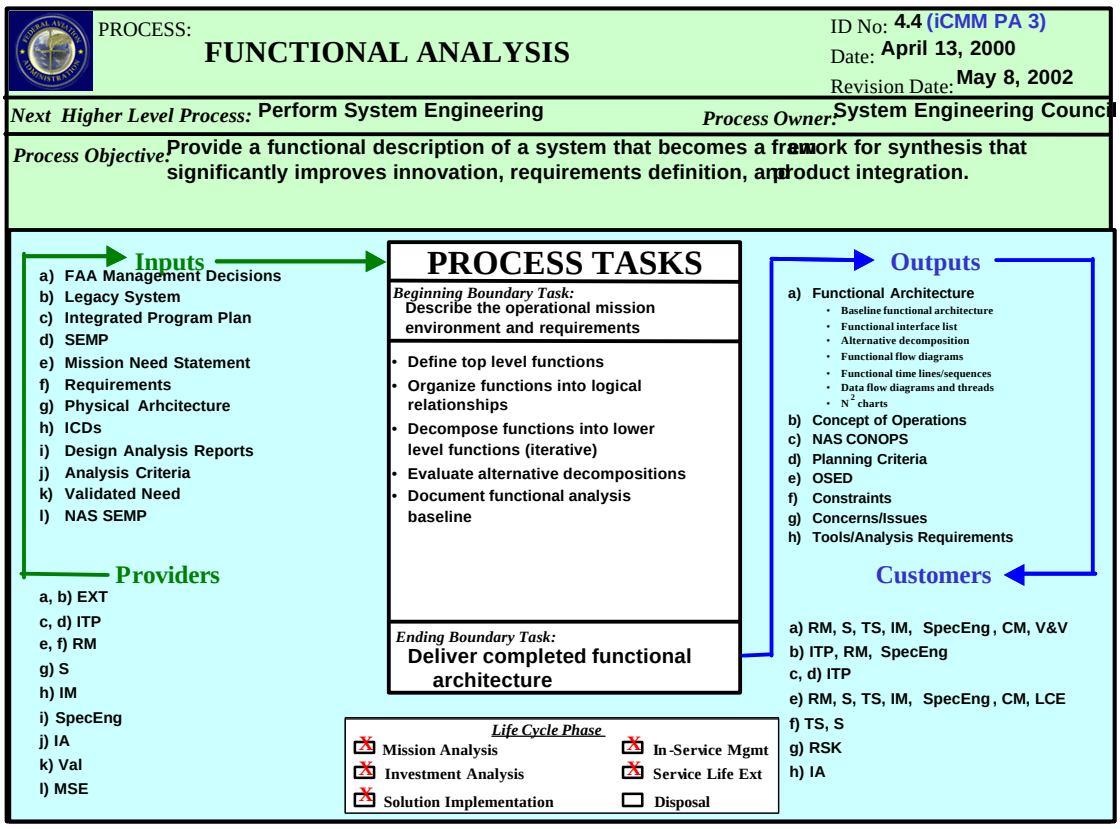


Figure 4.4-1. Functional Analysis Process-Based Management Chart

Systems may be described using two different facets. First, a system may be described as a physical architecture with elements that interact with themselves and the system environment in

accordance with a predefined process to achieve the system mission. At the same time, a system may be described by the functions that it performs. A system is intended to satisfy predefined functions, with the highest-level function defined as the stakeholder need (also the ultimate system requirements). A *function* is a characteristic action or activity that has to be performed in order to achieve a desired system objective (or stakeholder need). A *function name* is stated in the form of an action verb followed by a noun or noun phrase; it is an action that describes the desired system behavior. Examples of common functions include "read book," "eat food," and "go to store." A function is accomplished by one or more system elements composed of equipment (hardware, software, and firmware), people, and procedures. The function occurs within the system environment and is performed to achieve system operations. In Functional Analysis, because a function may be accomplished by more than one system element, functions are unable to be allocated. Rather, functions are used to develop requirements, which are then allocated to solutions in the form of a physical architecture.

When unprecedented systems or systems are being developed that radically differ from those currently in use, the approach named "form follows function" is applied. The first function to identify stems from the need, which is then decomposed into lower levels of needed functionality. The functional description is translated into the physical by assigning functionality to requirements and requirements into a Physical Architecture. While function names may be allocated to specific Physical Architecture entities directly, it is often the case that some combination of two or more architectural entities accomplishes one function. The FAA preference is to translate functions into primitive performance requirements and then allocate these performance requirements to physical architecture entities.

4.4.1.1. Functional Analysis Objectives

The Functional Analysis process helps to ensure that:

- All facets of a system's lifecycle, as illustrated in Figure 4.4-1, are covered from development to production, operation, and support
- All functional elements of the system are described, recognized, and defined
- All system concepts and requirements for specific system functions are related
- Requirements definition is improved
- Product integration is improved
- New and innovative designs and solutions are incorporated

4.4.1.2. Process Overview

Functional Analysis examines a system's functions and subfunctions that are necessary to accomplish the system's operation or mission. It describes *what* the system does, not *how* it does it. Functional Analysis is conducted at the level needed to support later synthesis efforts, with all operational modes and environments included. Each function required to meet the operational needs of a system is identified and defined; once defined, the functions are then used to define the system requirements, and a functional architecture is developed based on the identified requirements. The process is then taken to a greater level of detail as the identified functions are further decomposed into subfunctions, and the requirements and physical architecture associated with those functions are each decomposed as well. This process is iterated until the system is completely decomposed into basic subfunctions, and each subfunction at the lowest level is completely, simply, and uniquely defined by its requirements. In this process, the interfaces between each of the functions and subfunctions are fully defined, as are the interfaces with the environment and external systems. The functions and

subfunctions are arrayed in a Functional Architecture to show their relationships and interfaces (internal and external). Figure 4.4-2 illustrates the Functional Analysis process flow.

Functions shall be:

- Arranged in their logical sequence
- Well defined in their inputs, outputs, and functional interfaces (internal and external)
- Traceable from beginning to end conditions
- Analyzed, determined, and defined for time-critical requirements
- Successively established from the highest to lowest level for each function and interface
- Defined in terms of what needs to be accomplished in verb–noun combinations without describing *how* it is to be accomplished
- Traceable downward through successive functional decompositions

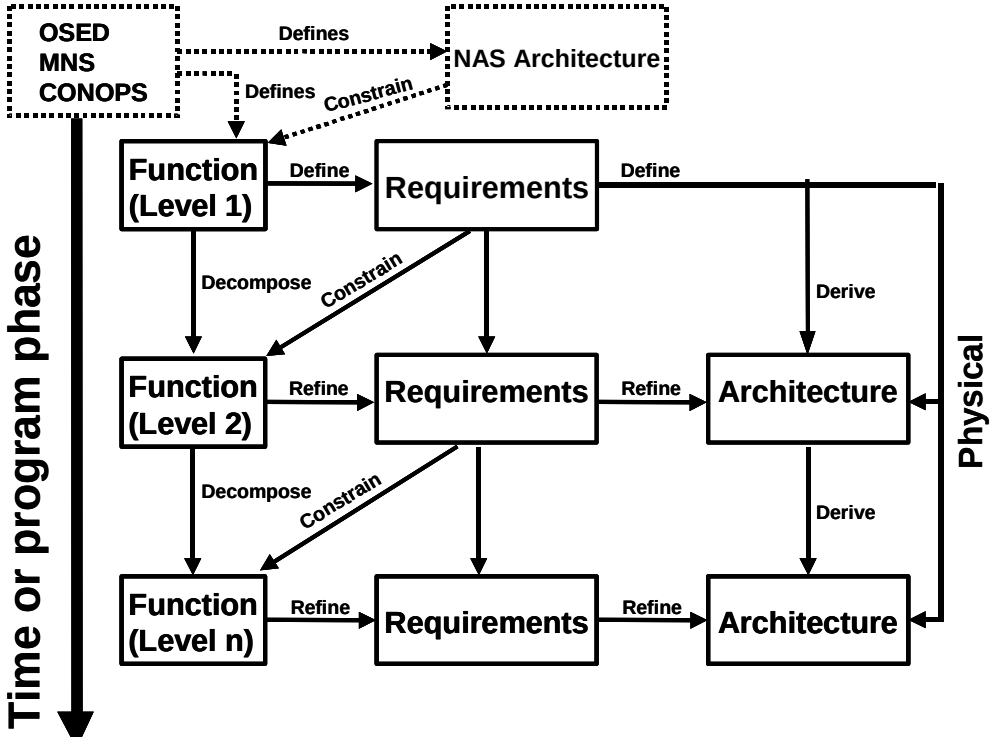


Figure 4.4-2. Functional Analysis Process Flow and Interface with Physical Architecture and Requirements

It is recommended that the Functional Analysis process be conducted in conjunction with Requirements Management (Section 4.3), Synthesis (Section 4.5), and Trade Studies (Section 4.6) (Figure 4.4-3) to:

- Define successively lower-level functions required to satisfy higher-level requirements and to define increasingly detailed sets of Functional Architectures

- Define mission- and environment-driven performance requirements and determine that higher-level requirements are satisfied
- Flow down performance requirements and design constraints
- Refine the definition of product and process solutions

4.4.2. Inputs to Functional Analysis

The more that is known about a system, the more complete the Functional Architecture. At the highest level of Functional Analysis for the FAA (the National Airspace System (NAS)), only the Mission Need Statement (MNS) may be available as input. The needs reflected in the MNS are translated into a Concept of Operations (CONOPS). A CONOPS is a high-level form of Functional Analysis that is solely derived from the user's perspective. It is recommended that the CONOPS serve as a baseline for the more detailed Functional Analyses to follow. (Paragraph 4.4.4.2 provides more information on CONOPS.) As iterations progress, it is recommended that higher-level Physical Architectures and Requirements be considered as they become available. If the output of the Requirements Management (Section 4.3) task is incomplete, the Functional Analysis task reveals missing Requirements and helps to refine or clarify others. Figure 4.4.3 depicts Functional Analysis's process flow, while Figures 4.4-4 and 4.4-5 illustrate several representative inputs and outputs to/from Functional Analysis.

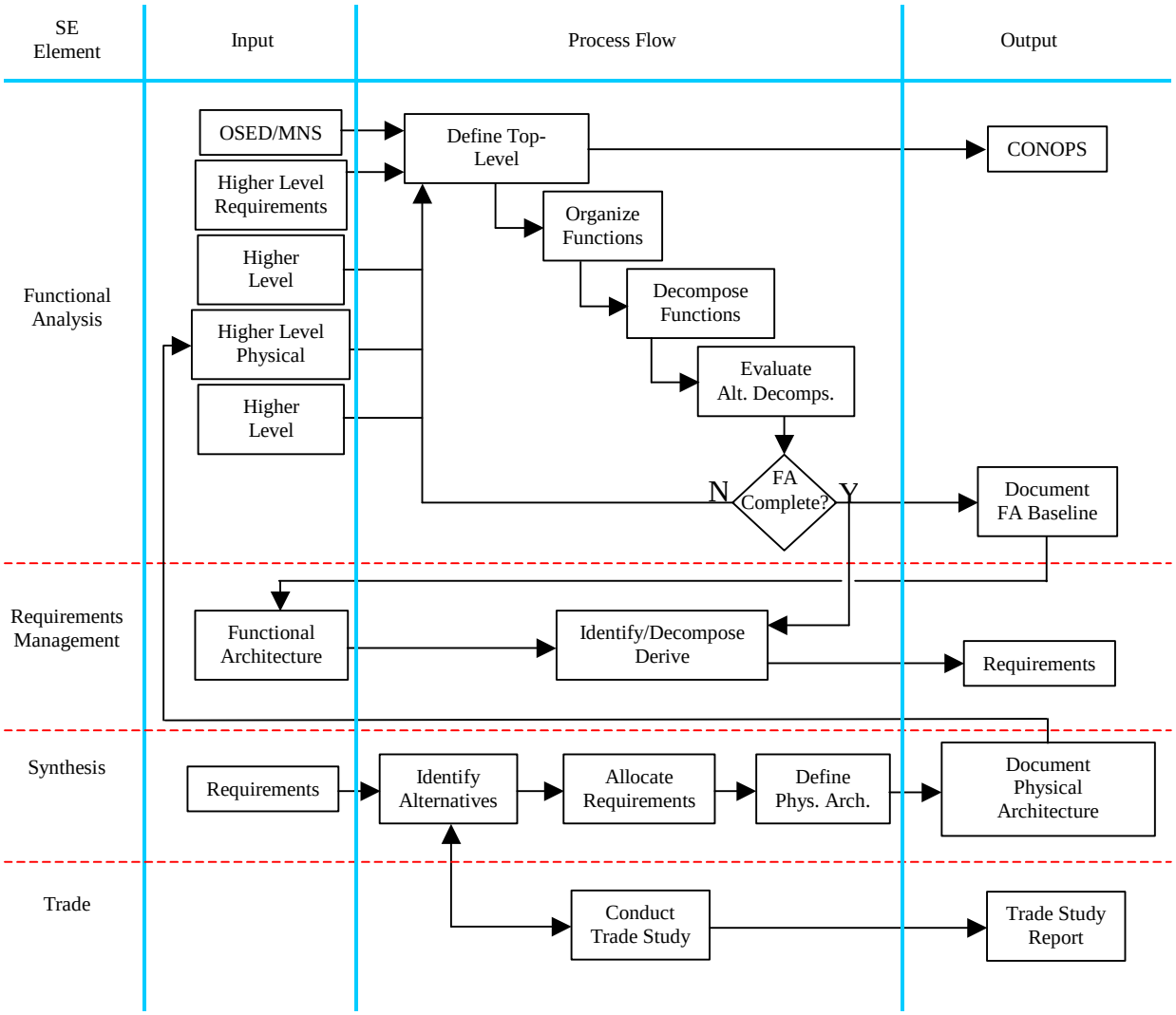


Figure 4.4-3. Functional Analysis Process Flow

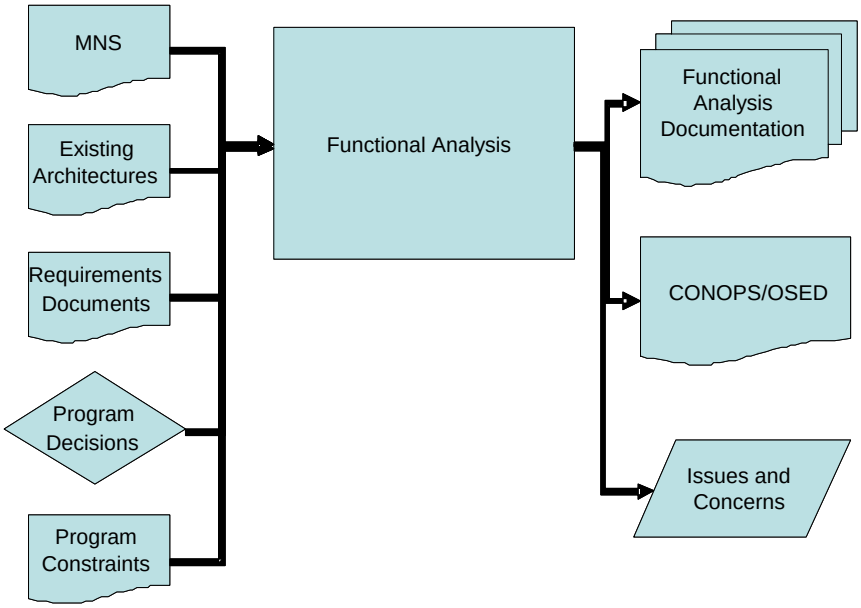


Figure 4.4-4. Several Representative Inputs to Functional Analysis

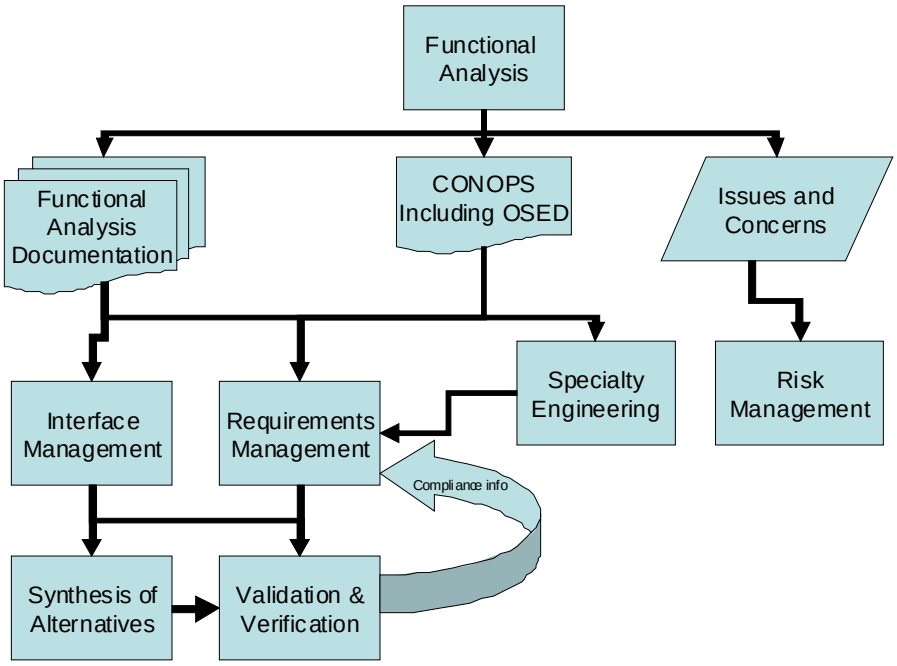


Figure 4.4-5. Several Representative Outputs of Functional Analysis

The following is a more comprehensive list of the inputs to Functional Analysis:

- FAA Management Decisions
- Information on Legacy Systems
- Planning documents, such as the Integrated Program Plan

- NAS Level (and program, if available) System Engineering Management Plan
- Defined NAS capability shortfalls and/or needs in the MNS (including validated needs statement)
- Requirements, such as any existing specifications and standards requirements, including requirements documents (reference documents)
- Program decisions (such as Constraints relating to existing hardware and software)
- Existing Physical Architectures
- Higher-level Functional Architectures
- Information on interfaces, including Interface Control Documents
- Design Analysis Reports
- Analysis Criteria

4.4.3. Functional Analysis Process Tasks

The Functional Analysis process is summarized in Figure 4.4-1. The five major process tasks listed in Figure 4.4-1 are described in the remainder of this section.

4.4.3.1. Task 1: Define Top-Level Functions (From Inputs)

The first task in defining the system from a functional standpoint is to review the MNS, existing Operational Services and Environmental Descriptions (OSED), and any existing requirements documents to ensure a complete understanding of the top-level system missions/functions, environments, Requirements, and imposed Constraints. The MNS defines the needs the system is expected to meet. The CONOPS is developed from the MNS and normally includes an OSED. (The OSED is defined in Paragraph 4.4.4.2.1.) A system understanding from the perspective of these documents ensures that the system's relationship to its environment and external systems is considered during the development of the primary system functions. Figure 4.4-6 is a simplified example of an MNS and CONOPS for an office requiring the capability to record and store information from a computer. This example is used only to develop a sample functional flow diagram (FFD) (Paragraph 4.4.3.2.2.1). An actual MNS and CONOPS include much greater detail.

The system's primary mission(s) is defined using the MNS and any available system

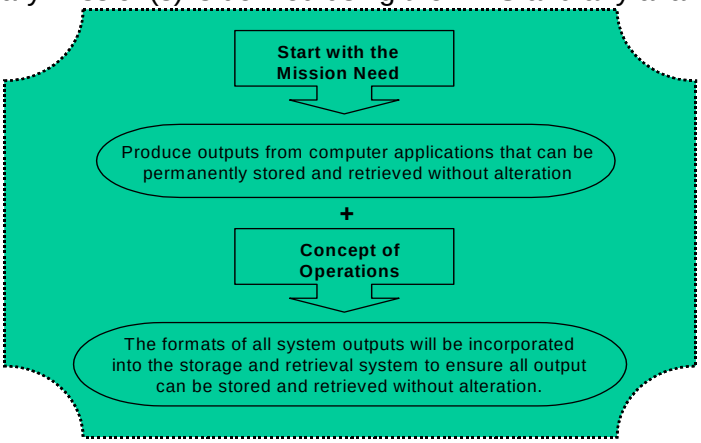


Figure 4.4-6. Mission Need Statement and Concept of Operations

descriptions, such as the OSED, the system's Requirements, and Constraints. This mission(s) is the primary function that the system fulfills, and it is named using the guidelines and naming convention described in the "Introduction to Functional Analysis" (Paragraph 4.4.1).

In addition, the internal and external interfaces (including ambient and operational environments) of the system are identified, and the functional relationships are defined. In the next task, these relationships are depicted through structured analysis using sequence diagrams, FFDs, and N^2 diagrams, which meet nearly all FAA program needs. In these depictions—examples of which appear in Figures 4.4-9 through 4.4-20—a large rectangular box represents the system, and the smaller boxes represent external elements outside of the main system. Flow arrows represent interfaces between the system and the external elements that describe which external element the system is transmitting to/receiving from and what data is being transmitted/received. Figure 4.4-7 shows the standard symbols used in these diagrams. ("Functional Analysis Tools and Techniques" (Paragraph 4.4.5) provides other techniques that may be used with approved tailoring to the process.)

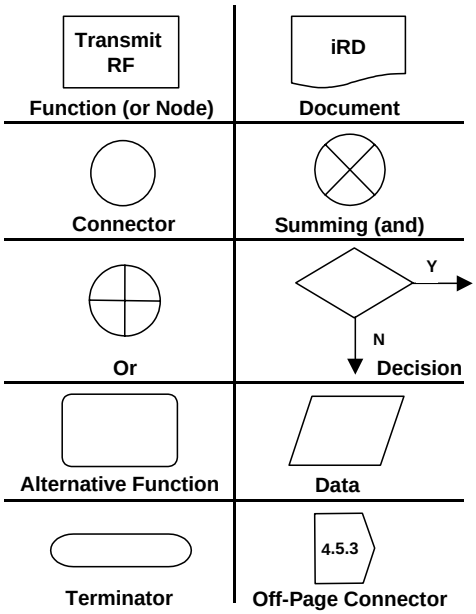


Figure 4.4-7. Symbology Template for Functional Flow Diagramming

In Task 1, the necessary functions that provide the required capabilities of the system, as specified by the need or Requirements, are defined. The activity represented by each of the functions shall be well defined, able to be implemented, and testable; and the interfaces to other functions shall be as simple as possible. It is recommended that these functions be developed with an eye toward the conversion of the Functional Architecture into Requirements and Requirements into a Physical Architecture. The development of complementary Functional and Physical Architectures requires multiple iterations between Functional Analysis, Requirements Management (Section 4.3), and Synthesis (Section 4.5).

Figure 4.4-8 lists functions based on the example MNS and CONOPS depicted in Figure 4.4-6. There are many approaches to describe these functions. The main criterion for task completion is a comprehensive list of the functions the system has to perform in order to meet its mission. For this task, the list does not need to follow a logical order.

List of Functions

- **Mission or central function: Produce outputs from computer applications**
  - **Provide output**
  - **Process output**
  - **Produce output**
  - **Generate output**
  - **Accept output information**
  - **Store output information**
  - **Retrieve stored output information**

Figure 4.4-8. List of Primary Functions

An analysis of operations and environment may be tailored to represent the available source of information. If detailed references to environmental data are absent in the initial Requirements Documents, Quality Function Deployment or other methods described in Requirements Management may be used as supplements to elicit the information necessary to support follow-on Physical Architecture and Requirements tasks.

Affirmative answers to the following questions signify completion of Task 1:

- Have all missions, phases, and modes of operation been considered for the system?
- Have all functional elements been properly identified?
- Have all functional interfaces of the system to and from the environment been adequately identified and listed (physical/functional interface, connection parameters and modes, etc.)?
- Have the results of this review been captured in a list that identifies the system's mission and primary functions as well as interfaces with other systems and the environment?

4.4.3.2. Task 2: Organize Functions Into Logical Relationships

The function list developed in Task 1 serves as an input to Task 2. The function list includes the central functions required for the system to accomplish its mission, but the list is not necessarily arranged in a sequence or logical relationship. During Task 2, the functions are arranged in at least one of the primary logical flow diagrams, which are applicable to most programs and indicate relationships based on function sequence and/or functional flow (input-function-output). The arrangement of the functions includes independent functions in parallel and dependent functions in series (e.g., when completion of the upstream function is necessary in order to begin the downstream function). A discussion of other techniques (used only when tailoring is approved) is included in "Functional Analysis Tools and Techniques" (Paragraph 4.4.5).

4.4.3.2.1. Sequence Relationships

The sequence family of relationships includes both sequence and timing. Sequence relationships shall be used if sequence or timing is critical to the overall system function and when the relationships are simple. When sequencing is selected, the functions are arranged in order of sequence (i.e., preceding functions depicted before subsequent functions).

4.4.3.2.1.1. Network Diagrams

Sequence relationships may be depicted as network diagrams. These diagrams shall be used if sequence is important to the function operation, but timing is not necessarily critical. Network diagrams display functions and sequential dependencies in a network format. A box (called a node) represents each function, and a line connecting two boxes represents the sequential dependency between the two functions. Figure 4.4-9 depicts a simple network diagram. Some analysts apply an action on line pattern, where the nodes represent events that partition the actions (on the lines) into time frames.

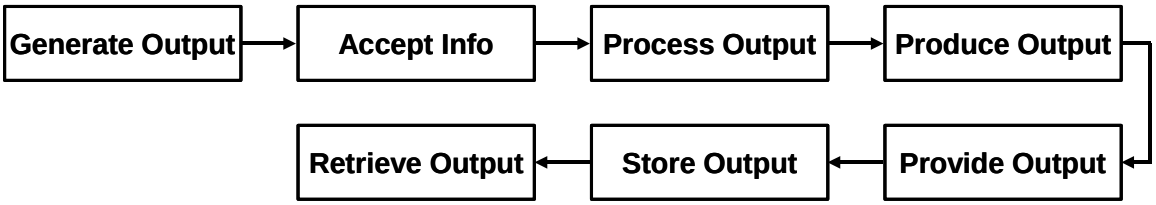


Figure 4.4-9. Depiction of a Sequence Relationship Using a Network Diagram

4.4.3.2.1.2. Time Line Sequence Diagrams

Another way to organize functions in sequence is to use time line sequence diagrams. A time line sequence diagram depicts each function as a line or rectangle on a chart similar to a Gantt chart. The functions are stacked with preceding functions depicted to the upper left of subsequent functions. Time line sequence diagrams shall be used when a sequence relationship is selected, and timing is critical to the function operation. Figure 4.4-10 depicts a simple graphical deterministic time line sequence diagram.

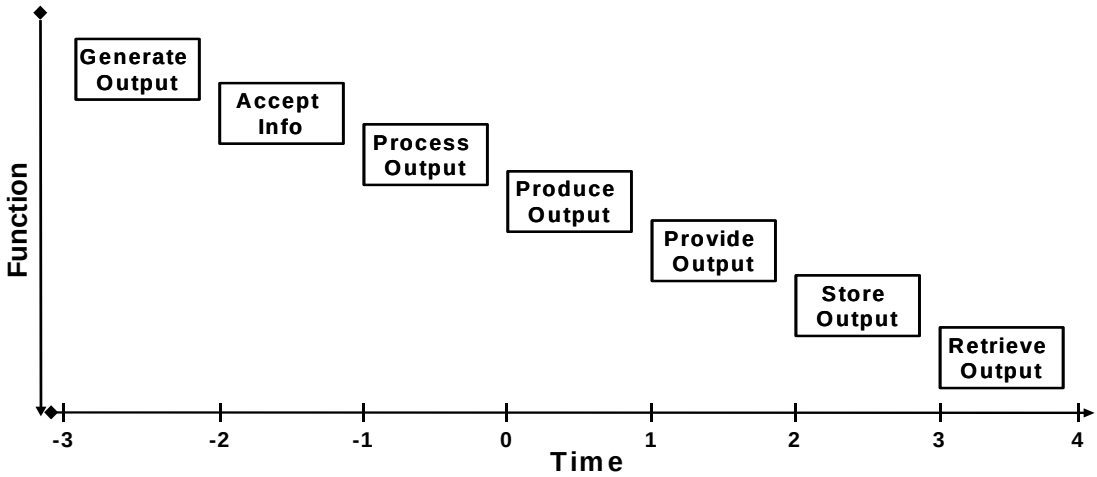


Figure 4.4-10. Depiction of a Sequence Relationship Using a Time Line Sequence Diagram

Time line sequence analysis considers functional durations and provides a more definitive description of the functional sequences than network diagrams are able to convey. It graphically depicts the concurrence, overlap, and sequential relationships of functions and related tasks. Time line sequence analyses are important in the tradeoff process between man and machine, including decisions regarding manual and automatic methods and allocation of times to subfunctions. In addition to defining subsystem/component time requirements, time line sequence analysis is used to develop Trade Studies (Section 4.6) in areas other than time considerations (e.g., is the spacecraft location to be determined by the ground network or by onboard computation using navigation satellite inputs?). Figure 4.4-11 depicts a maintenance time line sheet (TLS) that shows that the availability of an item (distiller) is dependent upon the concurrent completion of numerous maintenance tasks. Furthermore, the figure illustrates the traceability to higher-level requirements by referencing the appropriate FFD.

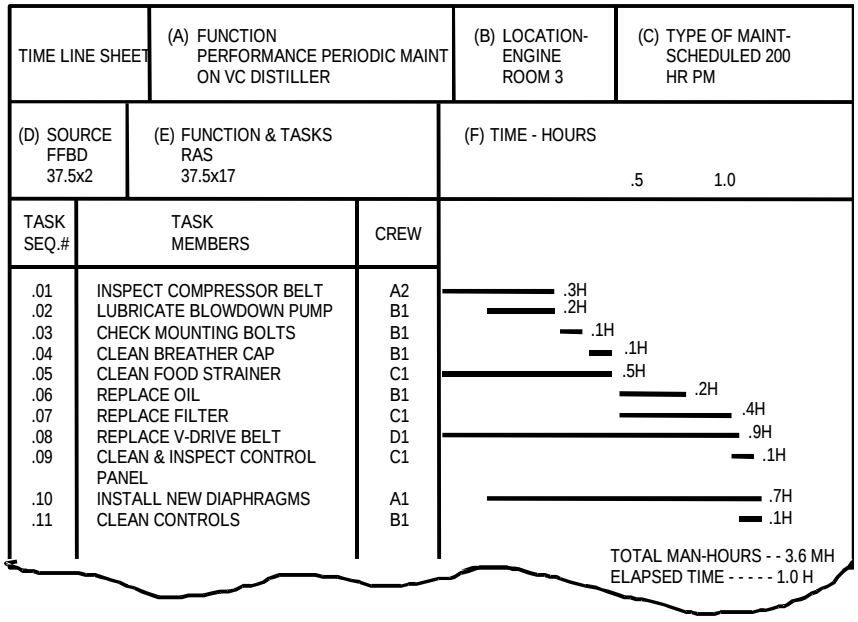


Figure 4.4-11. Time Line Sheet for Maintenance of a Distiller

Time line sequence analysis is performed on areas where time is critical to mission success, safety, utilization of resources, minimization of downtime, and/or increasing availability. The following areas are often categorized as time-critical:

- Functions affecting system reaction time
- Mission turnaround time
- Time countdown activities
- Functions requiring time line sequence analysis to determine optimum equipment and/or personnel utilization

Time line sequence analysis supports the development of design requirements for operation, test, and maintenance functions (additional techniques such as mathematical models and computer simulations may be necessary). In addition, the TLS is used to perform and record the analysis of time-critical functions and functional sequences. For time-critical functional sequences, it is necessary to specify the time requirements with associated tolerances.

4.4.3.2.2. Functional Flow (Input-Function-Output) Logical Relationships

The FFD family consists of a group of analyses that depicts functional (input-function-output) relationships between functions. This family includes the Department of Defense standard FFDs, N^2 diagrams, Integrated Definition for Function Modeling (IDEF) techniques, which are described in the following paragraphs, and the Unified Modeling Language (UML), which is described in Paragraph 4.4.5.2.6.2.

4.4.3.2.2.1. Functional Flow Diagrams

The FFD, the FAA's recommended technique for Functional Analysis, is a multi-tier, time-sequenced step-by-step diagram of the system's functional flow. FFDs usually define the detailed, step-by-step operational and support sequences for systems, but they are also used effectively to define processes in developing and producing systems. The software development processes also use FFDs extensively. In the system context, the functional flow steps may include combinations of hardware, software, personnel, facilities, and/or procedures. Although functional flow relationships are more complicated, they also convey more information than sequence diagrams. In the FFD method, the functions are organized and depicted by their logical inputs and outputs. Each function is shown in relation to the other functions by how the inputs and outputs feed and are fed by the other functions. A node labeled with the function name depicts each function. Arrows leading into the function depict inputs, while arrows leading out of the function depict outputs. Figure 4.4-12 depicts the output of function F0 as an input to function F1.

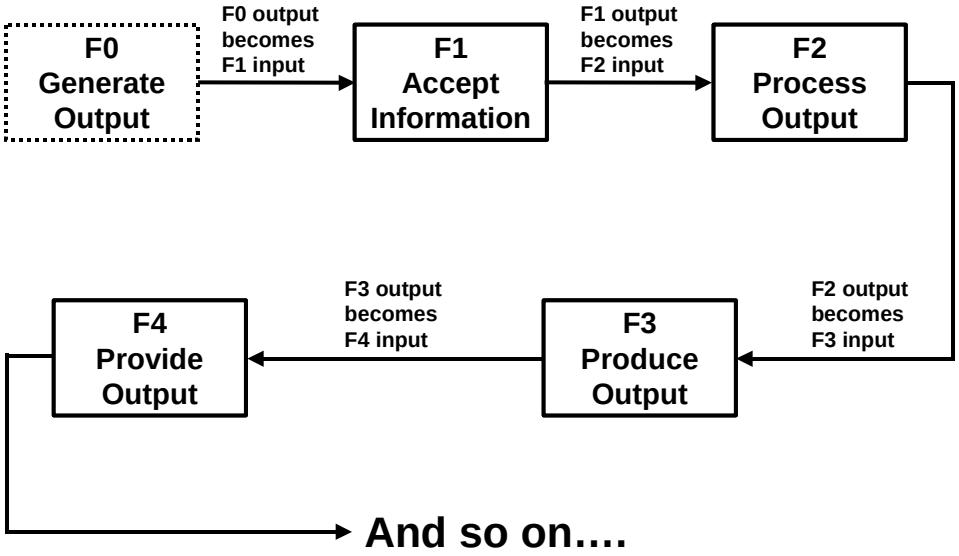


Figure 4.4-12. Functional Flow Relationship

With FFDs, the function is the machine or process that uses inputs to produce outputs. To illustrate: If a turbine engine is the system, then the function is the conversion of oxygen and fuel into mechanical energy in the form of thrust or torque. In Figure 4.4-13, the function is depicted as a box (node) with a function title of "Generate Torque/Thrust." Inputs are the elements needed for the function to operate correctly; the production of mechanical energy using a turbine engine requires oxygen and fuel. Therefore, oxygen and fuel are inputs to that function. Inputs are depicted as arrows leading into the functional node with the input arrows labeled appropriately. The output is the product of the function. In Figure 4.4-13, the engine function generates the "Torque/Thrust." The output is depicted as the arrow leading out of the functional node with the output arrow labeled appropriately.

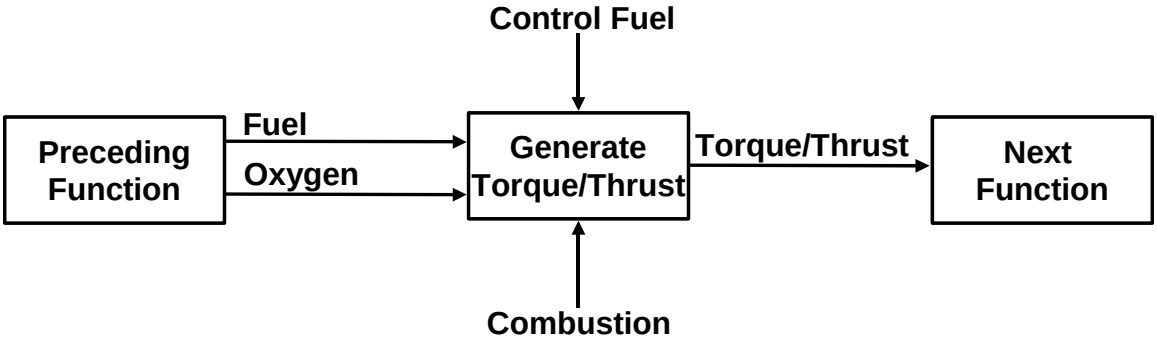


Figure 4.4-13. Input-Function-Output Relationship

NOTE

When IDEF techniques (Paragraph 4.4.3.2.2.3) are being used, controls and mechanisms may be added. Controls are elements that manage the function and

are outputs of other functions, while mechanisms are elements that enable the function to work. Controls are depicted as arrows entering the function from the top, and mechanisms are depicted as arrows entering the function from the bottom.

The functions depicted so far have been serial functions; however, many functions are parallel (i.e., they are functions that (1) independently feed the same downstream function, and/or (2) occur simultaneously). Figure 4.4-14 illustrates parallel functions.

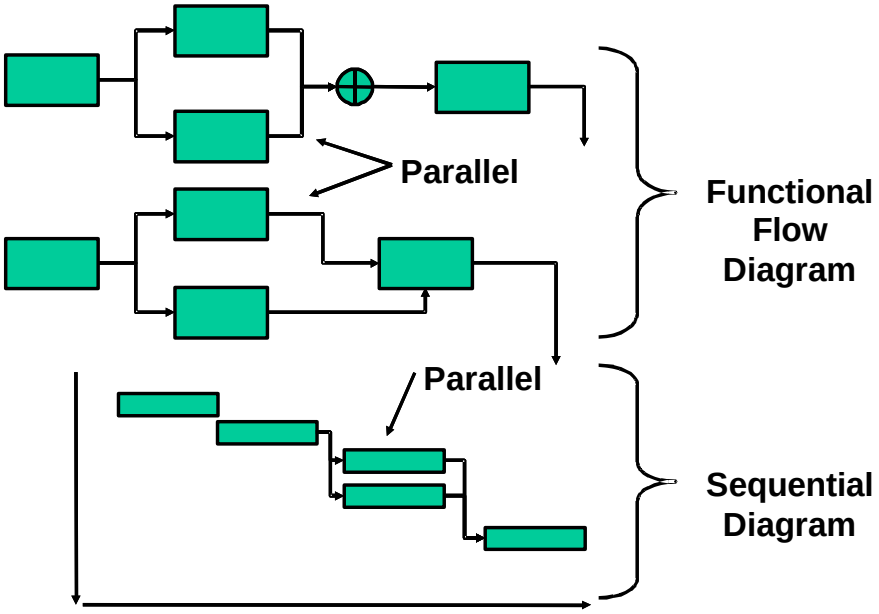


Figure 4.4-14. Parallel Functions

Figure 4.4-15 depicts a functional flow organization of the functions, in which functions are broken down into subfunctions using the techniques described in Task 2. This figure represents a simplified FFD, in which the inputs and outputs are not labeled, and the controls and mechanisms are not identified. Functional Analysis is performed to the level of detail needed to depict the functional description of the system.

Figure 4.4-15 also shows multiple functional levels; however, only the top level is complete. Each lower level shows an example expansion of one function. For example, at the second level, the top-level function F1 is expanded into its second-level functions, F1.1 through F1.6. At the third level, second-level function F1.4 is expanded. Finally, at the fourth level, function F1.4.3 is expanded. Each level indicates a different example of typical functional flow paths. Usually, only one or two levels are shown in one diagram to avoid confusion.

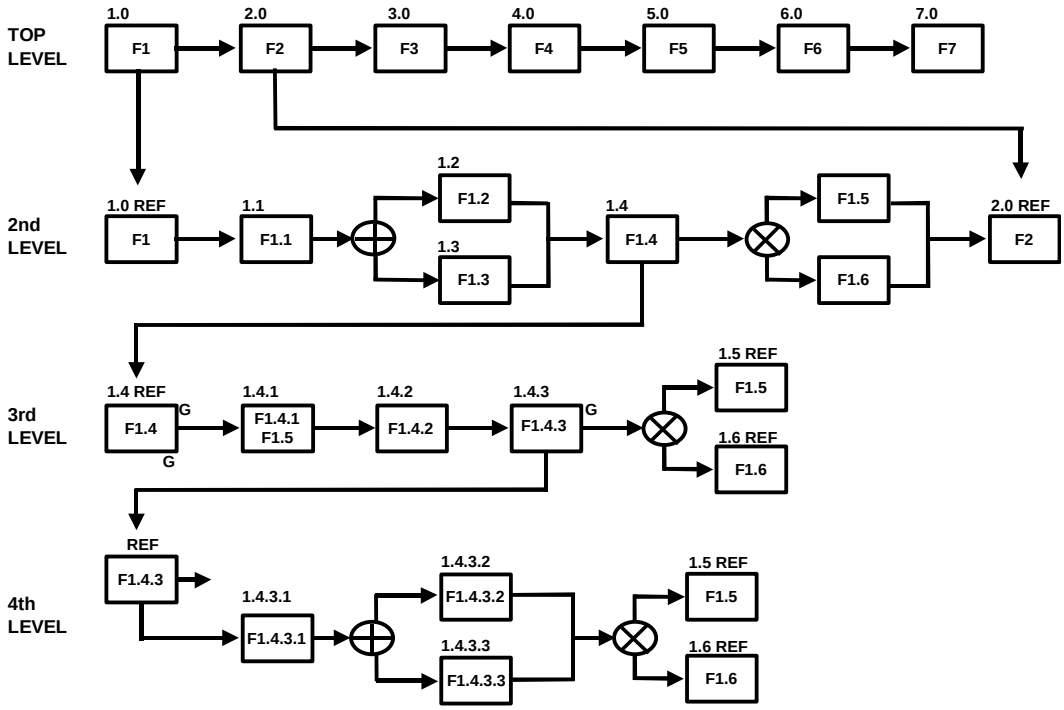


Figure 4.4-15. Generic Functional Flow Diagram Example

Adherence to the following rules promotes common understanding of FFDs:

- Number top-level functions with even integers and zero decimals (e.g., 1.0, 2.0, etc.) and cover the complete span of anticipated lifecycle functions
- Depict inputs to functions as entering from the left side and outputs as leaving from the right side
- Depict mechanisms as entering from the bottom and controls as entering from the top
- Display lower-level functions as emanating from the bottom
- Define the name of the function inside the box, replacing F1, F2, etc.
- Indicate a reference function (ref) at the beginning and end of all functional sequences, *except at the top level*
- Use an “OR” gate to indicate alternative functions; use an “AND” gate to indicate summing functions, where all functions are required (Figures 4.4-7 and 4.4-16)
- Indicate a “GO” “NO GO” sequence with an arrow leaving the right side of the function with the letter “G” for “GO” and an arrow out the bottom with “G-bar” for “NO GO”
- As is customary, when the second level or lower level is shown on a separate page, list the title of the function at the top center of the page for reference
- Typically, do not show the information flow, content of each functional step, and timing details on FFDs

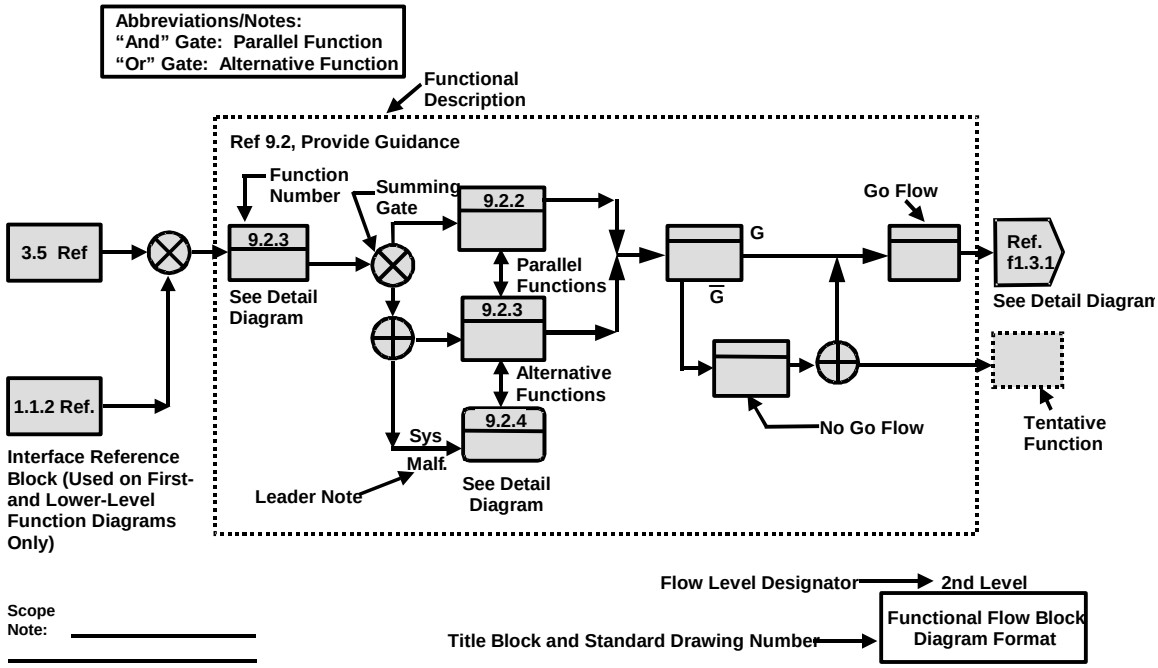


Figure 4.4-16. Functional Flow Diagram Example

4.4.3.2.2.2. Functional N^2 Diagrams

The N^2 diagram is a systematic approach to identify, define, tabulate, design, and analyze functional and physical interfaces. A functional N^2 diagram depicts the interfaces between functions in a system. The N^2 diagram is a visual matrix that requires the user to generate complete definitions of the system functional interfaces in a rigid, bidirectional, fixed framework. A basic N^2 diagram is illustrated in Figure 4.4-17.

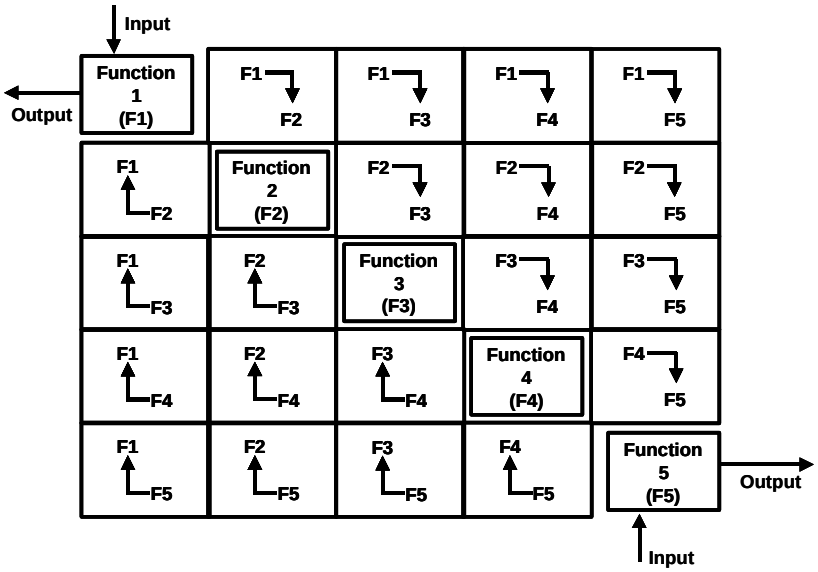


Figure 4.4-17. Functional N^2 Diagram

The N^2 diagram customarily is used to develop data interfaces, primarily in the software areas; however, it also may be used to develop other interfaces, including functional and physical interfaces. In this method, the system functions are placed on the diagonal axis; the remainder

of the squares in the N x N matrix represents the interface inputs and outputs. The presence of a blank square indicates that there is no interface between the respective system functions. Data flows in a clockwise direction between functions (i.e., the symbol F1 ↴ F2 indicates data flowing from function F1 to function F2; the symbol F2 ↥ F1 indicates the feedback). The transmitted data is defined in the appropriate squares. The diagram is complete when each function has been compared to all other functions. The N^2 diagram may be used in successively lower levels down to the component functional level.

N^2 diagrams are a valuable tool for not only identifying functional interfaces, but also for pinpointing areas where conflicts may arise between functions so that system integration proceeds smoothly and efficiently.

4.4.3.2.2.3. Integrated Definition for Function Modeling Diagrams

IDEF is a common modeling tool for conducting analysis, development, and integration of information technology systems and software engineering analysis. Whereas FFDs show the functional flow of a product, IDEF diagrams show:

- Data flow
- System control
- Flow of lifecycle processes

The U.S. Air Force originally developed IDEF for manufacturing planning. IDEF is a compound acronym that stands for Integrated Computer-Aided Manufacturing Definition. Originally called IDEF, other IDEF languages have since been developed, forcing the languages to adopt numbering system; thus, this technique is now called IDEF 0. IDEF 0 has demonstrated an ability to depict a variety of engineering, operational, manufacturing, and other types of processes at any level of detail. It provides disciplined, rigorous, and precise descriptions while promoting standardization in use and interpretation.

IDEF is a model composed of a hierarchical series of diagrams, text, and a glossary that are cross-referenced. The two primary modeling components are functions and data objects that interrelate the functions. As shown in Figure 4.4-18 (IDEF box format), the position at which the arrow attaches to a box conveys the role of the data object interface. These roles consist of:

- Input
- Mechanism
- Output
- Control

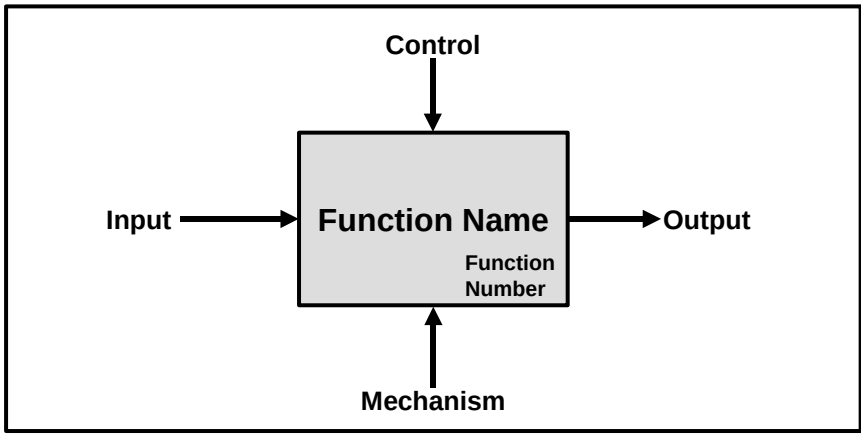


Figure 4.4-18. Integrated Definition for Function Modeling Function Diagram

The inputs, the data objects acted upon by the function or operation, enter from the left. The mechanism (additional support to perform the function) arrow attaches to the box from the bottom. The outputs of the function leave the function box from the right. The controls enter the top of the box.

The IDEF process begins with the identification of the prime function to be decomposed. This function is identified on a top-level context diagram that defines the scope of the particular IDEF analysis. Figure 4.4-19 illustrates a top-level context diagram for an information system management process. From this diagram, lower-level diagrams are generated. An example of a derived diagram—called a “child” in IDEF terminology—for a lifecycle function is shown in Figure 4.4-20.

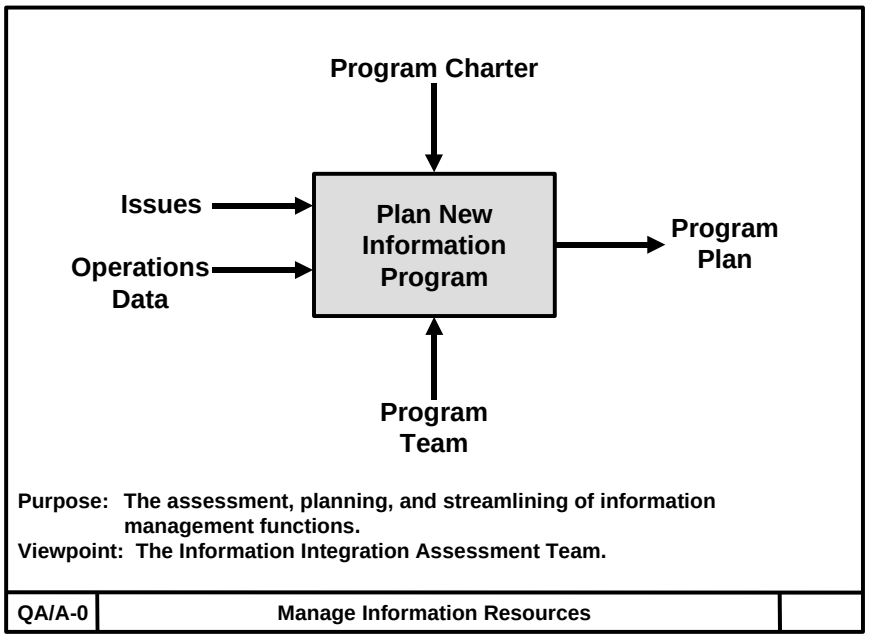


Figure 4.4-19. Top-Level Context Diagram

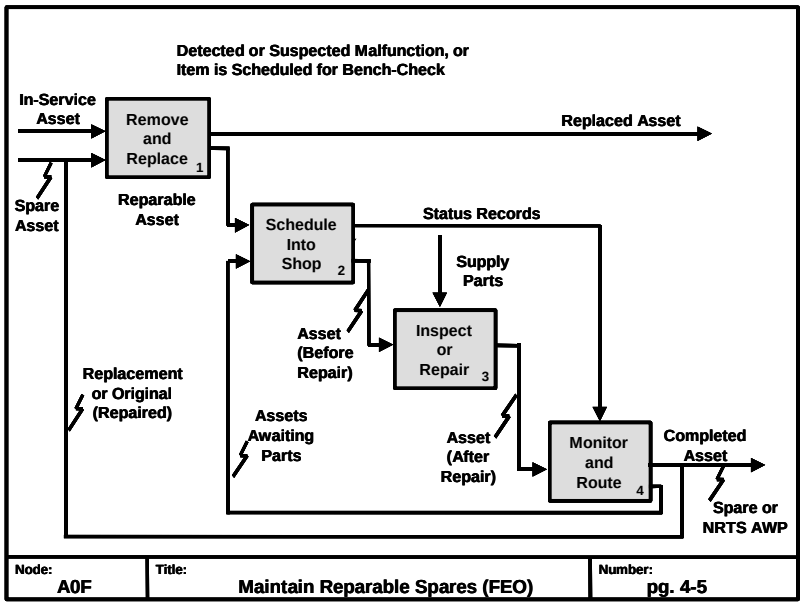


Figure 4.4-20. Derived Diagram ("Child" in Integrated Definition for Function Modeling Terminology)

Affirmative answers to the following questions signify completion of Task 2:

- Are all functions in the function list depicted?
- Are all functions written in the form verb–noun format?

- Are all functional interfaces depicted graphically?
- Does the depiction show end-to-end functional relationships?
- Are parallel and serial relationships accurately depicted?

4.4.3.3. Task 3: Decompose Higher-Level Functions Into Lower-Level Functions

In this task, higher-level functions are decomposed into subfunctions, with specificity increasing at each level of decomposition. Functional decomposition is performed using the techniques described in Tasks 1 and 2 with respect to sequence and logical diagramming or alternatively with the techniques described in "Functional Analysis Tools and Techniques" (Paragraph 4.4.5). The stepwise decomposition of a system basically is a top-down approach to problem-solving. Shown graphically in Figures 4.4-21 through 4.4-24, the decomposition is carried to a level at which the functions have been totally decomposed into basic subfunctions, and each subfunction at the lowest level is completely, simply, and uniquely defined by its Requirements. This means that functional decomposition continues as long as there is a further need to define lower-level Requirements. When the requirements development process ceases, Functional Analysis may cease.

The objective of Task 3 is to develop a hierarchy of Functional Analysis diagrams that describes the functions at all levels of the system. This hierarchy is only a portion of the Functional Architecture, which is not complete until all Requirements and other Constraints have been appropriately decomposed.

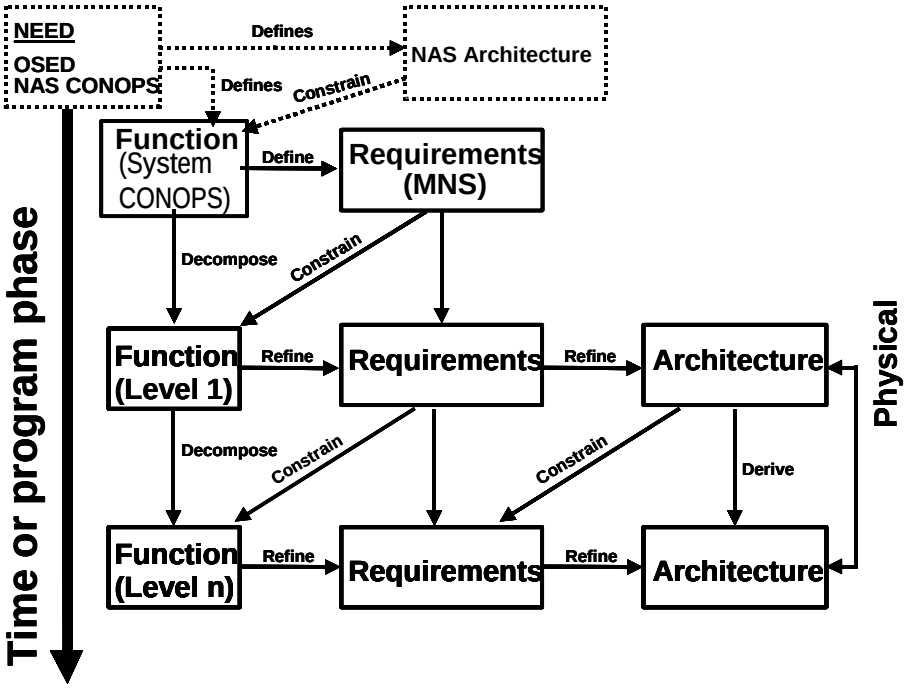


Figure 4.4-21. Decomposition of Higher-Level Functions into Lower-Level Functions

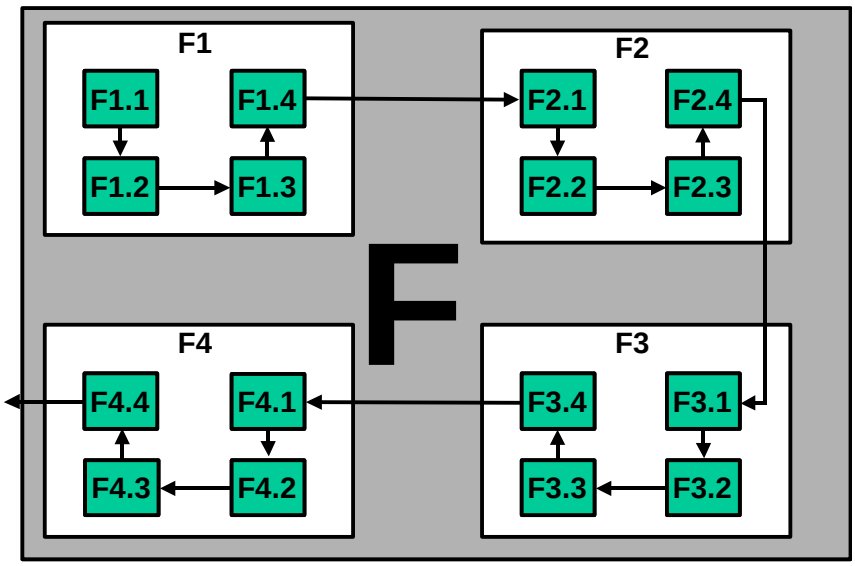


Figure 4.4-22. Another View of Decomposition of Higher-Level Functions into Lower-Level Functions

Task 3 is performed iteratively using the steps and techniques described in Tasks 1 and 2. Since higher-level functions exist for this task, the subfunctions are based on the higher-level functions developed in the previous tasks. In Figure 4.4-23, which uses the functions list from Figure 4.4-8, function F3 is decomposed into subfunctions labeled as the second level. Next, the functions in the second level are further decomposed to the third level. This process continues until all the functions are totally decomposed into basic subfunctions, and each subfunction at the lowest level is completely, simply, and uniquely defined by its Requirements. At each level, Functional Analysis feeds Requirements Management (Section 4.3) and Requirements feeds Synthesis (Section 4.5), as shown in Figure 4.4-21 and further illustrated in Figures 4.4-24 through 4.4-27.

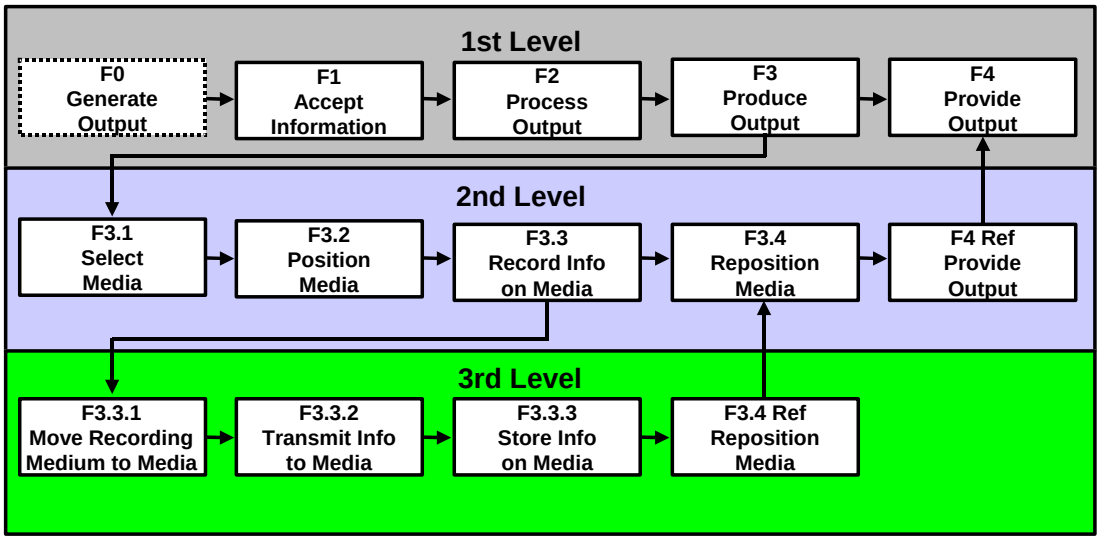


Figure 4.4-23. Higher-Level Functions Broken Down into Lower-Level Subfunctions

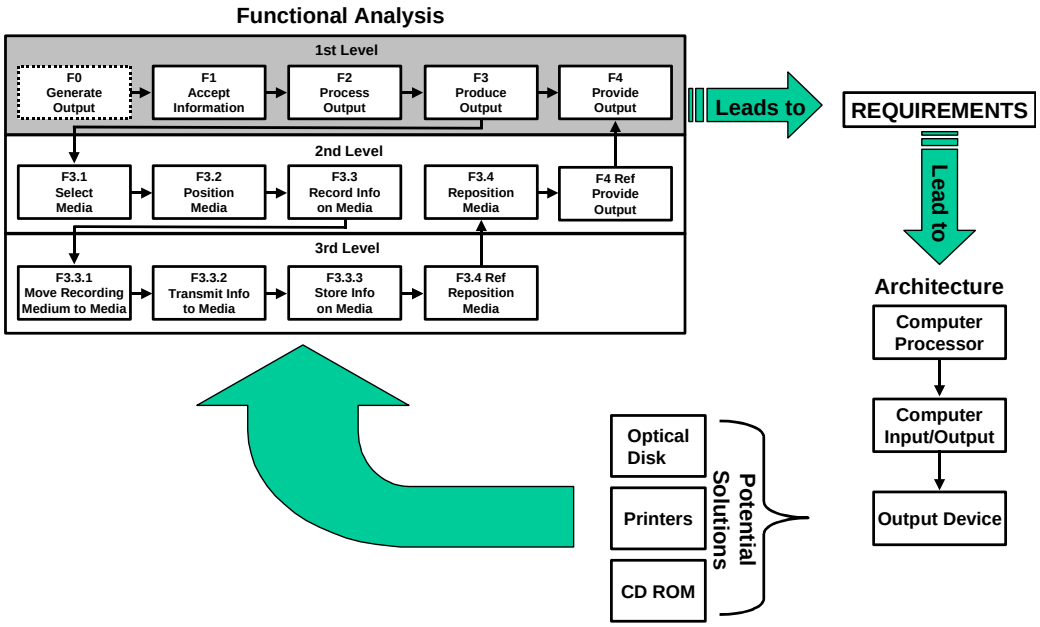


Figure 4.4-24. Functions Lead to Requirements; Requirements Lead to Physical Architectures

Requirements Management and Synthesis detail the process that turns functions into Requirements and Requirements into a Physical Architecture. It is important to note that the next Functional Analysis level is bound and framed by the Requirements and Physical Architecture refined from the preceding Requirements Management and Synthesis activities (Figure 4.4-25).

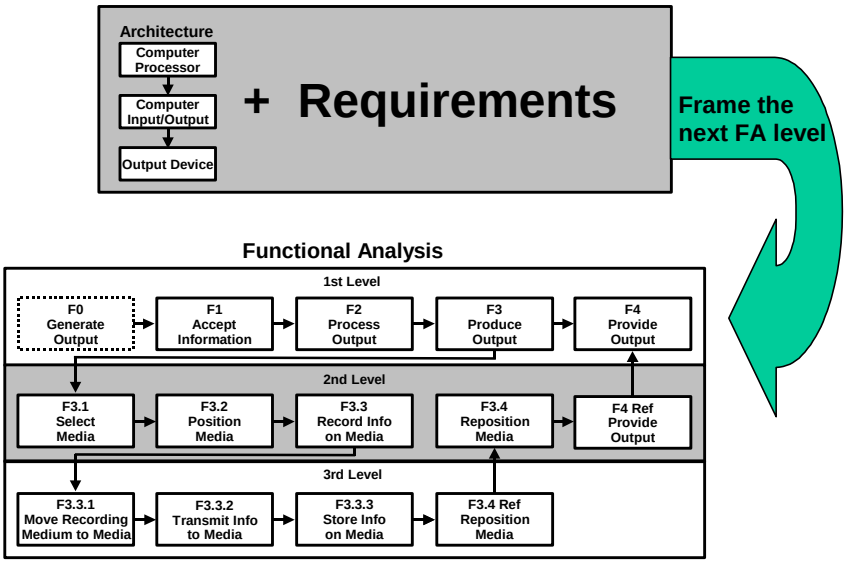


Figure 4.4-25. Requirements and Physical Architecture Frame the Next Functional Analysis Level

When this spiral process completes one rotation, the Functional Analysis process recommences (Figures 4.4-26 and 4.4-27) at the next lower level and repeats until each function is totally decomposed into its basic subfunctions, and each subfunction at the lowest level is completely, simply, and uniquely defined by its Requirements.

Affirmative answers to the following questions signify completion of Task 3:

- Has a complete set of Functional Analysis diagrams been prepared?
- Has each function been decomposed to its lowest level within program needs?
- Is each function completely, simply, and uniquely defined by its Requirements?
- Has a description of each function been developed?
- Is the requirements development complete?

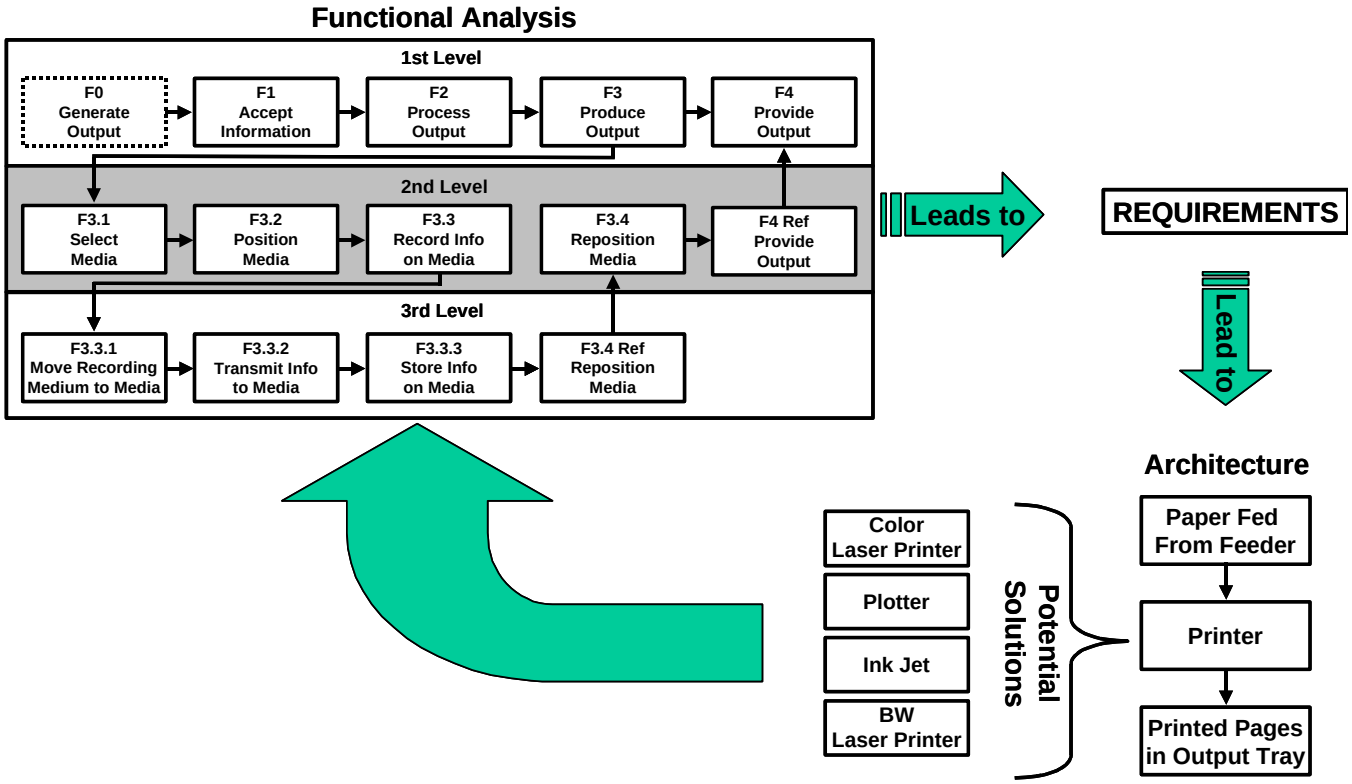


Figure 4.4-26. Repeating the Functional Analysis Process at the Next Lower Level

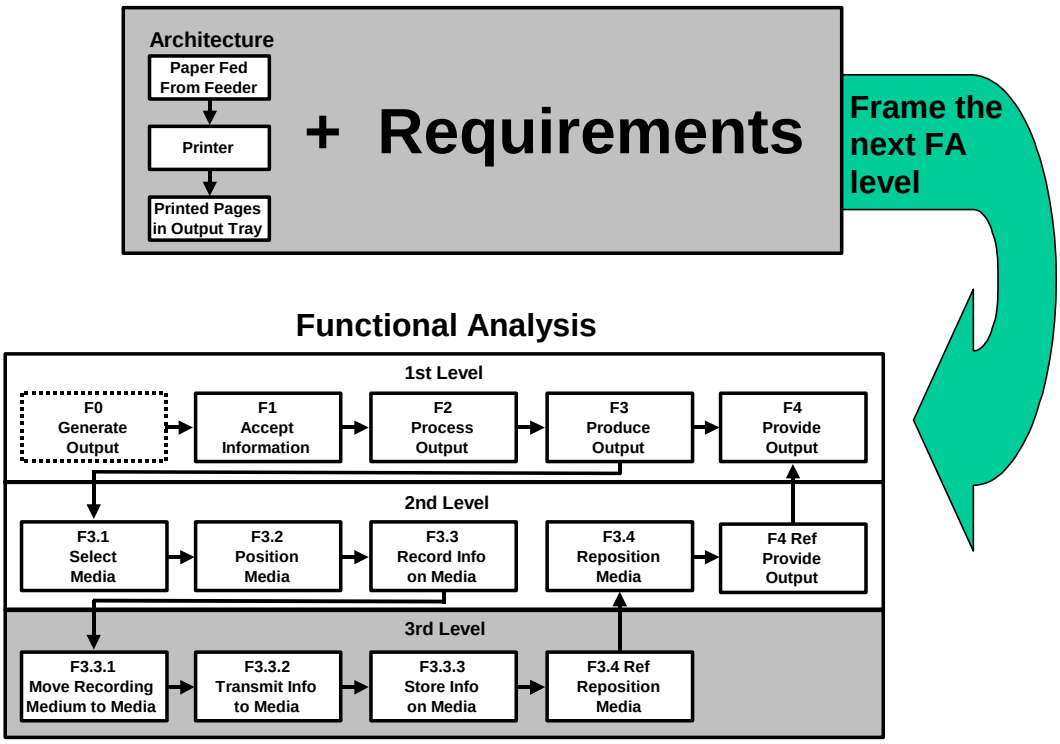


Figure 4.4-27. Preceding Requirements and Physical Architectures Continue To Frame Next Lower Level

4.4.3.4. Task 4: Evaluate Alternative Decompositions

In this task, alternative decompositions of functions (Functional Architectures) and Requirements at all levels are evaluated. These evaluations are necessary because there is no single "correct" decomposition; however, not all decompositions are of equal merit. It is necessary to evaluate alternative decompositions in order to select the decomposition best suited to the Requirements. There are other reasons to evaluate alternative decompositions. For example, as a result of Synthesis there may surface design constraints such as the desire to use commercial-off-the-shelf (COTS) or non-developmental item (NDI) components. Multiple Functional Architectures may then be produced to accommodate alternatives in accordance with various combinations of constraints. These are then compared using the Trade Studies process (Section 4.6) with the design criteria from Synthesis in order to select the Functional Architecture that most effectively meets mission objectives.

The evaluation of alternative decompositions of functions is subjective and dependent upon personal preference and taste. The purpose of Task 4 is to ensure that other methods to conduct the decomposition are evaluated. In this task, personal preference and consensus among the stakeholders become factors in the selection of the best Functional Architecture. Any selected Functional Architecture shall reflect the system's functions. However, variances in the alternative Functional Architectures may provide a competitive edge to one or more of the alternatives.

By the end of this process, the Requirements for each subfunction at the lowest levels of the Functional Architecture are allocated via the Synthesis process ("Task 3: Allocate Requirements" (Paragraph 4.3.4.3)) to hardware, software, interfaces, operations, or a

database, and then to a specific configuration item. As it is necessary to verify Requirements, the objective of Task 4 is to select those decompositions that promote straightforward Requirements that may be validated and verified. (Validation and Verification (Section 4.12) further addresses this issue.) In addition, decompositions that allow a single function to be used at several places within the hierarchy, thereby simplifying development, may be identified.

Task 4 requires "best engineering judgment," as the "goodness" of each functional decomposition is evaluated by measuring the degree to which each module displays the following attributes:

- Performs a single function
- Is a logical task
- Leads to a Requirement(s) that may be separately validated
- Has a single input point and a single output point
- Is independent within each level of the hierarchy (higher independence allows the implementation of the module independent of the other modules)

Because system design does not occur in a vacuum, it is necessary to consider opportunities to use COTS or NDI hardware and software. As a result, a subfunction that has already been implemented in a compatible form on another system may be preferred to one that has not.

The selection of a final system functional decomposition signifies completion of Task 4.

4.4.3.5. Task 5: Document Functional Analysis Baseline

The last task in the Functional Analysis process is documenting the process, including the selected Baseline as the basis for Requirements Management (Section 4.3) and Synthesis (Section 4.5). The documentation includes the outputs listed in Figure 4.4-1. At this point, any necessary revisions or changes to the functional decomposition, sequence and time lines, functional interfaces, etc., are made to ensure their completeness and consistency with one another. Also, the products of the Functional Analysis process (e.g., FFDs, functional descriptions, function interface descriptions, and time lines) are developed. These products may be documented separately or combined in a Functional Analysis Document (FAD).

Affirmative answers to the following questions signify completion of Task 5:

- Have all of the initial functions been decomposed into subfunctions?
- Do the subfunctions cover the total scope of the parent function?
- Are the functions arranged correctly with respect to the dependence of the functions?
- Have all functional interfaces been defined?
- Have any new functional interfaces between initial functions been identified that were discovered during the function decomposition process? (These may drive new system element interfaces.) If so, have the new interfaces been documented in control sheets?
- Has a Functional Analysis document been prepared to document the functional Baseline?
- Have all functional Requirements been identified and decomposed?

4.4.4. Outputs of Functional Analysis

4.4.4.1. Functional Architecture

The most common output of the Functional Analysis process is a "living" Functional Architecture document that contains a tailored combination of the following:

- Functional Architecture Baseline
- Functional interface list
- Alternative decompositions
- FFDs
- Functional time lines and sequences
- Data flow diagrams (DFD) and threads
- N^2 diagram
- Other functional descriptions

4.4.4.2. Concept of Operations

In addition to the previous list, the CONOPS may also be an output of the Functional Analysis process. A CONOPS is a user-oriented document that describes system functional characteristics for a proposed system from the user's viewpoint; it is essentially a top-level narrative Functional Analysis. It explains the existing system, current environment, users, the interaction among users and the system, and organizational impacts. The CONOPS document is written in order to communicate overall quantitative and qualitative system characteristics to the user, buyer, developer, and other organizational elements. The CONOPS aids in requirements capture and communication of need to the developing organization. Posing the need in the user's language helps to ensure that the user is able to more accurately express the problem. Subsequently, the system engineers have a better foundation upon which to begin the lower-level Functional Analyses, requirements definition, and initial design of the system.

Not all CONOPS are written as functional analysis documents. In these cases, the CONOPS would be an input to Functional Analysis rather than an output.

The following is a list of the essential elements indicative of all CONOPS:

- Description of the current system or situation
- Insight into the user's environment
- Description of the functions to be performed
- Description of the needs that motivate development of a new system or modification of an existing system
- Insight into the new Requirements
- Opportunity for the developer to recommend alternative solutions
- Description of the operational features of the proposed system
- User's view of the Requirements

At minimum, there are two levels of CONOPS: (1) NAS Level and (2) System Level CONOPS.

A NAS Level CONOPS is performed at the highest level of the Functional Analysis process and is a narrative expression of the user's desired change with some performance indicators. It is a high-level document that indicates, from the user's perspective, the desired end-state for the respective system in the NAS.

A System Level CONOPS is an extension of a NAS Level CONOPS with an emphasis on a particular system. It is more detailed and substantial, but it is still an expression of the user's needs with respect to a specific system within the NAS. It is recommended that a System Level CONOPS, in particular, have the following characteristics:

- Written in the user's language using the user's preferred format
- Written in narrative prose (in contrast to a technical requirements specification)
- Organized so as to tell a story and accompanied by visual forms (diagrams, illustrations, graphs) and storyboards whenever possible
- Provide a bridge between the user's needs and the developer's technical requirements documents
- Describe the user's general system goals, mission, function, and components
- Evoke the user's views and expectations
- Provide an outlet for the user's preferences
- Provide a place to document vague and unmeasurable Requirements (i.e., the user is able to state his/her desire for fast response or reliable operation); these desires are quantified during the process of developing the requirements specifications and during the flowdown of Requirements to the Physical Architecture
- Make the user feel in control

Figure 4.4-28 serves as a guideline for System Level CONOPS content.

1. Introduction
   a. System overview
   b. Definition of terms
   c. References
2. Operational need
   a. Operational problems solved
   b. Opportunities created
   c. Existing operations/functions that require change
   d. Organization constraints
   e. Actors that will interact with system
3. System justification
   a. Capability shortfalls of current system
   b. Potential benefits of new system
   c. Identified priorities of new features
      i. Critical
      ii. Essential
      iii. Routine
   d. Assumptions and constraints
4. OSED (include if available)
5. Business impact
   a. Impact on current business operations
   b. Changes to organization

Figure 4.4-28. Content Format for a System Level Concept of Operations

4.4.4.2.1. Operational Services and Environmental Description

The OSED is a comprehensive, holistic Communications, Navigation, and Surveillance/Air Traffic Management system description. It describes the services, environment, functions, and mechanizations that form a system's characteristics.

"What Is a System?" A system (as defined in Section 2.1) is:

> *An integrated set of constituent pieces that are combined in an operational or support environment to accomplish a defined objective. These pieces include people, hardware, software, firmware, information, procedures, facilities, services, and other support facets.*

The 5M Model, illustrated in Figure 4.4-29, graphically represents this system view. Useful system descriptions exhibit two essential characteristics: correctness and completeness. Correctness in a system description means that the description accurately reflects the system with an absence of ambiguity or error in its attributes. Completeness means that no attributes have been omitted and that the attributes stated are essential and appropriate to the level of

detail called for in the description. System descriptions that include all 5M Model elements achieve these two characteristics.

The 5M Model states that there are five basic integrated elements in any system. These elements are (1) the functions that the system needs to perform; (2) the human operators and maintainers; (3) the equipment used in the system, composed of the hardware and software; (4) the procedures and policies that govern the system's behavior; and (5) the environment in which it is operated and maintained.

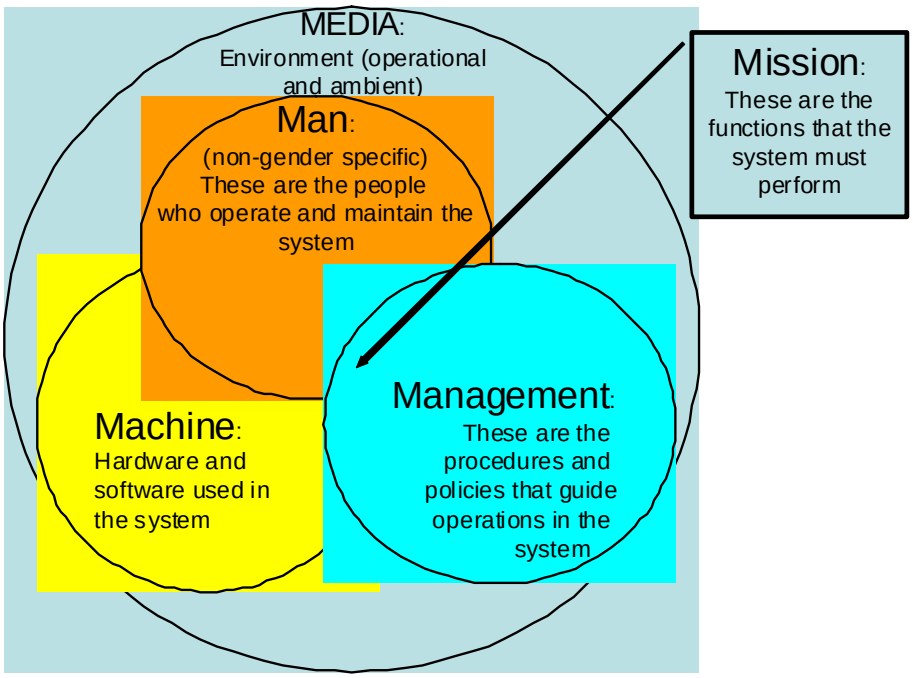


Figure 4.4-29. 5M Model

RTCA/DO-264, Annex C, contains detailed guidelines for the OSED for use as a starting point. For the purposes of SE in the FAA, these guidelines were tailored. It is recommended that an OSED have, at minimum, the information in Figure 4.4-30.

1. Operation Service Description: This section of the OSED is used to summarily describe the air traffic services and operational context of the new capability. This section describes the new air traffic service from an operator's viewpoint.
2. Functional description or architecture: This section describes the functions and Functional Architecture in accordance with Functional Analysis.
3. Procedures: This section describes the existing and new procedures and policies that govern the system's operation or maintenance and includes:
   a. Operational requirements and regulations, including separation minima
   b. Deployment requirements
   c. Operational scenarios
4. Human elements of the system: This section describes the operators and maintainers of the system, including information regarding:
   a. Anthropometric requirements
   b. Training requirements
   c. Specific skill set requirements
   d. Human-system integration requirements
5. Equipment and software: This section describes any known hardware and software that is required for system operation. This section, in particular, may not be appropriate in the early stages of development.
6. Environment description: This section is an expression of the various conditions in which the system is operated, including:
   a. Operational: The operational environment includes factors, such as traffic density and flow, flight phases, traffic complexity, route configuration, type of control, use of visual or instrument flight rules, etc.
   b. Ambient: The ambient conditions refer to visual and instrument meteorological conditions, altitudes, terrain elevations, and physical conditions, such as electromagnetic environment effects, precipitation, icing, etc.
7. Nonfunctional requirements: This section describes any other Requirements that are not covered in the other sections and includes, but is not limited to, the following:
   a. Time constraints
   b. Information exchanges
   c. Exception handling

Figure 4.4-30. Guidelines for an Operational Services and Environmental Description

4.4.4.3. Concerns/Issues

Appendix D contains guidance on concerns/issues as a product of Functional Analysis.

4.4.4.4. Tools/Analysis Requirements

Tools/Analysis Requirements for performing Functional Analysis throughout the remainder of the program's lifecycle needs to be provided to the Integrity of Analyses process (Section 4.9).

4.4.4.5. Planning Criteria

Any Planning Criteria necessary for performing Functional Analysis throughout the remainder of the program's lifecycle needs to be provided to the Integrated Technical Planning process (Section 4.2).

4.4.4.6. Constraints

Constraints on trade studies that surface as a result of performing Functional Analysis are to be provided to the Trade Studies process (Section 4.6).

4.4.5. Functional Analysis Tools and Techniques

Contractors working for the FAA may choose to employ structured analysis models rather than the FFDs preferred by FAA. To facilitate communication between FAA system engineers and these contractors, it is recommended that FAA system engineers understand these models in order to engage in technical conversations with contractors who employ them.

4.4.5.1. Tools

Analysis tools may include but are not limited to general SE and design/simulation aids. Because requirements represent the basic thread through SE, Functional Analysis data shall be interoperable with requirements definition information. The results of the Functional Analysis process shall be captured in order to modify system requirements and other derived products.

The selection of tools shall ensure that the data is transportable and able to be integrated with other related Functional Analysis results. A list of tools that may be used to perform Functional Analysis is available on the International Council on System Engineering Web site (www.incose.org).

4.4.5.2. Techniques

In addition to the techniques described in "Task 2: Organize Functions Into Logical Relationships" (Paragraph 4.4.3.2), this paragraph covers several alternative approaches that FAA system engineers may come in contact with from organizations that apply techniques other than FFDs. These techniques are provided in order to cover two issues: (1) cases in which time line sequence diagrams and FFDs do not adequately address FAA needs; and (2) cases in which contractors use these techniques to perform Functional Analysis, and the FAA engineers need to understand what they mean. The alternatives include the following:

- Hierarchical functional block diagramming
- Modern structured analysis
- Models and simulation
- Thread analysis
- Object-oriented analysis (OOA)

4.4.5.2.1. Hierarchical Functional Block Diagramming

By listing the functions for an expansion of one block on a higher-tier block diagram, the engineer is actually engaging in function outlining, which is equivalent to hierarchical block diagramming. Rather than building sequences of functions in FFDs, the engineer may build an indentured list or hierarchy of functions where, in order to accomplish a particular function, it is necessary to complete the immediate lower-tier functions first.

Generally, this process is easier to follow than a sequence-oriented model. Thus, the question arises: Why build a sequence- or flow-oriented diagram when the goal is a hierarchical physical architecture? It is easier for system engineers to move from a hierarchical functional diagram to a hierarchical architecture diagram than from a sequence-oriented functional diagram to a hierarchical physical architecture diagram. However, therein lies the problem. Engineers employing hierarchical functional diagrams often define a functional architecture based on the last physical architecture they worked on, which generally causes a one-to-one correspondence between their functional and physical architectures. The danger in this approach is the potential for the engineer to fail to consider all of the alternative implementations of the needed functionality and, subsequently, miss opportunities to take advantage of new technology. It is more difficult to move from a sequence-oriented functional model to a hierarchical physical architecture diagram; however, that difficulty encourages a more comprehensive examination of methods to implement exposed functionality.

4.4.5.2.2. Modern Structured Analysis

Modern structured analysis offers a more free-form analytical environment than the block-oriented models. The modern structured analysis model is constructed using DFDs that feature bubbles rather than blocks, a data dictionary (DD), and process specifications (p-spec).

4.4.5.2.2.1. Data/Control Flow Diagrams and Context Diagrams

Data/control flow diagrams (D/CFD) graphically model the processes that transform data/control in a system. These diagrams model the system's work as a network of activities that accept and produce data/control messages. Alternatively, they are also used to model the system's network of activities as work accomplished on a processor. Each successive level of D/CFDs represents the internal model of the transformations contained in the previous level of D/CFDs.

The context DFD—the ultimate DFD—consists of one bubble depicting the system connected to terminators drawn as blocks and named to identify the external inputs and outputs of the system. The bubble of the context DFD is decomposed to expose more detailed needs of the system. The lower-tier DFDs, of which there may be hundreds or even thousands for a complex problem, consist of only four objects:

- Bubbles (drawn as simple circles) identify needed computer processing. Bubbles have functionality that may be further decomposed in a lower-tier DFD or defined in a p-spec. P-specs are written only for the lowest-tier bubbles in the diagrams. Needed product behavior may be explored and illustrated by structured English, tables, or state diagrams within the p-spec.
- Directed line segments (arrows) show the flow of data between the bubble and temporary data stores.
- Temporary data stores (represented by a pair of parallel lines) identify a need to temporarily store data created in a bubble or applied from outside the system.
- Data sources and external inputs are represented by rectangles.

Figure 4.4-31 illustrates the application of DFDs and the top-down decomposition process used to produce a system model.

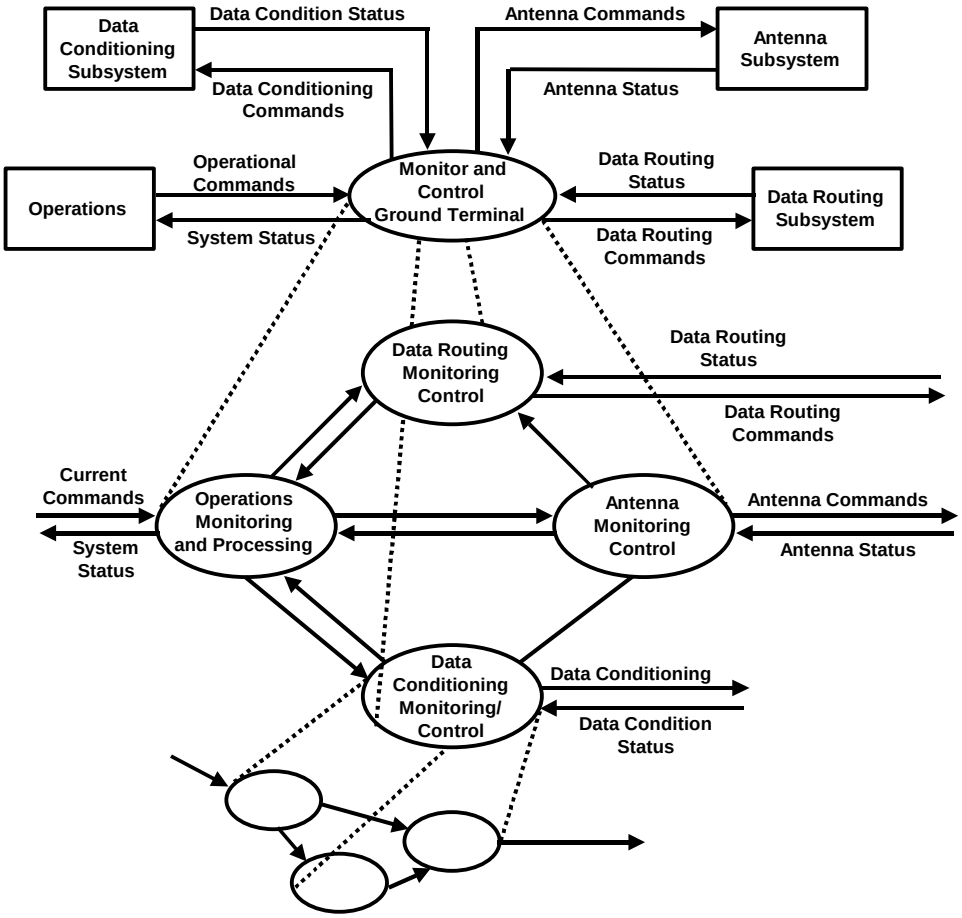


Figure 4.4-31. Data Flow Diagram

Building a system model by interviewing users usually begins with the processes defined at the primitive level and data defined in forms and manual files. Figure 4.4-32 illustrates part of a model built from user interviews. After building the model, the next task is to organize the data flows logically and then collapse the lower-level functions into higher-level functions. Figure 4.4-33 illustrates a logically organized version of the model built from interviews.

The DFD function titles, when wrapped in “shall statements,” become requirements statements.

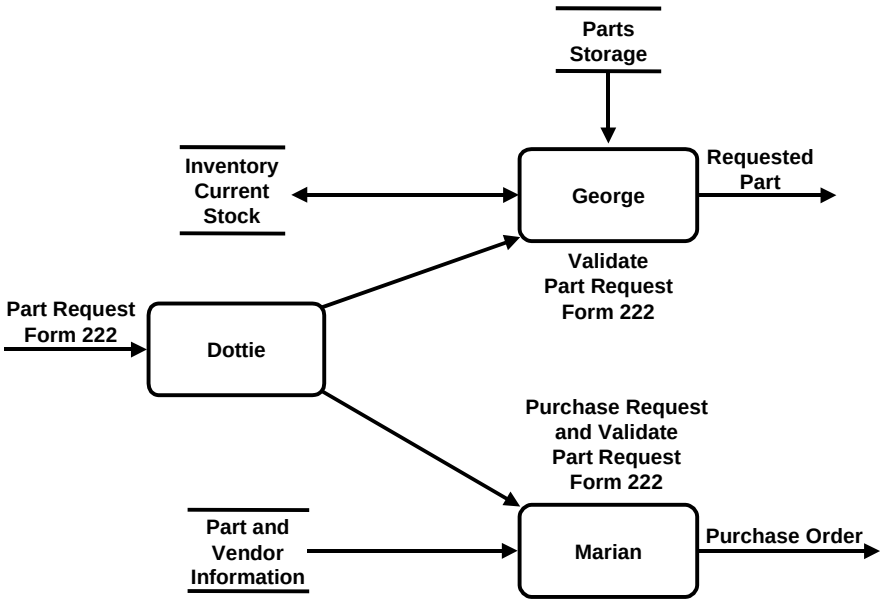


Figure 4.4-32. Primitive Data Flow from User Interviews

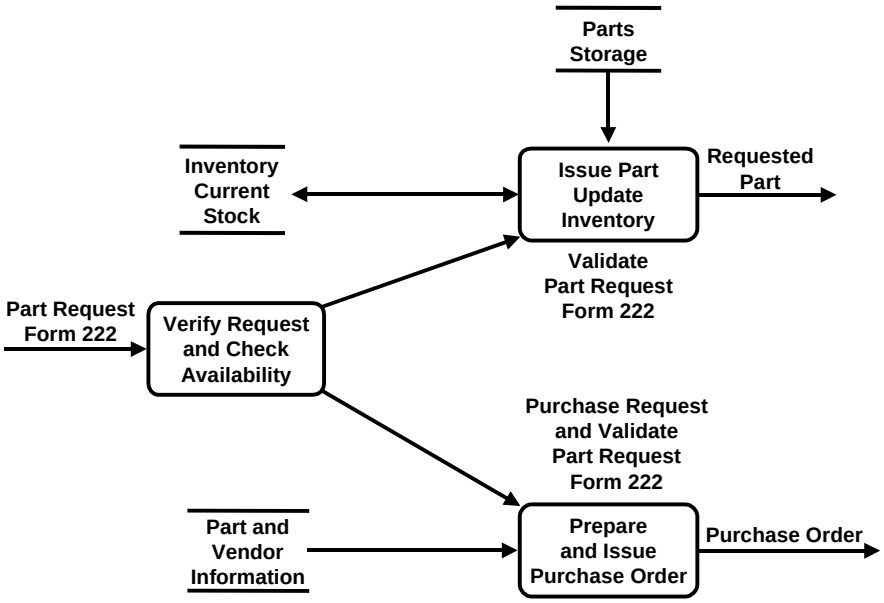


Figure 4.4-33. Logically Organized Data Flow

4.4.5.2.2.2. Data Dictionary

DDs are documents that provide a standard set of definitions of data flows, data elements, files, databases, and processes for a specific level of system decomposition. These documents aid communication across the development organization. The DD also defines data items

mentioned in the transformation specifications. For every data line and every data store illustrated on every DFD, a unique line in a DD that clearly defines the data item is required.

A DD defines the content of each data item, table, and file in the system. P-specs describe the capabilities that each process is required to provide. The specifications may be written in structured English and/or in the form of decision tables and decision trees. State diagrams graphically depict the logical states that the system may assume. Associated process descriptions specify the conditions that require fulfillment for the system to transition from one logical state to another.

When working from a set of customer documents, a top-down approach is used to decompose customer-defined processes. As each process is decomposed, so is the data. Only the data that a process requires to produce the specified outputs is documented in a DD. Functional decomposition usually proceeds to a level where the requirements for each lower-level function are stated on one page or less (i.e., the primitive level). Interaction with the customer may be necessary to decompose and define data elements at lower levels.

4.4.5.2.2.3. Process Specifications

For every lowest-tier bubble in the DFD analysis, it is necessary to write a p-spec that contains the p-spec for the bubble. This specification may be phrased in normal English text, structured English that follows a particular computer tool syntax, tables, state diagrams, or any combination of these constructs. P-specs, at the primitive level, when wrapped with “shalls” subsequently become requirements statements.

4.4.5.2.2.4. State Transition Diagram

After the DFDs and DD are complete, the next step is to identify the various states the system may assume and to produce diagrams depicting how the system transitions between states. It is suggested that a top-down approach, such as a state transition diagram (STD), be used to identify various states of the system, working down through the subsystem.

An STD is a graphical model of the dynamic behavior of a system—it is a sequential state machine that graphically models the time-dependent behavior of a control transformation. Figures 4.4-34 and 4.4-35 are examples of STDs for system and subsystem functions. Descriptions of how the system transitions from one state to another become “shall statements” in the requirements document.

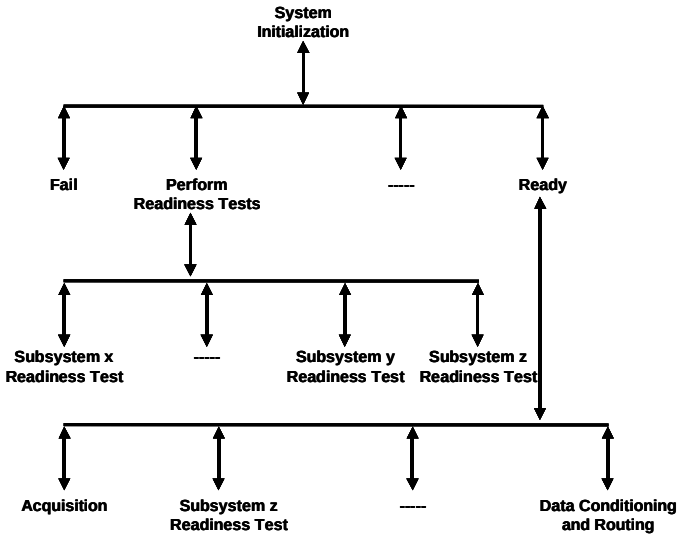


Figure 4.4-34. State Transition Diagram for System Functions

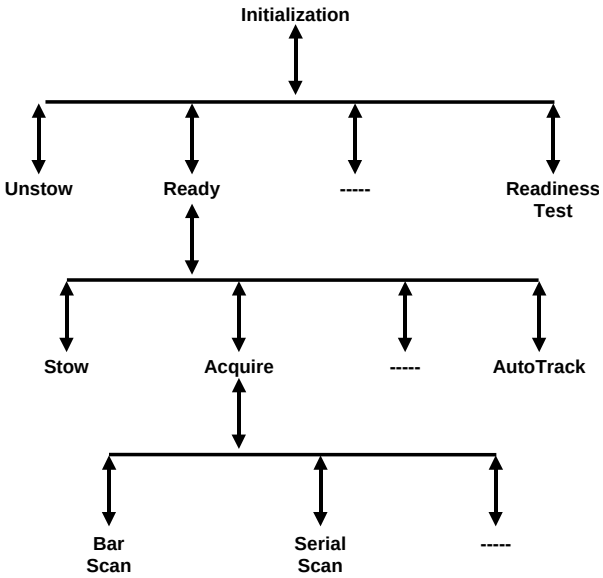


Figure 4.4-35. State Transition Diagram for Subsystem Functions

4.4.5.2.3. Hatley-Pirbhai Extension to Modern Structured Analysis

Because the traditional modern structured analysis process has proven inadequate for modeling real-time systems, the Hatley-Pirbhai Extension to modern structured analysis was created. This model extended the requirements model of modern structured analysis process to include an additional construct called a control flow diagram (CFD)—an augmentation of the corresponding DFD that has control as well as data processing functions. The CFD has the same bubbles as its companion DFD. The data lines that join the bubbles on the DFD are related only to the data associated with processing needs. The data lines shown on the CFD are only those data items related to control functions. This model may be considered a special

case of modern structured analysis and is particularly useful when the problem entails difficult control problems.

4.4.5.2.4. Models and Simulation

Models are abstractions of relevant characteristics of a system that are used to understand, communicate, design, and evaluate (including simulation) the system. They are used before the system is built and while it is being tested or in service. A good model has essential properties in common with the system/situations it represents. The nature of the properties it represents determines the uses for the model. A model may be functional, physical, and/or mathematical.

For complex system problems, it is necessary to analyze and design a number of different systems, each of which is represented by a specific model. The different models permit individual investigation of different aspects. These different modeling perspectives are incrementally constructed and integrated in a unified description (system model) to maintain a holistic system perspective from which the emergent properties of the system are deduced and verified.

The system model emphasizes the interactions of the objects in the context of the system, including the objects in the environment. Object semantics represent the components of a system, their interconnections, and their interactions when they are responding to the stimulus from the objects in the environment. These object semantics are partitioned into a static as well as dynamic modeling representation that describes the system's structure and behavior, respectively.

In this sense, the models embody the decisions made over the different steps of the Lifecycle Engineering process (Section 4.13). The models are developed as part of the decisionmaking process and support the evolution of the system design process as well as the iterative nature of the engineering in an environment where changes and enhancements to the models are managed in a controlled manner.

4.4.5.2.5. Thread Analysis

One major challenge to Functional Analysis is the development of software that implements the desired behavior of the system. Because system behavior is primarily implemented in software, a critical issue in system development is "how system engineers interact with the software engineers to ensure that the software requirements are necessary, sufficient, and understandable." This problem is addressed at the practitioner level, and experience has shown that the approach of passing paper specifications between systems and software developers does not yield satisfactory results.

Stimulus-condition-response threads are an excellent way to control the software development process, including translation from system to software requirements, design verification, review of software test plans, and integration of software and system testing. The threads enumerate the number of stimulus-condition-response capabilities to be tested. Threads also tie to performance requirements. Experience in the past 20 years on a variety of thread versions shows that such approaches are both feasible and effective.

4.4.5.2.5.1. The Use of Threads

System and software engineers shall work together to identify the system-level threads and the subset of the threads that the computer system supports. In this context, a thread consists of a system input, system output, description of the transformations to be performed, and conditions

under which the transformations hopefully occur. Such threads may be represented textually or graphically in a variety of ways, some of which are supported by tools. The following guidelines apply to the use of threads:

- The threads satisfy the need for efficient communication between system and software developers
- The identification of a thread from input to output allows the identification of the subthread to be allocated to the processing subsystem and, hence, software
- The description of stimulus-condition-response threads eliminates the ambiguities found in current specifications
- The description of threads is inherently understandable, particularly if provided in some graphical format
- The use of such threads aids in evaluating the impact of proposed changes

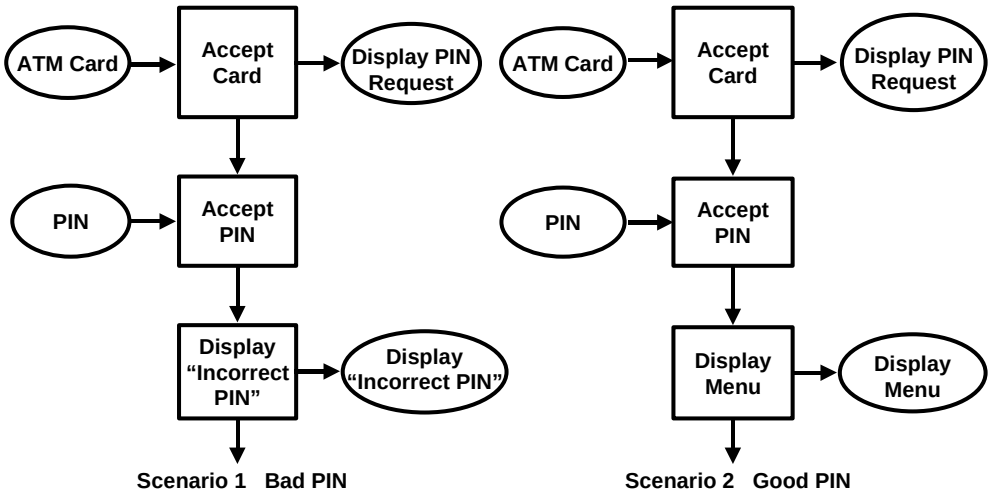
In the following steps, the development of software requirements is evolutionary, starting with allocation of processing requirements to a processing system and ending with publication and review of the software requirements.

4.4.5.2.5.2. Step 1: Deriving the System-Level Threads for Embedded Systems

No matter how the system description is developed, even if it is no more than the identification of system functions for different modes of operation, system inputs and outputs shall be identified in order to anchor the specification to reality. This process starts with the initial scenarios that describe the system's intended operations, which may be rewritten into the form of stimulus-condition-response threads.

To illustrate, consider the bank automated teller machine (ATM) system, which, by processing ATM cards and personal identification numbers (PIN), enables customers to perform banking transactions. Figure 4.4-36 presents two top-level scenarios that describe the top-level behavior of the ATM system when presented with an ATM card and a PIN. The two scenarios are PIN is accepted and PIN is rejected. From the scenarios or the integrated behavior, the stimulus-condition-response threads are identified. This set of threads may be specified in a number of notations. Figure 4.4-37 presents the stimulus-condition-response threads in a functional format. Note that the conditions for each of the threads are to avoid ambiguity. These conditions are a combination of two factors:

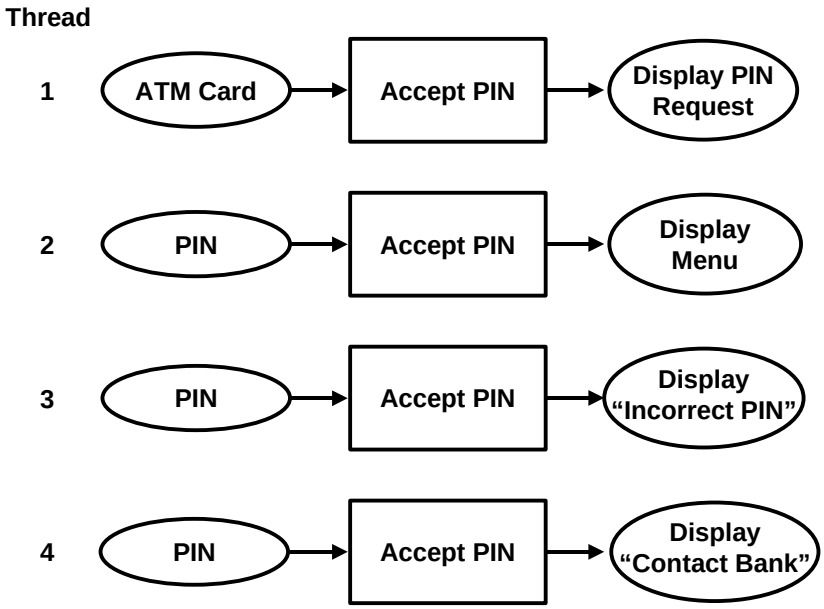
- The mode of the system, which determines which kind of input is expected
- The combination of values of the system state information and the contents of the input



Scenarios

Figure 4.4-36. Top-Level Scenarios in Thread Analysis

Thus, a correct PIN yields a menu, while an incorrect PIN results either in a message to "try again" or the machine "swallowing" the card, depending on the mode of the system. These conditions require that a thread be associated with the conditions in order to make them testable. To show the conditions explicitly, the "Accept PIN" function is decomposed to show its input-output behavior under different conditions.



Sample ATM Threads

Figure 4.4-37. Stimulus-Condition-Response Threads

4.4.5.2.5.3. Step 2: Decomposing the Threads to the Subsystem

It is necessary to decompose functions to the level where functions are uniquely identified by their requirements. This process is illustrated in Figures 4.4-36 through 4.4-40. In Figure 4.4-36, the top-level scenarios are defined; in Figure 4.4-37, examples of stimulus-condition-response threads are provided; in Figure 4.4-38, stimulus-condition-response threads are defined with their conditions; in Figure 4.4-39, the threads are defined in condition format; and in Figure 4.4-40, the system-level function “Accept PIN” is decomposed into functions to read the card (allocated to a card reader) and the functions and conditions allocated to the computer. Usually, most or all of the conditions are allocated to the computer system, with mechanical functions allocated to the other less intelligent components. Hence, most of the system threads yield a thread, with conditions, allocated to the computer subsystem, of which the majority is then allocated to the computer software with the software driving the computer hardware requirements. Thus, there is a direct traceable relationship between the system level, computer system level, and software level of requirements.

Figures 4.4-38 through 4.4-40 identify the difference between the system and computer system threads. The system uses a card reader component to read the card, a terminal component to accept push button inputs from customers, and a processor component to provide the intelligence to process the requests. Note that this process results in the requirement for the computer system to direct its threads to translate “card info” and “PIN info” to various output displays.

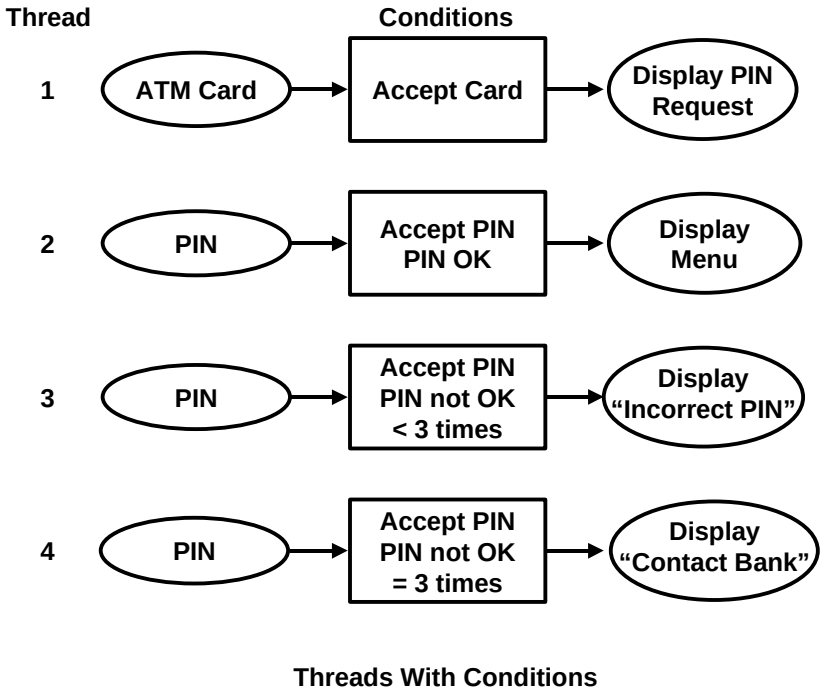


Figure 4.4-38. Threads Identified With Conditions

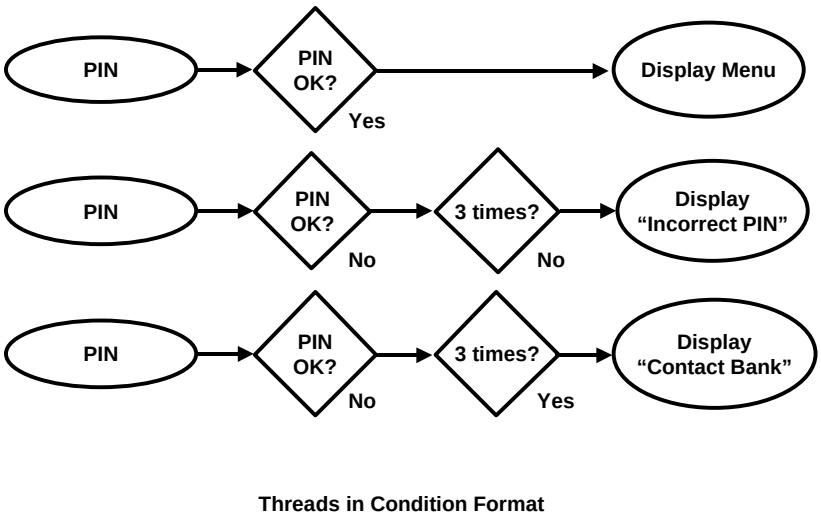


Figure 4.4-39. Threads in Condition Format

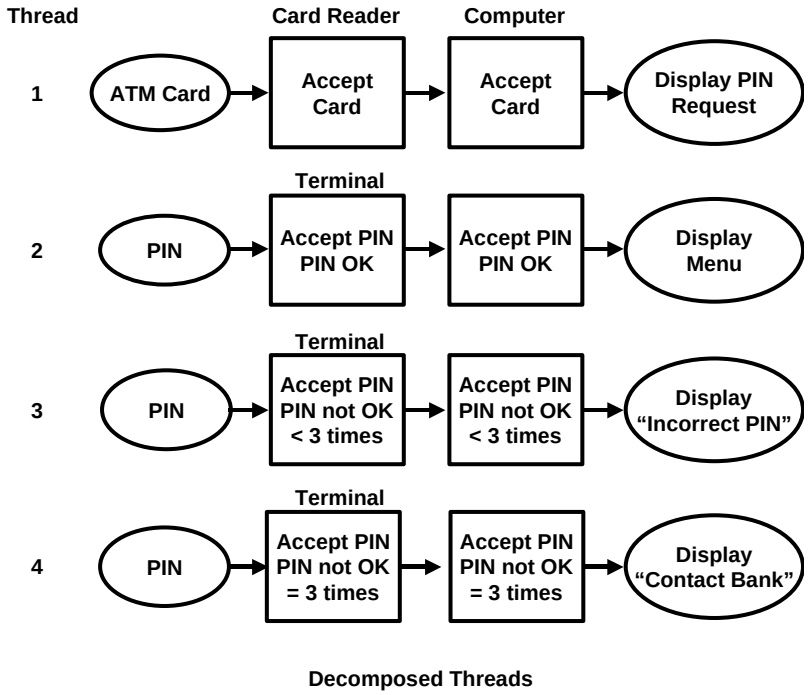


Figure 4.4-40. System-Level Functions Decomposed

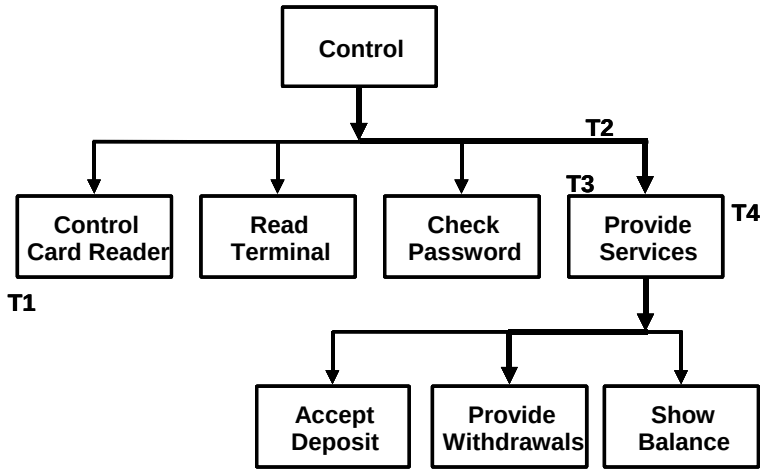
4.4.5.2.5.4. Step 3: Reviewing the Requirements and Design

Irrespective of the requirements format, computer system-level threads need to be traceable through the document. If a thread is untraceable, it signifies an omission in the requirements. If additional threads are identified that do not deal with interface designs or computer system-level fault detection/recovery, such threads may represent unnecessary processing; and, if so, it is

necessary to omit them. To illustrate, Figure 4.4-41 presents a simple software design in which a top-level program control calls lower-level units of code to execute operations.

Threads 1 through 4 are traceable through this design, thus validating it. The same approach works when an object-oriented design presents a number of objects implemented as independent software processes. When software design occurs that divides the overall software into computer software configuration items (CSCI), computer software components (CSC), and computer software units (CSU), the above process of decomposing and allocating the system-level threads into the components is repeated for each level of component. Again, if a thread is untraceable, it signifies an omission in the design. The system engineer traces the allocated system requirements to the software requirements review, which is followed by the CSCIs, CSCs, and CSUs for the software preliminary and critical design reviews.

If the software designers trace the computer system to software design threads as part of the requirements satisfaction demonstration, then the system engineer need only verify the completeness of the traceability. Tools strengthen the reliability of such a traceability evaluation. If the software designers do not perform this activity, then it is recommended that a joint team of system and software engineers perform the tracing to verify the design in preparation for the design reviews. In any event, the software-level threads shall be identified in order to provide systematic test planning.



Mapping S/W Threads onto a S/W Design

Figure 4.4-41. Tracing the Threads

4.4.5.2.5.5. Step 4: Tracing the Threads to the Test Plans

It is recommended that the collection of threads be exercised by the collection of tests outlined in the test plan—at the software level, computer system level, and the system level. This collection may be represented by a database and displayed in a cross-referenced matrix showing the relationship of system to software thread, software thread to software design threads, and threads to test cases at the various levels of integration, enabling the tools to ensure that every level of thread is tested at some point.

It is strongly recommended that the software threads be used to drive the test planning process using the concept of builds of software. For a system test, other components are added, and the system test threads are tested. For the ATM example, the difference is that in the software

only test, the software receives information in the format expected from the card reader; in the system test, the card reader component itself is used as the source of the data when an ATM card is the input.

This same approach is also used to construct the system-level test plans in a way that exploits the early availability of computer software that provides user-oriented capabilities. Thus, an early build of software may be integrated with a card reader to perform a test of Thread 1 through the system before the remainder of the software is developed. If the card reader is not available until later in the test cycle, then other threads may be tested first.

4.4.5.2.5.6. Notation

Several kinds of notations may be used for tracking the threads, but these notations usually fall under requirements- and design-oriented notations. Requirements-oriented notations describe the inputs, conditions, and outputs, while the design-oriented notations describe the threads with respect to the major design elements. Because both eventually describe the same stimulus-condition-response information, their use is essentially equivalent (though the design-oriented notation is more useful for actually defining the builds of software).

4.4.5.2.5.7. Conclusion

System engineers need to take the lead in constructing a sufficient process for system and software engineers to communicate, as it is the responsibility of the communicator to communicate in a language that the recipient understands. It is not feasible for system engineers to wait for software requirements methodologies to stabilize and accomplish this objective because software requirements and design techniques show no signs of stabilizing. The problem needs to be addressed within the existing context of multiple software requirements languages.

4.4.5.2.6. Object-Oriented Analysis

4.4.5.2.6.1. Early Versions

Early models advanced by Yourdon (2000) focused on objects that encapsulated computer processing and data, thus ending the separate analysis of these two previously inseparable facets of any computer software entity and, thereby, providing a tremendous improvement in software analysis. The model encouraged problem space entry using objects that represented the physical entities in the problem and solution space. Functionality and behavior of the problem space was explored based on these objects; therefore, it was not possible to follow the concept of form follows function when applying it. Early OOA models may be effective in analyzing systems with heavy precedence but problematic when exploring unprecedented problems.

Most authors who supported early OOA encouraged identification of objects that reflected elements of the problem space, that these objects be linked and organized into major subject areas, and that they be followed by refining the objects by identifying object functionality in terms of a DFD and behavior using state diagrams. Note that it was not easy to begin with functionality or behavior, rather one had to explore functionality and behavior in terms of previously defined objects.

4.4.5.2.6.2. Unified Modeling Language

4.4.5.2.6.2.1. Background

The UML is a language for specifying, visualizing, constructing, and documenting the artifacts of software systems as well as for business process modeling.[1] The UML represents a collection of "best engineering practices" that have proven successful in modeling large and complex systems. Rational Software and its partners developed the UML, which is now an industry standard (www.omg.org/uml). It is widely supported, and there are numerous commercial packages available (www.incose.org) that may be used to develop UML-compliant models. These packages provide a collection of functionality ranging from purely drawing UML diagrams (low cost) to full round-trip engineering with model syntax checking and code generation (higher cost).

The principal benefit obtained from employing a standardized modeling language is that it provides a common framework for communicating system design and behavior between the organizations and various individuals, including users, architects/developers, and operators, involved with the system under development. Developing a model for an industrial-strength software system prior to its construction or renovation is as essential as having a blueprint for a building. Comprehensive models are essential for communication among project teams to ensure architectural soundness. As the complexity of the system increases, so does the importance of efficient modeling techniques.

The UML focuses on a standard modeling language, not a standard process. Although the UML has to be applied in the context of a process, experience has shown that various organizations and problem domains require a different process. The UML authors promote a development process that is use-case driven, functional architecture centric, iterative, and incremental. However, this specific development process is not required or enforced by the language. The UML merely provides the capability for:

- Model elements—fundamental modeling concepts and semantics
- Notation—visual rendering of model elements
- Guidelines—idioms of usage within the trade

Additionally, the UML provides extensibility and specialization mechanisms to extend core components. Though the UML is object-oriented by default, it is independent of particular programming languages.

4.4.5.2.6.2.2. Development Artifacts

The decision regarding which diagrams to create is largely dependent upon the system under development. Focusing on the relevant aspects of the system is critical in the abstraction process. The UML provides a rich notation to describe the static and dynamic behaviors of the system through several diagrams. These diagrams provide complementary views of the system, which are then developed and used by the various stakeholders.

The UML diagrams fall into the four following groups: use-case diagrams, class diagrams, behavior diagrams, and implementation diagrams.

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[1] OMG Unified Modeling Language Specification, Version 1.4, September 2001.

Use Case Diagram: A use-case diagram depicts one or more use-cases with its associated primary and secondary actors. An actor defines a role that a person plays with respect to the system. A use-case, by definition, yields an observable result of value to its primary actor. A secondary actor may be invoked by the use-case and provides a service. Actors may have a primary role in one use-case and a secondary role in another use-case. Use-cases are particularly well suited for capturing requirements. Figure 4.4-42 is an example of a use-case diagram.

Class Diagram: A class diagram provides a static view of the system's classes and depicts the relationships between the various classes. A class is a fundamental construct in all object-oriented languages and includes the notion of data and functions that are logically grouped. Individual class diagrams may depict attributes (e.g., data) and operations (e.g., functions) with varying levels of detail as necessary.

Behavior Diagrams: Behavior Diagrams are used to depict the dynamic operation of the system and include statechart diagrams, activity diagrams, sequence diagrams, and collaboration diagrams. A statechart diagram typically describes all possible states that a particular object may inhabit and how the object's state changes with regard to external events. Activity diagrams describe sequences of activities in which an activity typically represents a real-world process. Sequence diagrams depict a time-ordered flow of events between classes and actors and frequently describe a complex interaction between a small number of classes. Similarly, collaboration diagrams depict a time-ordered flow of events between actors and classes using a different layout; they are frequently drawn at a more abstract level. Collaboration diagrams are well suited for identifying underlying design patterns. Figures 4.4-43 and 4.4-44 are examples of behavior diagrams.

Implementation Diagrams: Implementation diagrams include both component and deployment diagrams. A component diagram depicts the various components and their dependencies in which a component typically represents a physical module of code. Alternatively, a deployment diagram depicts the physical relationships between software and hardware components.

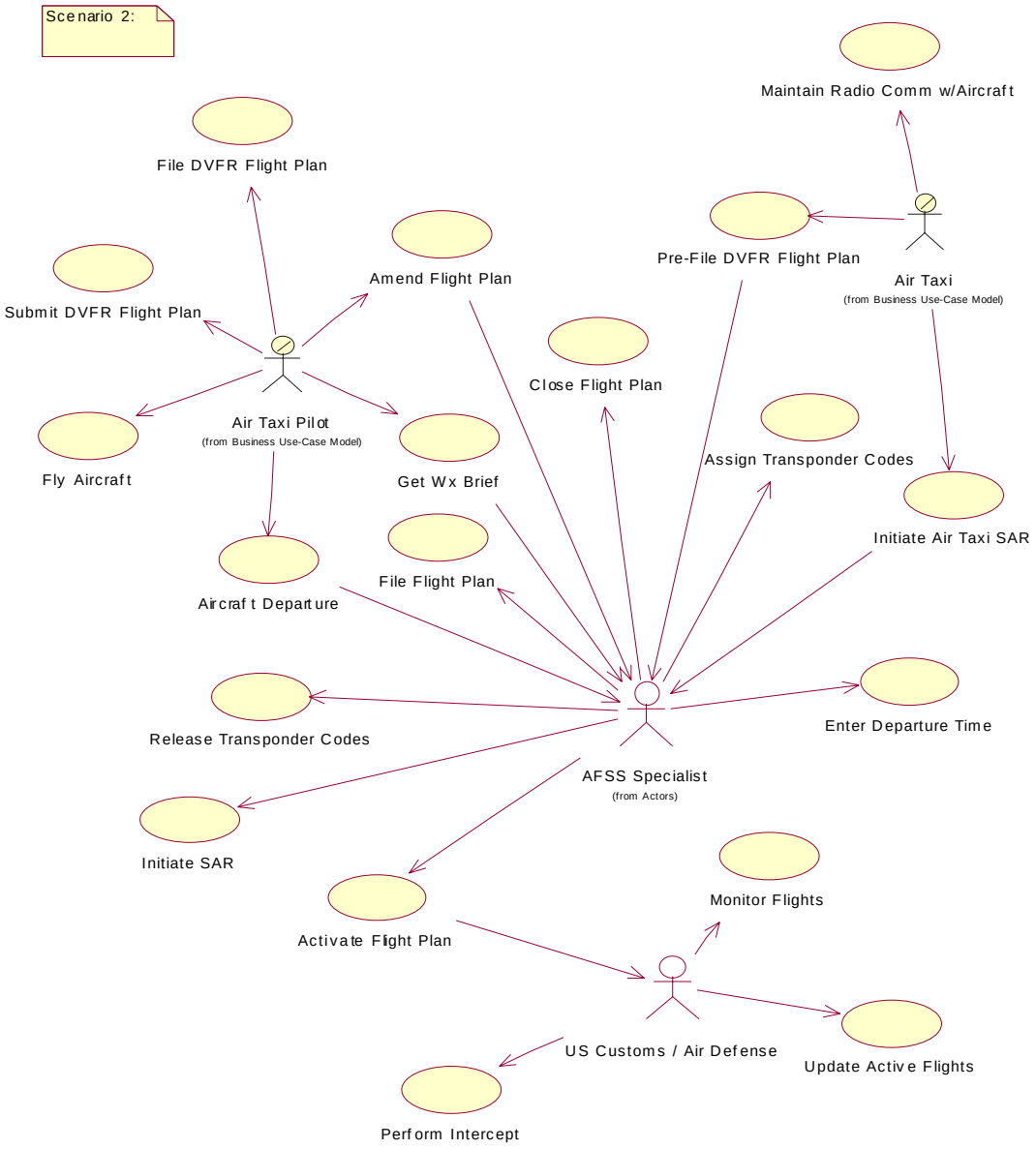


Figure 4.4-42. Day Visual Flight Rules Prefiled Flight Plan Use-Case Diagram

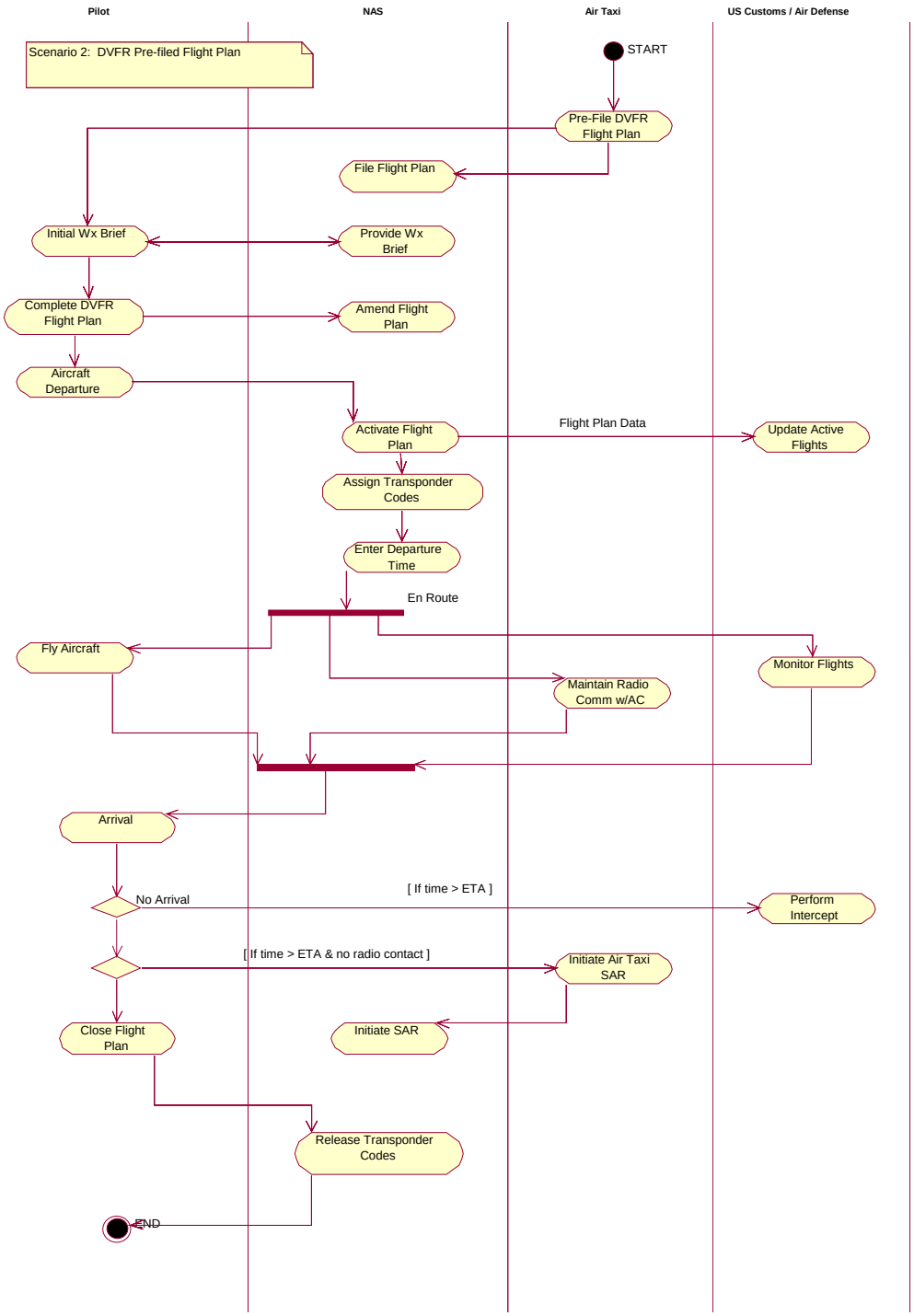


Figure 4.4-43. Day Visual Flight Rules Prefiled Flight Plan Activity Diagram

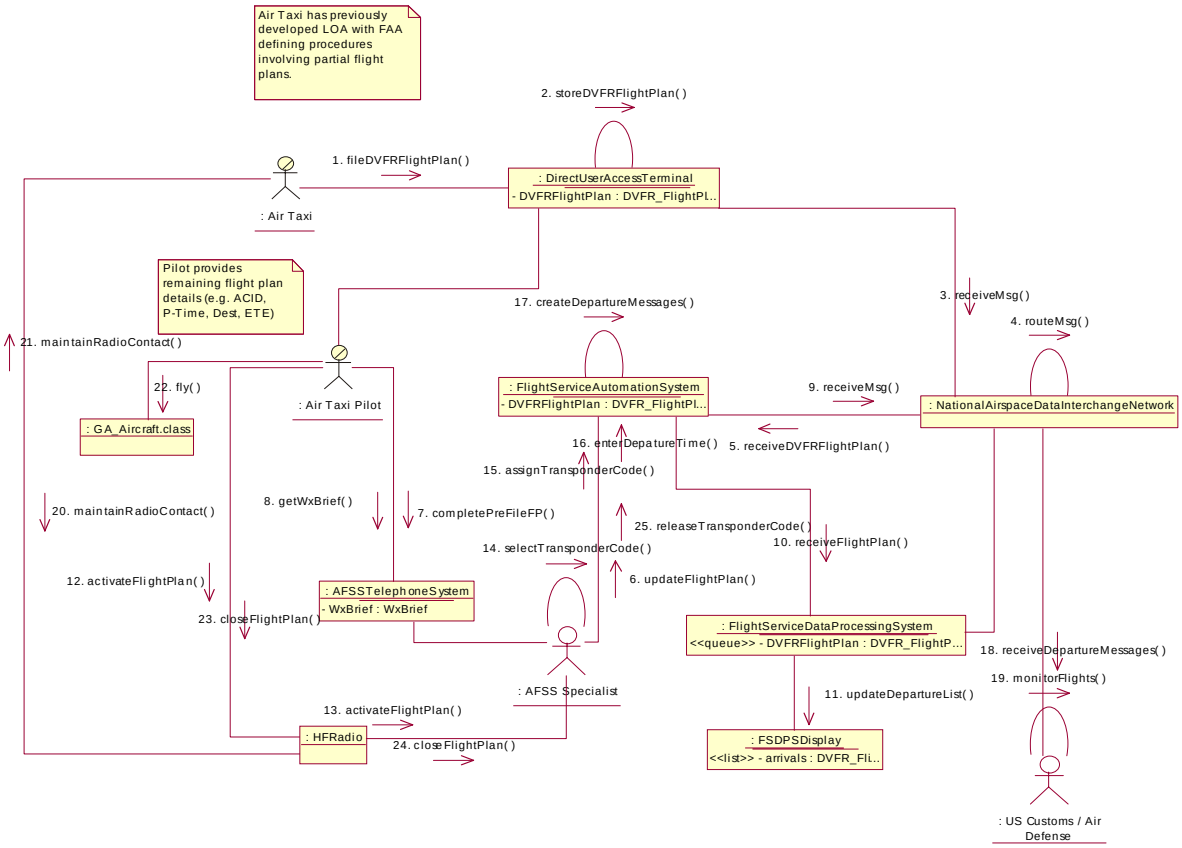


Figure 4.4-44. Day Visual Flight Rules Prefiled Flight Plan Collaboration Diagram

4.4.6. Functional Analysis Process Metrics

Candidate metrics used to measure the overall process and products of Functional Analysis include the following:

- Percent of analysis studies completed (schedule/progress)
- Depth of the functional hierarchy as a percentage versus the target depth
- Percent of performance requirements allocated at the lowest level of the functional hierarchy

Of the seven general measurement categories (see Table 4.1-1), the two that are applicable to Functional Analysis are Process Performance and Product Quality. In addition to the measures listed above, other candidate measures for Functional Analysis are provided in the table below. It is recommended that each effort tailor these measures and add other applicable project-specific measures to ensure the contribution of necessary information to the decisionmaking processes.

Table 4.1-1. Candidate Measures for Functional Analysis*

Schedule and Progress	Resources and Cost	Product Size and Stability	Product Quality	Process Performance	Technology Effectiveness	Customer Satisfaction
Achievement of specific milestone dates	Total effort compared to plan	Documentation of interfaces	Technical performance	Process productivity	Technology impact on product	Customer survey results
Test status	Resource utilization	Requirements	Defects	Process activity cycle time	Baseline changes	Performance rating
			Standards compliance	Defect containment		

*NOTE: These measures are only general examples to indicate the type of information that might be included in the individual section measurement matrix.

4.4.7. References

1. Blanchard, B. "System Engineering Management. 2nd ed. New York, New York: John Wiley & Sons, Inc.
2. Blanchard, B., and W. Fabrycky. "Systems Engineering and Analysis." 2nd ed. Englewood Cliffs, New Jersey: Prentice Hall.
3. Defense Systems Management College. "Systems Engineering Fundamentals." Fort Belvoir, VA: Defense Systems Management College Press, 1999.
4. Department of Defense. Military standard system safety program requirements. MIL-STD-882, 1984.
5. Federal Aviation Administration. "NAS Modernization System Safety Management Program." Washington, DC, 2001 < http://fast.faa.gov/toolsets/index2.htm>
6. International Council on Systems Engineering. "Systems Engineering Handbook," Version 2.0, 2000
7. National Aeronautics and Space Administration. "NASA System Engineering Handbook," June 1995.
8. RTCA, Inc. "Guidelines for the Approval of the Provisions and Use of Air Traffic Services Supported by Data Communications." RTCA DO-264.
9. SAE. "Certification Considerations for Highly-Integrated or Complex Aircraft Systems." Aerospace Recommended Practice ARP-4754, 1996.
10. SAE. "Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment." Aerospace Recommended Practice ARP-4761, 1996.
11. Sage, Andrew B., and William B. Rouse, eds. "Handbook of Systems Engineering and Management." New York, New York: John Wiley & Sons, Inc., 1998.
12. Yourdon, Edward. "Modern Structured Analysis."

4.5 Synthesis

Synthesis is simply design. Design is the creative process that we use to develop solutions to requirements, thereby employing systems engineering (SE) to satisfy operational needs. In the Synthesis process, we first conceive and then later refine specific designs to satisfy operational needs.

Synthesis defines design solutions and identifies systems that satisfy the requirements baseline. Synthesis translates requirements, as set in context by the Functional Architecture, into the design architecture, consisting of the Physical Architecture with its associated technical requirements. The resulting architecture provides an arrangement of system elements by designing their composition and interfaces, both internal and external. Additionally, the design architecture incorporates environmental, technical, and other constraints.

Synthesis is seldom, if ever, a one-step process, but rather accomplished many times over the life of a project in response to many factors, such as newly evolving technology, test data from the present or previous designs, changes in requirements from the user, changes in the price or availability of components, feedback from the field once a system is deployed, and so on. As with all SE functions, different objectives and activities exist within different phases of the acquisition process.

4.5.1 Introduction

The Synthesis process is only a portion of the overall SE discipline, with other processes occurring before, during, and after. Synthesis also leverages efforts conducted under various Specialty Engineering (Section 4.8) disciplines through concurrent engineering. Accordingly, Synthesis requires a number of inputs into the process to achieve the anticipated results, or outputs, of the process. See Figure 4.5-1.

Synthesis is conducted to translate the requirements (based on the Functional Architecture) into a Physical Architecture by defining the system elements. These elements are then refined and integrated into the system's physical configuration, which satisfies the functional and performance requirements. This process relies heavily on prior establishment of clearly defined, documented, and validated requirements.

When entering the Synthesis process, do not assume that the entire requirements set associated with the functional area under consideration is achievable within the cost and schedule constraints. However, do assume that all requirements associated with the functional area under consideration have been validated in accordance with Validation and Verification (Section 4.12). The engineers involved in Synthesis are challenged to find the best possible solution that optimizes achievement of the requirements baseline for the functional area under consideration. This requires close and continual coordination with Requirements Management (Section 4.3) and Functional Analysis (Section 4.4).

Success of the Synthesis or design process relies on a structured and disciplined approach to achieving the desired outcomes. Synthesis outputs naturally emerge from taking the appropriate steps during the conduct of design. Conducted properly, Synthesis may define the build-to characteristics of the system or system elements. The Configuration Items are established and defined during Synthesis. At each level of the resulting design architecture, the requirements and interfaces shall be verified. The Synthesis process shall not only identify

technically feasible and programmatically achievable design alternatives, but these alternatives shall be well analyzed, documented, and finally placed under disciplined management.

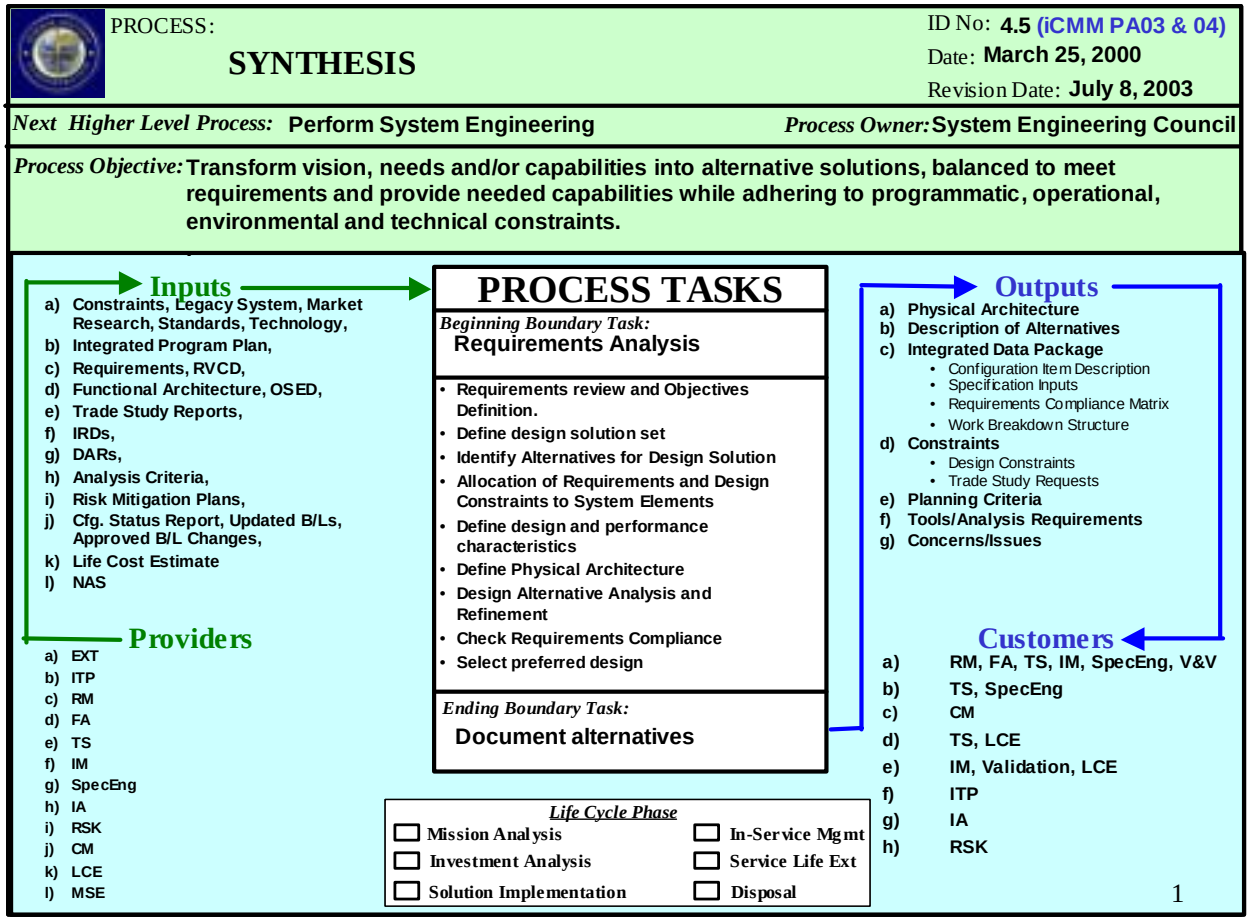


Figure 4.5-1: The Synthesis Process; Inputs, Tasks, and Outputs

4.5.2 Process Inputs

The Synthesis process starts at the conclusion of a number of preceding key SE steps, as illustrated in Figure 4.5-2. These SE processes result in a number of outputs that serve as necessary inputs to Synthesis.

Like Synthesis, the processes preceding it are not necessarily one-step processes. Each may undergo a number of iterations through the given process before the output is ready for the next process to begin. Additionally, the Requirements Management (Section 4.3) and Functional Analysis (Section 4.4) processes are tightly coupled, and a few iterations through these processes occur before readiness to proceed into Synthesis.

Once Synthesis begins, it works as an iterative process, at times initiating iteration back through Requirements Management, and known as the requirements verification loop. Synthesis might also at times initiate iteration back through Functional Analysis, known as the design loop. During these iterative loops through preceding processes, the requirements baseline and/or Functional Architecture are constrained and refined to optimize the potential for viable design alternatives. This ensures that the Functional Architecture and requirements at lower levels of the Physical Architecture reflect the envisioned design.

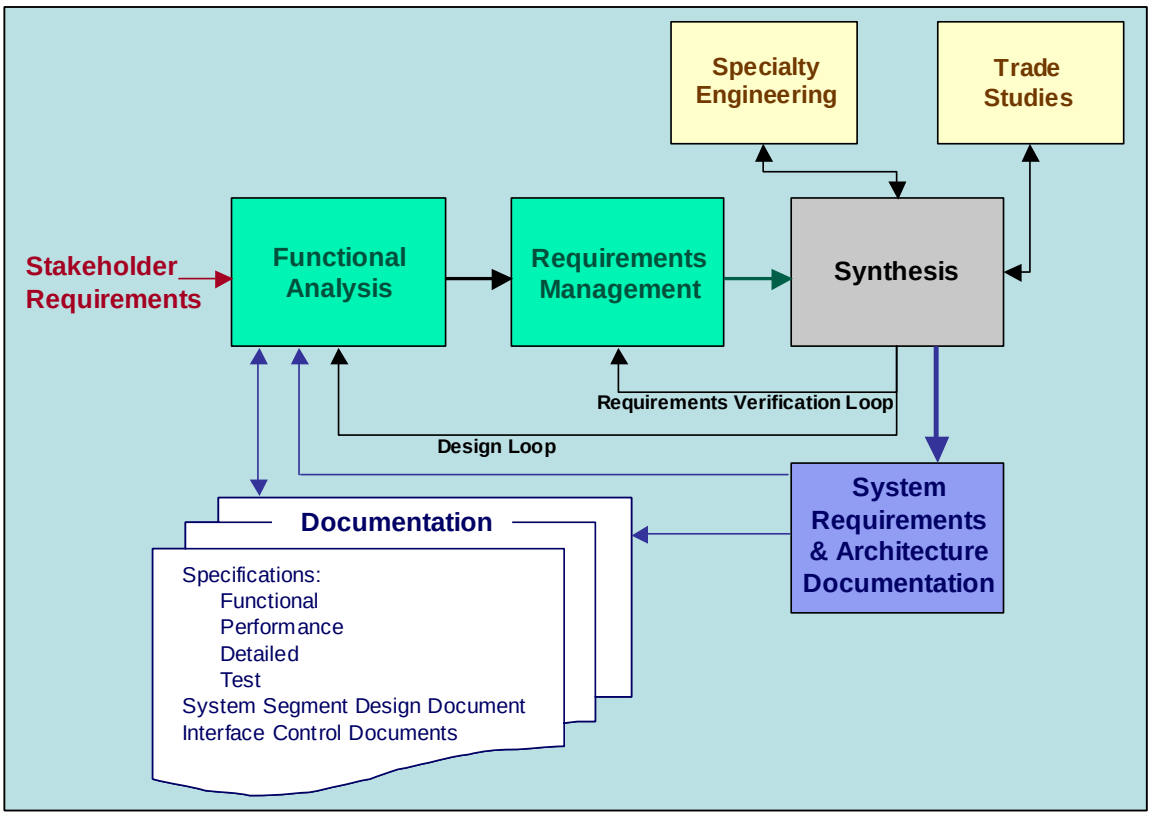


Figure 4.5-2: Requirements and Architecture Definition

4.5.2.1 Initial Inputs

The inputs resulting from the previously conducted SE processes are known as the initial inputs, as they serve to initiate Synthesis. They shall be available before system design begins.

4.5.2.1.1 Functional Architecture

During Functional Analysis (Section 4.4), the high-level functions are decomposed to lower-level functional groups or areas that can be satisfied by system design alternatives. The Functional Architecture shall describe the functional arrangements and sequencing of subfunctions resulting from decomposition. The Functional Architecture does not consider design solutions, but only tasks that the solution(s) shall perform. Synthesis, by contrast, considers the grouped and decomposed functions, or functional areas, in light of technically feasible and achievable solutions.

Functional Analysis provides the design group the appropriate area of the Functional Architecture at which to begin the design process. This Functional Architecture is translated into an established requirements set that documents the problem or set of problems to be solved by Synthesis. The problem for the design group is to identify and define a system or systems that adhere to the prescribed Functional Architecture while meeting stakeholder requirements.

4.5.2.1.2 Requirements Baseline

The user needs and system functions are translated into a set of clearly defined, prioritized, measurable, and validated requirements (Section 4.3) for which the design group shall provide a

solution or solution set. The established requirements baseline dictates the tasks that the system(s) under design shall perform through functional requirements. The baseline also dictates how well the system(s) shall perform its tasks through documented performance requirements. And finally, the requirements baseline ensures system compliance, function, and performance through measurable verification requirements on the Requirements Verification Compliance Document (RVCD).

Not only is information needed regarding what the system shall perform, how well it is to be performed, and how performance is to be measured, but the baseline also establishes the system's limitations. The requirements baseline contains the constraint requirements levied on potential solutions. Design constraints further limit the ability of the system under design from reaching its desired level of achievement. System design usually faces limitations. Therefore, design constraints shall be identified, documented, and managed so that they do not manage design by default. The constraints determine the output of the system under design, whether or not they are acknowledged.

During the Synthesis process, the limitations of engineering shall themselves be considered. Often, solutions are limited by "the laws of physics" or state of the art. The design group undertaking the Synthesis process needs to clearly understand technical as well as programmatic limitations in order to trade risk, schedule, and financial constraints in overcoming challenges to satisfying the requirements baseline.

4.5.2.1.3 Legacy System Definitions

In the FAA, it is rare when a solution is introduced into a pristine environment (i.e., an environment in which a system is not already satisfying user needs.) It is also rare that established needs do not evolve and change as the operational environment also evolves and changes. Consequently, it is important to understand the existing legacy system that currently seeks to satisfy documented needs.

Understanding shall include knowledge of the legacy system functions, performance, and its shortfalls. Only then can the design solution provide an alternative that improves existing capabilities, adds new functionality, and complies with evolving user needs. All documentation regarding system functional, performance, and constraint requirements is therefore a necessary input into the Synthesis process.

The design constraints imposed by the need to operate with existing interfacing systems shall also be understood. Interface Control Documents provide the information needed to ensure integration into the existing environment.

Finally, the new system shall eventually operate in the existing support environment. Documentation regarding legacy system maintenance and support is needed to ensure that the system is designed in a manner that enables it to continue to perform the needed user tasks at the needed level of performance once introduced into the support system.

4.5.2.1.4 Integrated Program Plan

The Integrated Program Plan (IPP), an output of the Integrated Technical Plan (Section 4.2) group, is the document within the Acquisition Management System that provides the plans for the detailed actions and activities necessary to execute the program within the cost, schedule, and performance baselines. The IPP encompasses all elements of program implementation. This may include the acquisition of systems and equipment, construction or modification of

facilities and the physical infrastructure, functional integration of planned capabilities within the existing infrastructure, and procurement of services.

To perform Synthesis, one shall also know the schedule or budget constraints, provided as clearly documented input. If the program phase is such that an IPP exists, it is to provide this needed information. If such a plan does not exist, the design team has to determine the cost and schedule constraints through interface with program management and other stakeholders.

4.5.2.1.5 Operational Services and Environment Description (OSED)

The OSED provides operational, safety, performance, and interoperability requirements. (See Functional Analysis (Section 4.4).) This document provides needed information for the Synthesis process. The OSED identifies the desired air traffic services and or capabilities and their operational environments, including documented operational functions, performance expectations, and selected technologies. It defines the customer needs so that more appropriate alternative selections are feasible during Synthesis.

4.5.2.1.6 Preliminary Work Breakdown Structure (WBS)

A preliminary WBS is provided and initially guides Synthesis efforts. (See Integrated Technical Planning (Section 4.2).) It is then refined under Synthesis by incorporating the characteristics necessary to support the functional and selected Physical Architecture(s) of potential design alternatives. The WBS defines categories of work, work packages, and, ultimately, through Synthesis the identification of associated physical elements. The WBS is invaluable from the planning and management perspective as it establishes a top-down framework for allocating and computing costs. The WBS assists in tracking the status of engineering efforts, resource allocations, cost estimates, expenditures, and cost and technical performance.

During Synthesis, the WBS shall be scrupulously maintained and finalized to show in a hierarchical manner all work elements needed to complete a given program or project. As solution Physical Architectures are defined, the physical elements are introduced into the WBS.

4.5.2.2 Other Inputs

Beyond the inputs available from SE processes occurring prior to Synthesis, there are inputs to be gathered during Synthesis from sources both internal and external to the SE process.

4.5.2.2.1 Market Research

Market research is conducted during Synthesis to gather data necessary to conduct the process and for various reasons. During various stages of the Acquisition Management System (AMS) cycle, the role of market research in the Synthesis process varies.

The first time through the Synthesis loop, when an initial requirements database has been established (initial Requirements Document) and provided as input to the Synthesis process, market research helps to determine the available technologies or various systems that can meet all or part of the requirements baseline.

If multiple viable alternatives do not exist, the baseline and Functional Architecture are to be modified for optimization of alternative solutions. This optimization may occur numerous times as needed. During the final Synthesis iteration, the requirements baseline is finalized (final Requirements Document) and market research is conducted in concert with the design team to identify vendors who meet all requirements of the finalized baseline.

One final and important consideration for market research is to determine the market base for proposed design alternatives. A smaller potential market base for a system and/or its components inevitably translates to an increase in cost risk and a greater potential for the market not to continue to produce the needed items for the needed timeframes as the demand for the supply diminishes. Market research is therefore valuable in determining not only what is available in the market place, but also in determining the extent of its availability and the likelihood of it continuing to be available for the required project/program lifecycle for which Synthesis is to provide a solution.

4.5.2.2.2 Risk Mitigation Plans

Risk Mitigation Plans, although invaluable, may or may not be available for a given iteration through the Synthesis loop. The initial time through the Synthesis loop, finalized requirements baseline and Functional Architecture, are not available. Therefore, the risks associated with potential design alternatives are undefined, and concerns and issues associated with those risks are not yet forwarded to risk management by the Synthesis team.

Subsequent iterations through the Synthesis loops will have incorporated those initial concerns and issues; however, and a risk mitigation plan will have been developed under risk management (in concert with the Synthesis process).

4.5.2.2.3 Trade Study Reports

Trade Study reports are invaluable, whether available to the Synthesis process from previous related efforts or whether solicited through the course of the process. The Trade Study report provides documented answers to many issues and concerns for the Synthesis process, such as feasibility of design alternative, state of technology to support the alternative, and so on.

Existing Trade Study reports may identify related technologies that Synthesis may consider for incorporation into design alternatives. These existing reports provide valuable insight into what is feasible given the current state of the art.

When the Trade Study is conducted in concert with Synthesis, it is geared toward exploring and determining feasibility, associated risks, maturity of design, conformance to the requirements baseline and Functional Architecture, and adherence to the various constraints to the program/project. This input is solicited in the sense that the Synthesis process works in concert with the trade study process to determine objectives and needed outcomes for the Trade Study report. (See Trade Studies (Section 4.6).)

4.5.2.3 Summary of Needed Input for Synthesis

The availability of data depends on the status of the Synthesis process. If it is the first-time entry into Synthesis, or the first Synthesis loop, not all data becomes available. However, as the Synthesis process continues, more data becomes available from other SE disciplines. Table 4.5-1 summarizes the data that is required for the Synthesis process and its availability.

Table 4.5-1: Needed Synthesis Data

Input	Delivering Process	SEM Reference	Availability
Requirements Baseline	Requirements Management	Section 4.3	1st and subsequent loops
Functional Architecture	Functional Analysis	Section 4.4	1st and subsequent loops
Legacy System Specifications	External to SE	N/A	1st and subsequent loops
Legacy Interface Requirements	Interface Management	Section 4.7	1st and subsequent loops
Draft IPP	Integrated Technical Planning	Section 4.2	1st Synthesis loop
Operational Services and Environment Description	Functional Analysis	Section 4.4	1st and subsequent loops
Preliminary WBS	Integrated Technical Planning	Section 4.2	1st Synthesis loop
Market Research	External to SE	N/A	May not be available 1st loop through Synthesis
Trade Study Report	Trade Studies	Section 4.6	May not be available 1st loop through Synthesis
Risk Mitigation Plans	Risk Management	Section 4.8	May not be available 1st loop through Synthesis

4.5.3 Process Steps

The activities of Synthesis involve selecting a preferred solution or arrangement from a set of alternatives and understanding associated cost, schedule, performance, and risk implications. Synthesis entails undertaking a number of necessary and distinct steps geared toward achieving measurable goals and objectives while striving to manage or overcome constraints. Alternative candidate designs are first conceptualized; candidate alternative solutions are then defined and refined in order to meet the established requirements baseline.

Engineering analysis is used, as necessary, to evaluate alternatives. Evaluation identifies, assesses, and quantifies risks and selects proper risk-mitigation approaches. The risk management plan, if available, is utilized to refine the various design alternatives and achieve a balance between risk and technical progress. Too much risk within a given alternative could result in an unachievable design at the end. Assuming too little risk within a given alternative could also result in a solution that cannot be reached within the schedule constraints established for the project. These two extremes are balanced against the requirements baseline and established Functional Architecture through the guidance provided in the Risk Mitigation Plan(s). (See Integrated Technical Planning (Section 4.2).)

The analysis of alternative solutions also results in an understanding of cost, schedule, and performance impacts. As subsystem requirements are defined, the identification of the needs, requirements, and constraints for lifecycle processes is completed. The specific tasks that define Synthesis are identified in Figure 4.5-3.

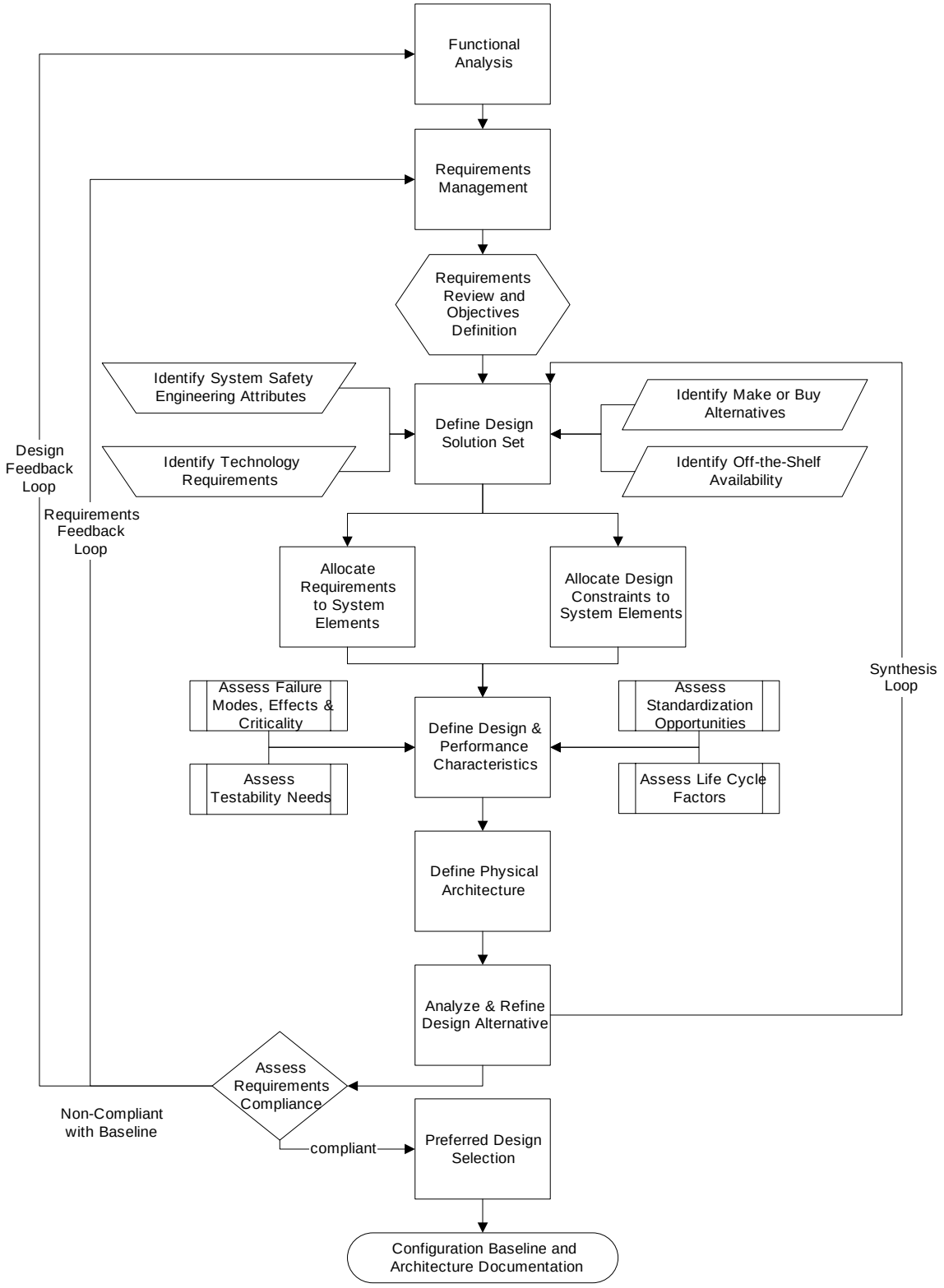


Figure 4.5-3: The Synthesis Process Activities

Synthesis demands creativity in order to achieve success. The ability to discover new solutions, to look at the requirements from new perspectives, and to formulate new concepts from two or more previously held ideas challenges the design group during this process. In order for the

design group to succeed, each individual member of the team shall exercise awareness and sensitivity to problems associated with each proposed approach. They shall exercise flexibility, originality, self-discipline, and persistence while maintaining adaptability, nonconformity, tolerance for ambiguity, self-confidence, and a healthy skepticism.

In addition to exercising necessary individual characteristics, the team shall also be aware of necessary group characteristics and dynamics essential for the successful development of achievable yet satisfactory design alternatives.

A group of "*like-thinkers*" typically arrives at a mutually agreeable solution, or solution set, in less time and with less discourse than a diverse group with differing perspectives and priorities. The solution reached in this relatively pain-free manner may not have always considered and analyzed every facet of the approach and all problems associated with it. As a result, the solution may not in the end satisfy all the requirements and design constraints levied on the Synthesis process. The devil's advocate plays an important role in the group and is as equally important to achievement of the group's goals, as is the consummate politician.

Once a diverse and well-balanced group is formed, the group can begin to develop design alternatives and a set of prioritized objectives through a variety of methods. The group can use such methods as brainstorming, brainwriting, and dynamic confrontation (see text box at right). Whatever method or combination of methods is selected for this creative development of alternatives, care is to be exerted to ensure that no one individual is allowed to dominate the group and, therefore, its outcomes. Likewise, care shall also be exerted to ensure that every member of the group is given ample opportunity to contribute to the group's efforts.

Brainstorming

This technique involves both idea generation and idea reduction. First idea generation occurs by simply identifying as many solution ideas as possible. Later in idea reduction those potential solutions are ranked into groups, with a specific group encompassing those potential solutions considered most useful to the group.

This technique is frequently considered a powerful one as it often results in the most creative and effective solutions. These solutions may arise from a combination of seemingly unrelated ideas, generated early in the process. Brainstorming encourages creative and original thinking.

Brainwriting

This technique builds on the concept of brainstorming, as it is the same technique but simply replaced verbal communication with writing. Utilizing this technique, team members write down a number of relevant ideas on a sheet of paper (usually limited to three ideas). The paper is then passed to another team member who then develops those ideas. New ideas and elements are added to the original concept(s) and the augmented pages are then passed onto another team member.

This process continues until each team member receives back the sheet of paper containing the original concepts they created. At this point the beginning phase is complete and a group leader collects all idea/solution sheets.

The next phase is then commenced with all the sheets being handed out to the entire group. The group then works to revise the ideas developed in the prior phase.

This technique alleviates one of the problems associated with brainstorming in that dominant members may not easily steer the efforts of the entire group.

Dynamic confrontation

This technique is an adversarial group process. The main idea in this technique is for team members to criticize every idea. A presentation is first made and then every element and assumption of that idea is intensely challenged. This technique tests out every idea thoroughly and forces all members to thoroughly think through and develop their ideas.

4.5.3.1 Requirements Review and Objectives Definition—Step 1

After ensuring that all needed available Synthesis data is together (see Table 4.5-1), Synthesis begins with a review of the requirements baseline and the Functional Architecture in order to understand what is to be performed and at what level of performance to meet stakeholder

needs. Requirements Management does not dictate *how* the stakeholder needs are to be met. The design Synthesis process determines how to achieve stakeholder needs.

Establishing objectives assists in optimizing adherence to the requirements set within the technological and programmatic limits imposed on the design process. Objectives shall be linked to stakeholder needs and system requirements. Objectives take into consideration operational criteria, mission success, technical performance, cost, schedule, quality, risk, failure rate, maintainability, and supportability. Through definition and prioritization of all design solution objectives, the optimal solution is achieved that best satisfies the requirements set under consideration.

Often, devices perform their functions at varying performance levels in differing environments. For instance, the system delay for a computer system gathering surveillance data from various sources and formulating a graphical representation of all existing air vehicles in a given space and presenting it to the controller on a display is vastly different at various locations and at various times during the day. Stakeholders would only state minimum NAS requirements for presentation of data to them from the source. The engineers involved in Synthesis shall decide how they are to meet those stated requirements in the various environments. A tailored system for each location might be provided, thus lowering the overall cost of upfront procurement, as computer systems with less processing power may be utilized in small airport areas. However, the training and support regarding multiple systems shall also be addressed in terms of added cost for multiple versions of the system. In this example, the Synthesis engineers shall evaluate the operating environment of the solution to determine what the objectives are for performance, upfront procurement cost, and the lifecycle costs of supporting the resulting system. These items represent three distinct objectives to be satisfied in selecting a design that fulfills the stakeholder needs.

Another facet to consider is that a single system design may not necessarily satisfy all of the requirements associated with the functional area under consideration. Multiple systems may be required to satisfy the entire requirements set.

Ideally, it is recommended that alternative solutions satisfy all requirements, but it is useful to include solutions that challenge the requirements and lead to a better system concept. Various options are to be considered eventually in light of the objectives for the resulting system(s). Such alternatives include relaxing requirements of marginal utility that are costly to implement or extending requirements when added capability can be purchased cheaply while resulting in operational benefits.

4.5.3.1.1 Performance Objectives

The performance objectives, although highly dependent on potential system solutions, shall be clear, as they serve to define the main purpose of the system. The engineering team shall not only define all terms that measure how the system performs, but the actual desired performance levels shall also be stated. The accuracy, capacity, response time, throughput, and other similar requirements are reviewed and analyzed against feasible design possibilities. The threshold performance levels are clearly documented for the design under consideration. Most, if not all, of the performance requirements are contained in the requirements baseline provided under Requirements Management. However, the stated performance objectives that are to be achieved by any potential system or systems are clearly documented at the outset of Synthesis so that the tradeoff between these and other objectives may follow.

4.5.3.1.2 Reliability Objectives

The reliability objectives shall be defined in terms of the likelihood, or probability, that the resulting system will operate at its objective performance level for a defined period of time under normal operating conditions. To clearly define the reliability objectives, engineers shall translate the environmental and operational data as contained in the OSED. Allocation of the RMA requirements in the requirements baseline is conducted in concert with the requirements process and Specialty Engineering in order to allocate the various reliability maintainability objectives to the various design alternative functional areas.

4.5.3.1.3 Compatibility Objectives

The engineering team shall define the objectives for the system to work, or interface, with both existing systems and those under agency development. Interface objectives are stated in terms of not only the data and physical interface, but also in terms of the working environment imposed by the existing systems or system elements with which the potential design alternative shall interact. The objectives shall address both backward compatibility with legacy systems and forward compatibility with known evolving technologies, protocols, and standards.

4.5.3.1.4 Extensibility Objectives

The engineering team shall define the objectives to allow for alternative design approaches to be able to adjust to a changing environment. For example, the ability to process more flight data to adapt to a growth in air traffic shall be clearly defined and documented. This is particularly important when it is known that the existing environment is to evolve. As the environment evolves, so shall any design alternative evolve to adapt to the new environment. Projections for changes are documented along with the stated objectives for extensibility of the design alternative.

4.5.3.1.5 Flexibility Objectives

Flexibility differs from extensibility, which means the ability to adapt to and accommodate growth needs. Flexibility is the ability of the design alternative to serve new or multiple uses. An example of flexibility is a multipurpose display that provides graphical display of flight plan data, surveillance data, or both simultaneously without need for modification.

4.5.3.1.6 Cost Objectives

A limited budget is a never-ending facet of the Synthesis process. Thus, it is essential to define clearly at the outset the cost objectives for any potential design alternative. Try not to overemphasize cost of the item over all other objectives. The old adage, “You get what you pay for,” is all too often true. Consequently, cost objectives are best stated as a range within which the design alternatives shall reside. Cost objectives shall include all facets of the potential design alternatives’ lifecycle. Restricting objectives merely to the initial cost of a design solution may not fairly consider other design alternatives that have higher initial cost, but whose overall lifecycle costs are lower due to quality, reliability, and supportability characteristics. Therefore, the cost objectives shall be defined for all stages of the intended lifecycle.

4.5.3.1.7 Schedule Objectives

What a design alternative does, how well it performs the function(s), and where it performs become irrelevant if the design alternative is not delivered to the user when needed. A design alternative delivered before its time is as potentially damaging to the effort as one delivered too late. Therefore, the schedule objectives for all facets of the design alternatives’ lifecycle shall be defined clearly and comprehensively. The schedule objectives for test, operational introduction, full operational capability, service life, and so on are all documented.

4.5.3.1.8 Objectives Tradeoffs and Hierarchy Definition

Rarely, if ever, are projects faced with unlimited time and financial resources. Tradeoffs and compromises are common during Synthesis in order to achieve the design objectives with an acceptable level of requirements compliance. It is essential to define the design objectives and rank their relative importance.

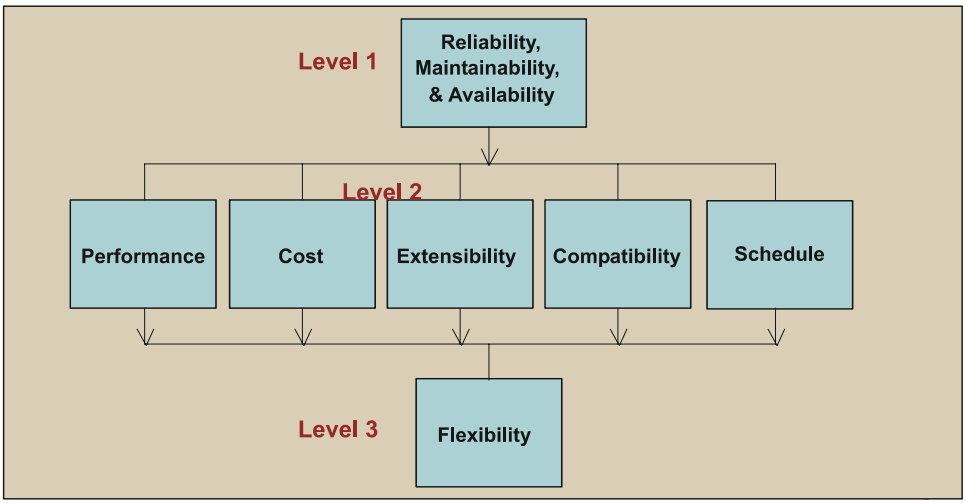
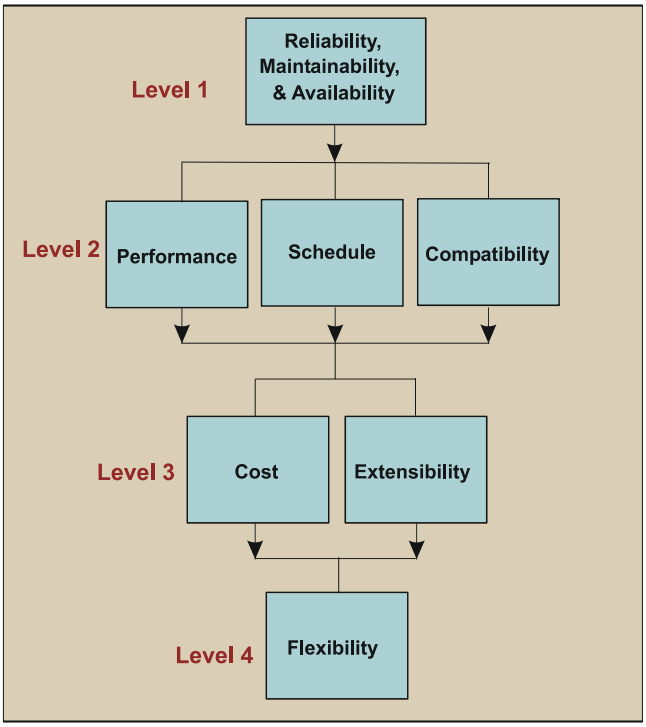


Figure 4.5-4: Example Three-Level Objectives Hierarchy

The prioritized set of objectives, defined during the brainstorming, brainwriting, and dynamic confrontation meetings, is to be well established and documented before design solutions are considered.

Objectives in both the above categories and additional categories to be considered under the program/project are first documented as a list. The list is expanded to include more categories as determined necessary in concert with program management, Specialty Engineering, and stakeholders. The importance of each objective relative to the others is then determined for all objectives. Once all the relative priorities are established, priority levels are defined based on the findings. This task, although not simple, is necessary, as the results are invaluable later when design alternative tradeoff analysis is performed.

Assume that each of the categories in Section 4.5.3.2 has one objective; there are then a total of seven resulting objectives. For this example, examine a project that eliminates a reliability deficiency in an existing fielded system. In this particular example, RMA is therefore considered of higher importance than all other alternatives. Also, as the product introduced is only an interim solution to fulfill a shortfall, system flexibility is considered less important than all other factors. If all remaining objectives are considered to be of equal importance, there are three priority levels (Figure 4.5-4)



Establishing the objectives hierarchy is seldom this simple. The items in level two of the figure are rarely seen as equal in importance. This level may be further broken down into groups, with

Figure 4.5-5: Example Four-Level Hierarchy

each group containing objectives of equal importance and with one group being considered to be more important than the other. This leaves four levels of priorities instead of three, and the hierarchy is established, complete with relative objective priorities, and priority-level definition (Figure 4.5-5).

4.5.3.2 Define Design Solution Set—Step 2

During this Synthesis step, grouping of needed functions into common functional areas is complete and the Functional Architecture is established. The design team shall now begin partitioning desired functional requirements into design elements. During review of various designs in terms of whether or not they will perform the desire functions, each function in the Functional Architecture is mapped to a component of the system under review. Some components may perform only one function; others may perform more functions (Figure 4.5-6).

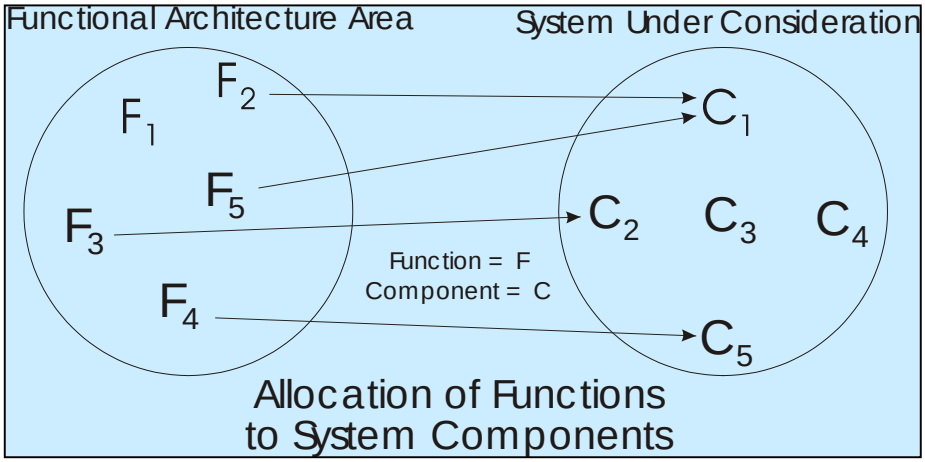


Figure 4.5-6: Functional Partitioning to System Components

This Synthesis process step boils down to generating alternative design solutions for the functional elements identified during Functional Analysis (Section 4.4) that perform the needed functions and adhere to the requirements for that functional area. It is recommended that the alternative solutions be composed of one or a combination of more than one of the following: hardware, software, material, data, facility, people, and techniques.

There are a variety of tasks conducted to identify various design alternatives. Various subteams may perform the tasks sequentially or concurrently. If the Synthesis group is small, the preferred choice is for all members to look at identifying alternatives sequentially. If the group is large enough and good communications exist among all members, the option to concurrently identify solutions by the various means described below is worth exploring. Both approaches require that the entire group conduct prior planning. Concurrent exploration of alternatives requires close coordination throughout identification of alternatives until all possibilities are identified; whereupon, the subteams may once again combine to complete this Synthesis step. Figure 4.5-3 illustrates the tasks feeding the Synthesis step that identifies the various design alternatives.

4.5.3.2.1 Technology Assessment

This assessment addresses not only potential incorporation of existing technology into design solutions, but also looks at the risks and limits imposed by and on that technology. Each alternative under consideration is analyzed against the changing technologies available in the marketplace. Available technologies are studied for use in the design under consideration, potential improvements to design performance, improvement to maintainability of the resulting system, cost-effectiveness, and maturity.

The need for a new technology that makes possible a performance or functional improvement not previously possible shall be carefully weighed against the risk imposed by that technology. The potential benefits of inserting the technology shall outweigh the potential risks to cost, schedule, and performance.

To continue consideration of the potential technology insertion, the impacts to the end user shall be considered through human factors analysis. The tasks, roles, and jobs assigned to humans are analyzed and assessed to discover whether the end users of the resulting system have the required knowledge, skills, and abilities. If the needed knowledge, skills, and abilities do not exist, then the cost and schedule risks of achieving them with the new technology are weighed against the benefits derived from the technology. Training and personnel pipelines are fully evaluated to ensure that they meet requirements.

4.5.3.2.2 Identify Specialty Engineering Attributes

The design team shall work in concert with specialty engineers to identify the characteristics of each potential alternative necessary to fulfill interdisciplinary needs.

The design team works in concert with safety engineers to analyze each alternative, and to identify potential hazards to the hardware/software components of the system, the humans involved in the system as users and support personnel, or the environment. The analysis shall demonstrate that the design under consideration results in safe system operations. All aspects of the design, development, manufacture, test, operation and support of the potential design are included in the analysis.

The design team works in concert with human engineering to analyze each alternative for human factors suitability. Each alternative is analyzed with respect to the human user system interface. (See Specialty Engineering (Section 4.8).)

4.5.3.2.2.1 System Safety Engineering

System hazards are identified and assessed for the design alternative. The hardware, software, operational, and ambient environments, and procedures and human elements of the design alternative are analyzed, and historical or test data is applied to estimate the risk (severity and likelihood) of each identified hazard. Controls are then designed in accordance with the safety order of precedence described in Specialty Engineering Section 4.8.1. All hazards and their associated controls are prioritized according to their risk criticality rating. The analysis results are used to direct further design efforts to characterize the system's controls, safety features, redundancy, and degradation elements.

4.5.3.2.3 Off-the-Shelf Opportunities

Each design alternative is analyzed to determine if an off-the-shelf item exists that fulfills the allocated requirements. Off-the-shelf solutions may include non-developmental hardware or software.

Once off-the-shelf solutions are identified, each shall undergo assessment to ensure that a variety of factors are considered in determining suitability. The number of systems available off the shelf shall be gauged against the number users need. The quantity needed shall encompass not only those needed initially by the user community, but also those needed to serve as replacements over the anticipated service life of the system.

Another facet of the suitability assessment process is consideration of the environment in which the prospective off-the-shelf item shall eventually operate. The ability of the proposed item to adapt to the existing support structure is a necessary component in determining its suitability. If the item requires new equipment and/or training for support during its lifecycle, the benefits of the item shall outweigh its cost and schedule impacts.

Finally, the manufacturer(s) of the off-the-shelf item shall undergo assessment. Attributes such as product maturity, upward/downward compatibility, manufacturer track record, financial stability, and quality practices shall be factored into the commercial product selection process. If the products or manufacturers fall short in any of the reviewed categories, they shall be considered a risk. Refer to Appendix F of the FAA COTS Risk Mitigation Guide for a more detailed listing of COTS nontechnical selection factors.

4.5.3.2.4 Make-or-Buy Alternatives

A cost analysis is performed for the design alternative(s) and used to support a make-or-buy decision. This analysis needs to address whether it is more cost-effective to produce the design element versus using an established supplier.

When cost, schedule, and risk are considered, it is most beneficial to design and develop (a "make" decision) a peculiar system that satisfies all requirements of the functional area. The team may proceed with this approach as a viable design alternative.

4.5.3.3 Identify Alternatives for Design Solution—Step 3

Input from preceding processes and previous Synthesis steps identify not only potential alternatives, but also design constraints for potential solutions. This input helps determine if existing or newly developed items can accomplish the functional element under consideration.

Synthesis strives to identify viable design alternatives, refine those alternatives to fulfill the requirements baseline, and finally select the most balanced and beneficial design to introduce into the field. To accomplish this goal, all possible alternatives are first identified. These are reduced to reflect only those alternatives considered viable or worth pursuing.

4.5.3.3.1 Populate the Solution Set

The design team identifies all possible design solutions that may serve to satisfy all or part of the requirements baseline. At first, it is merely an exercise in exploring all possibilities. Once the team has exhausted all possibilities, the design solution set is evaluated both as a group and individually. If only one possible design alternative has been identified, then the job is not complete. No matter how large or difficult the requirements baseline and the functional area with which it is associated, there always exists at least one possible design alternative: *do nothing*. The default is to continue the status quo and not present new and/or innovative design solutions. Given the fact that a great effort went into previous SE processes (such as Requirements Management (Section 4.3) and Functional Analysis (Section 4.4)), it is unlikely that entrance into Synthesis would have occurred if all requirements in the functional area, with its associated requirements baseline, were satisfactorily met. Clearly, it is possible to identify an insufficient number of alternatives. The task is to develop additional alternatives that present better options.

The following methods can be used to develop new alternatives.

- **Change the characteristics of existing alternatives.** First, list all existing alternatives. For each alternative in the list, itemize its main characteristics. Generate a table with the rows representing the list of alternatives and the columns representing the main characteristics of all alternatives. In all likelihood, each of the potential alternatives possesses characteristics that are both similar and distinct from those of the other alternatives. The positive characteristics are identified. Missing characteristics needed by a design alternative and not represented by any potential solution are then listed. Finally, more alternatives are then added to the list, as the characteristics within the previously listed alternatives are varied, enhancing the new alternatives with needed positive characteristics and eliminating as many negative characteristics as possible.

- **Go back to the objectives.** Focus on the most important objectives one at a time. List alternatives that meet each of those top-level objectives. Then, work down the objectives hierarchy, developing more alternatives or refining existing alternatives that satisfy those additional objectives.

- **Finally, look at all the objectives and requirements set.** List alternatives that maximize the number of objectives and requirements that are able meet with the alternative.

If there still seems to be lack of viable alternatives, step through the various methods, introducing more creativity and ingenuity each time through. Eventually, a solution set reaches a stable point, and identification of design alternatives is complete.

Now that a significant number of design alternatives are identified, all alternatives are evaluated. First, determine that a number of sound viable design alternatives exist that can satisfy all or most of the baselined requirements. It is possible to continue the Synthesis process with too many design alternatives, as the remaining steps detail and document each alternative to a great degree. Therefore, proceeding with too many alternatives can waste valuable time and resources. One can argue that proceeding with one alternative is not sufficient. Likewise, one might also argue that proceeding with 10 alternatives that shall be thoroughly defined and documented is an unnecessary excess; so reduction of the alternatives set to a manageable size or number (based on the scope of the stakeholder need) of alternatives shall occur.

4.5.3.3.2 Reduce Solution Set to Manageable Number of Alternatives

When viable design solutions are identified, compromise of requirements considered absolutely necessary to satisfy the operational needs shall not occur. Those requirements considered so important to satisfying the user needs that a system not meeting them is deemed unnecessary or unacceptable are to be considered "*threshold requirements.*" A potential design solution shall satisfy threshold requirements for further consideration as a design alternative. Threshold requirement compromise or tradeoff is not an option for consideration. A design alternative not meeting a threshold requirement that cannot be modified easily to meet the requirement(s) is eliminated and not considered further.

The objectives hierarchy is used next. If the remaining alternatives set contains potential solutions that do not meet the top-level objectives, and they cannot be easily or affordably modified to do so, then those alternatives are eliminated from the set of potential alternatives. As with requirements, some objectives are not subject to compromise, and it is recommended

that alternatives not meeting the high-priority objectives, as defined earlier, no longer be considered.

If potential solutions are only able to satisfy a portion of the functional area requirements or objectives, consider various options to develop a set of viable design solutions. One or more of the solutions that nearly satisfy the objectives and/or requirements could be modified to achieve satisfactory results. The following options may be used to modify either the problem (functional area under consideration with its associated requirements) or the alternative design solutions:

- **Trade Study Request.** To determine if one or more of the options can be modified to fulfill the desired requirements and/or objectives, a detailed analysis, such as that conducted under Trade Studies (Section 4.6) is requested. Under the Trade Studies process, incorporation of new technologies and a variety of other means are investigated. If the results of the study render viable design alternatives, then Synthesis proceeds into the next step, requirements allocation. However, if it turns out that no alternative can meet all of the requirements in the functional area under consideration, the requirements and/or the functional areas are analyzed.

- **Initiate Requirements Feedback.** When the requirements baseline for the functional area under consideration cannot be satisfied through viable design alternatives, feedback to Requirements Management (Section 4.3) is initiated. If requirements are only partially met by all potential designs, the ability to meet the requirements set is analyzed concurrently by Synthesis and Requirements Management. Consideration is given to modifying requirements to lower and achievable levels. Full compliance is deferred until technological or other advances allow for full compliance with the original requirements. Requirements that cannot achieve even partial compliance in the various designs are addressed through the design loop.

- **Initiate Design Feedback**. Due to discovery of design issues, the Functional Analysis (Section 4.4) is reexamined, and the initial decomposition or performance allocations are reassessed. Design issues include identifying a promising physical solution or open-system opportunities that have different functional characteristics than those foreseen by the initial Functional Architecture requirements. Issues also include the inability of all design alternatives to fulfill the same functional area requirements, which may be addressed by repartitioning of the functional area. The functional area is subdivided so that allocation of those requirements to be satisfied by the alternative designs are made down to perspective system elements. The remaining functional areas whose associated requirements are not to be satisfied remain with the Functional Analysis (Section 4.3) process. The associated requirements are documented as unsatisfied in the Requirements Management (Section 4.3) process. The functional area(s) with the associated unsatisfied requirements are partitioned out of Synthesis, back to Functional Analysis for future Synthesis loop identification of potential solution(s).

Review and analysis of all remaining alternative solutions are conducted in concert with Specialty Engineering, risk management, lifecycle engineering, and integrated program planning in order to determine adequacy and suitability of each remaining alternative. The alternatives are pared down to preferred design solutions.

4.5.3.4 Allocation to System Elements—Step 4

The previous Synthesis steps have resulted in a promising set of conceptual designs for systems satisfying the requirements baseline for the functional area under consideration. Each design concept shall now be developed in more detail so that requirements and design constraints are assigned to the top-level elements of that system design.

4.5.3.4.1 Allocation of Requirements to System Elements

In prior steps, the functional area and associated requirements were adjusted in concert with Functional Analysis and Requirements Management, respectively. As this Synthesis step is entered, the requirements to be satisfied by the design solution(s) are established, and this step furthers the design process by allocating the requirements to system elements.

These elements are the highest-level distinct elements of the system in the areas of hardware, software, and humans in the system. Each system element shall perform at least one function within the functional area to be considered separately and distinctly in the traceability of requirements.

The design engineers proceed in allocating requirements to the selected system elements. All requirements that the system shall satisfy are documented, and formal tracking of those requirements through the various design and acquisition phases of the system begins. Documentation includes information regarding the hardware, software or other components of the system to which each requirement is allocated.

4.5.3.4.2 Allocation of Design Constraints to System Elements

Design constraints that apply directly to system elements are identified. These constraints do not apply to the functions performed, but rather the elements: hardware, software, or people. Design constraints differ from constraint requirements in that they recognize existing limitations to design of a system, its interfacing systems, and its operational and physical environment. Such design constraints include power, weight, data throughput rates, memory, and other resources. These constraints represent the inability to achieve a capability or level of performance due to such issues as technology, and available facility space for the system.

Design constraints are especially important in analyzing the design of potential replacements for existing systems. This is of particular interest to design engineers when major elements of the original system may be retained. The design constraints once allocated clearly defines which system elements remain, are added, or modified.

Those technology constraints identified during the prior technology assessment are to be allocated to the system elements. Those constraints identified during review of Specialty Engineering attributes are allocated to ensure that inappropriate design characteristics are not introduced into the selected system. Finally, environmental constraints are allocated down to the system element level. Environmental constraints may be introduced by climatic conditions in which the total system is to operate, by the facilities in which the system is to be housed, or more globally by environmental hazards and constraints (such as Environmental Protection Agency regulations) imposed in the region(s) where the systems is to be used.

4.5.3.5 Define Design and Performance Characteristics—Step 5

With the system concepts now defined, identify the design and performance characteristics of each alternative. Once defined, the design and desired performance characteristics are

documented. The system(s) characterization is all-inclusive and addresses all facets of the system under design, including the associated human-engineering elements and lifecycle considerations or needs.

During this phase, there is strong benefit to practice concurrent engineering. The entire functionality of the system(s) under design is considered. When the design and performance characteristics are defined, the entire lifecycle of the potential system shall be considered, from inception to disposal, in an integrated process. This requires involvement of all Specialty Engineering disciplines (Section 4.8) in the Synthesis process. Thus, sound engineering decisions are made based on strong consideration of all phases and aspects of the system under design consideration.

4.5.3.5.1 Assess failure modes, effects, and criticality

Failure modes, the effects, and the criticality of failure are assessed for the design alternative. The hardware, software, and human elements of the design alternative are analyzed and historical or test data is applied to estimate the probability of successful performance of each alternative. Use a failure modes and effects analysis to identify the strengths and weaknesses of the design solution (See Reliability, Maintainability, and Availability Engineering (Section 4.8.2).) For critical failures, a criticality analysis is conducted to prioritize each alternative by its criticality rating. The analysis results are used to direct further design efforts to characterize redundancy and graceful system degradation elements of the system.

4.5.3.5.2 Assess testability needs

The testability of the design is analyzed in relation to the operational or maintenance needs. The team determines the need for a built-in test, Remote Maintenance Monitoring, and/or a fault-isolation test for each potential design alternative. For elements that are normally maintained by the users or field support engineers, test mechanisms are considered in the design and incorporated as necessary. Diagnostic operations to support lower-level maintenance actions are likewise incorporated into the design solution.

4.5.3.5.3 Standardization Opportunities

The alternative is assessed for possible use of standardized end items that are technologically and economically feasible. Use of design elements that implement commercial and international standards is strongly considered.

4.5.3.5.4 Lifecycle Factors Assessment

The design of each alternative is assessed to determine the degree to which quality factors (producibility, ease of distribution, usability, supportability, trainability, and disposability) have been included in the solution. Additionally, associated lifecycle process needs, requirements, and constraints are identified and defined for each design under consideration. (See Lifecycle Engineering (Section 4.13).)

4.5.3.6 Physical Architecture Definition—Step 6

A Physical Architecture defines and describes the way in which the various Functional Architecture elements can be brought together to form physical entities. The physical entities shall represent a viable design alternative and shall provide one or more services that address user needs as translated by the requirements baseline. The Physical Architecture may involve such physical entities as runways and various forms of equipment; such nonphysical entities as software; or a combination of the two.

The Physical Architecture identifies the physical subsystems, and architecture flows between subsystems that implement the functions and provide the needed services/capabilities. The Physical Architecture further identifies the system inputs and outputs.

In constructing a Physical Architecture, the following definitions are used:

- **Physical Entities.** The classes of physical entities used are:

  – Subsystems. Subsystems are the primary structural components of the Physical Architecture. They perform functions that "belong" together and whose interfaces require interoperability and compatibility.

  – Users. These are people who interact with the architecture implementation. They could either be those who use the system (such as the flying public or pilots in the NAS) or operators who use features of the system (such as air traffic controllers in the NAS). Each interface to a user involves human interaction with the system.

  – External Systems. These are organizations and agencies and/or their systems that may likely interact/interface with the system under design (such as DoD or National Weather Service to the NAS).

  – Environment. This is the physical world, such as pavement, air, obstacles, and so on.

- **Physical Interfaces.** These are mechanical, electrical, data, and other interfaces between system elements or subsystems. Physical interfaces also include all interfaces between the system and its outside world.

4.5.3.6.1 Decomposition into Physical Entities

The architecture can be viewed at several levels of detail. The architecture defines collections of subsystems while defining their interfaces. Consideration is given to a variety of engineering and programmatic disciplines along with stakeholder contributions, and all are incorporated into the Physical Architecture.

4.5.3.6.2 Physical Interfaces Definition

Identify and define the physical interfaces among products, subsystems, humans, lifecycle processes, and external interfaces to higher-level systems or interacting systems. Physical interfaces that impact design include communication, data, support, test, control, display, connectivity, or resource replenishment characteristics of the interaction among subsystems, the products, humans, or other interfacing systems or a higher-level system (See Interface Management (Section 4.7).)

4.5.3.7 Design Alternative Analysis and Refinement—Step 7

As a particular design alternative is refined, it is analyzed to determine how it satisfies the allocated functional and performance requirements, interface requirements, and design constraints and how it adds to the overall effectiveness of the system or a higher-level system. During analysis, specialty engineers work with design engineers to ensure that requirements such as reliability, availability, maintainability, supportability, safety, human factors, security, electromagnetic compatibility, and spectrum management are incorporated into the design.

Additionally, lifecycle process requirements are identified and defined for each alternative system product solution and aggregate of solutions.

4.5.3.7.1 Assess design capacity to evolve

The design alternative is analyzed with respect to its capacity to evolve or be reengineered, accommodate new technologies, enhance performance, increase functionality, or incorporate other cost-effective or competitive improvements once the system is in production or in the field. It is recommended that limitations that may preclude the ability of a system to evolve be identified and the approach analyzed and refined to resolve any limitations. The supportability of an evolving system may require the support process to evolve along with the product. This consideration may significantly affect support funding and training requirements.

4.5.3.7.2 Develop models and prototypes

Models and/or prototypes are developed to assist in:

- Identifying and reducing risks associated with integrating available and emerging technologies

- Verifying that the design solution (made up of hardware, software, material, humans, facilities, techniques, data, and/or service) meets allocated functional and performance requirements, interface requirements, workload limitations, and constraints

- Verifying that the design solution satisfies Functional Architecture and baseline requirements

The models, data files, and supporting documentation are maintained, and each version of a model or data file that impacts requirements, designs, or decisions saved in the integrated database. Models may be digital, partial, or complete and may be hardware, software, or a combination of both, or may include human models or human-in-the-loop simulations or mockups for usability testing and workload measurement. (See Trade Studies (Section 4.6).)

4.5.3.8 Check Requirements Compliance—Step 8

Compliance with the requirements baseline for the functional area is reviewed and analyzed. For each alternative, the solution level of compliance to all requirements is documented. If full compliance is not reached by any of the alternatives, and they all fail to meet the same requirements, the design loop is initiated. If some, but not all, of the alternatives fail to fully meet all of the requirements, and compliance varies among approaches, the requirements feedback loop is initiated for each design. This is not to be confused with Verification (Section 4.12).

4.5.3.8.1 Design Loop

The design loop involves revisiting the Functional Architecture to verify that the Physical Architecture developed is consistent with the functional and performance requirements. It is a mapping between the functional and Physical Architectures. During design Synthesis, reevaluation of the Functional Analysis may be caused by discovery of design issues that require reexamination of the initial decomposition, performance allocation, or even the higher-level requirements. These issues might include identification of a promising physical solution or open-system opportunities that have different functional characteristics than those foreseen by the initial Functional Architecture requirements.

4.5.3.8.2 Requirements Feedback Loop

The system design is audited to determine compliance with the requirements set. Audits are performed at various levels, from the top-level Physical Architecture down through each hierarchy level to the lowest-level system element or configuration item. Compliance with the requirements is assessed through both informal and formal reviews. The audit results are then fed back to earlier Synthesis steps as needed, resulting in another Synthesis loop. The audit results may call for requirements changes at varying levels, or they may lead to design changes to ensure compliance.

4.5.3.9 Select Preferred Design Solution—Step 9

The best alternative solution is selected using all prior analysis conducted in Synthesis or in conjunction with Requirements Management (Section 4.3), Functional Analysis (Section 4.4), Trade Studies (Section 4.6), Specialty Engineering (Section 4.8), and Risk Management (Section 4.10). The selected solution shall be the one that offers the most balanced design. Upon being selected, the design is detailed and finalized. The designation and description of interfaces (internal and external) among design elements are finalized. The design is baselined and placed under formal configuration management processes.

4.5.4 Process Outputs

It bears repeating that Synthesis is an iterative process, concurrent with Functional Analysis (Section 4.4) and Requirements Management (Section 4.3). The engineering team shall use good judgment in aligning the degree of detail of the Synthesis outputs with the position of the project in the AMS cycle.

Prior to the selection of the preferred design solution, Synthesis outputs are completed concisely and at a very high level for *all* possible solutions. As the functional analysis and baseline requirements become more specific, there are fewer and fewer alternative solutions that answer the need. As the process narrows to the “best” solution, the top choices have detailed, documented outputs from the Synthesis team. Once the Joint Resources Council chooses the preferred solution, the Synthesis team completes the definition of the design process to the finest detail.

Therefore, the following Synthesis outputs occur throughout the iterative process, but vary in scope and level of detail based on the project’s position within the AMS cycle.

4.5.4.1 Physical Architecture

For all the alternative solutions, the system elements are identified along with their arrangement and the interactions between them. A description of the salient features of the overall solution is developed as well as descriptions for the system elements and their relationships establishing a potential System Architecture baseline. The descriptions are diagrams, schematics, concept drawings, tabular data, and narrative reports.

The design architecture is established at a level appropriate to document the design solution and interfaces. It includes the requirements traceability and allocation matrices, which capture the allocation of functional and performance requirements among the system elements. It is recommended that design architecture definitions be stored in the integrated database along with tradeoff analysis results, design rationale, and key decisions to provide traceability of requirements up and down the architecture. It is recommended that verification of the design architecture be accomplished to demonstrate that the architecture satisfies both the validated

requirements baseline and the verified Functional Architecture. This information is further compiled into a Requirements Compliance Matrix.

4.5.4.2 Description of Alternatives

4.5.4.2.1 Concept Description Sheets

A separate description for each of the alternatives developed and refined during Synthesis is documented. For the selected or preferred design, more detail is provided, such that other SE processes can best utilize the information. A complete description of the system, the system operational use, and characteristics is documented in the description sheets.

4.5.4.2.2 Architecture Block Diagrams

The hierarchical relationship of all system elements is to be documented in an Architecture Block Diagram (ABD). The ABD includes hardware and software elements and their hierarchy, documentation and data, facilities, test equipment, and support.

An external ABD is also to be developed to depict the external elements that affect the selected system. It is recommended that the external ABD, like the system ABD, include all hardware, software, facilities, personnel, data, and services having a significant effect on the selected system.

4.5.4.2.3 Schematic Block Diagrams

Schematic Block Diagrams (SBD) illustrate the physical partitioning and interfaces for each candidate hardware and software design solution determined to be viable. It is recommended that SBDs not be developed for every conceivable design, but only for those that are worthy of detailed evaluation (based on position within AMS cycle).

4.5.4.2.4 Interface Drawings

Drawings are developed for all system physical element interactions. Additionally, all interactions to external physical elements are also documented in drawings. The drawings provide the visualization of interfaces and are the basis by which interface specifications and control documents are developed later under Interface Management (Section 4.7).

4.5.4.3 Integrated data package

The drawings, schematics, software documentation, manual procedures, and so on are developed as necessary to document the selected design elements in an integrated data package.

4.5.4.3.1 Configuration Item Descriptions

Each of the system elements are identified during the Synthesis process. This includes all hardware configuration items (HWCI) and computer software configuration items (CSCI). Documentation and description of each HWCI and CSCI occurs at identification of the item in summary or preliminary fashion. Once a final design alternative is selected, detailed documentation for each HWCI and CSCI of the selected system is developed, thus establishing a configuration baseline for the system (See Configuration Management (Section 4.11)).

4.5.4.3.2 Specification Inputs

During Synthesis, compliance with the requirements baseline (RVCD) was assessed. This analysis sometimes results in recommendations for requirements modification or elimination. Any proposed modifications or deletions are documented and forwarded to Requirements Management (Section 4.3).

4.5.4.3.3 Requirements Compliance Matrix

All requirements have been mapped to the system elements. As the mapping occurred during Synthesis, a matrix was developed containing all requirements, the subsystem or element to which they were assigned, and the level of adherence to the requirements achieved by the component. The matrix is designed for each level of the Physical Architecture, and all performance, functional, and constraint requirements are listed in the matrix to reflect each level of the architecture. Compliance levels are determined using system/cost-effectiveness analysis, simulations, demonstrations, inspection, and or testing.

4.5.4.3.4 Refined Work Breakdown Structure

The selected design's Physical Architecture is used to refine the Work Breakdown Structure (WBS) by translating the decomposition into a WBS format. The refined WBS provides enhanced work planning, cost/schedule tracking, and control by extending the existing WBS to account for the system elements identified during Synthesis.

4.5.4.4 Constraints

Constraints are formed before entering the Synthesis process, and yet more may be identified during the process. Synthesis looks at many different aspects of the system design, including cost, scheduling, feasibility, requirements, function and others. As various solutions to the MNS are considered and refined, constraints become apparent.

Constraints are clearly seen when performing step 4 of the Synthesis process, Allocation of Requirements to System elements (Paragraph 4.5.3.5.1). The constraints identified may cause iteration through the design feedback loop or the Requirements feedback loop. An evolutionary development is initiated, if necessary, for any design element for which a lesser technology solution was selected over a higher-risk technology, and for which the capacity to evolve was designed into the element and interfacing elements. (See Trade Studies (Section 4.6).)

4.5.4.4.1 Design Constraints

Constraints specific to the Synthesis process, design constraints, are identified and documented in step 5 (see Paragraph 4.5.3.5.2). These constraints do not apply to the functionality of the system, rather they are in the area of hardware, software, or people. Because these design constraints are so important in analyzing replacement of existing systems, they are documented and sent on for further study in the Lifecycle Engineering process (Section 4.13), aiding in identifying the timing of future replacement schedules. Additionally, these design constraints become another output of the Synthesis process, as requests for Trade Study (Section 4.6) evaluation are sent out.

4.5.4.5 Planning Criteria

Planning criteria describing planned activities for the Synthesis process are output to the Integrated Technical Planning process (Section 4.2).

4.5.4.6 Tools/Analysis Requirements

Tools/Analysis Requirements for performing Synthesis throughout the remainder of the program's lifecycle need to be provided to the Integrity of Analysis process (Section 4.9).

4.5.4.7 Concerns/Issues

Appendix D contains guidance on Concerns/Issues as a product of Synthesis and how to best convey that information to the Risk Management team (Section 4.10).

4.5.4.8 Planning Criteria

Planning criteria describing planned activities for the Synthesis process are output to the Integrated Technical Planning process (Section 4.2).

4.5.5 Metrics

Performance of the Synthesis process itself shall be measured on a regular basis and recorded in the metrics library on a monthly basis. The following metrics, at a minimum, may be used to evaluate performance:

1. Trade Study Satisfaction Assessment (see Trade Studies (Section 4.6))
2. For approved engineering problem reports:
    a. Quantity, by type of problem report
    b. Cycle-time from disposition to incorporation of change into released engineering documents, by type of report
3. Technical Performance Measurements: objective versus achieved values
4. Number of approved engineering changes: by product, type, and stage
5. Documents/drawings submitted for engineering release:
    a. Unacceptable submittals
    b. Total submittals
6. Number of technical action items identified during reviews and audits
7. Design efficiency metrics, such as weight, required power, and envelope dimensions (volume)
8. Cost and schedule variance for the completion of Synthesis steps
9. System requirements not met
10. Number or percent of system requirements verified by system analyses
11. Number of TBDs in system architecture or design
12. Number of interface issues not resolved

13. Percent of identified system elements that have been defined

4.5.6 Tools

4.5.6.1 Schematic Block Diagrams (SBD)

Along with the definition of design alternatives, it is important to establish the relationships between alternatives at each level of design activity. A medium for accomplishing this is by using SBDs.

A simplified SBD shows the components that may comprise an element and the data that may flow between them. An expanded version is usually developed that displays the detailed functions performed within each component and their interrelationships. For complex systems, this may then be developed into a logic diagram for auditing the schematics produced. This audit is a critical SE function. It is recommended that Interface information also be embedded into the SBDs, as appropriate. The interface data forms the basis for the interface specifications to be developed at multiple levels of the system hierarchy. An N^2 diagram (see Functional Analysis (Section 4.4) for examples) is very useful for developing and auditing interfaces at all levels.

If software is an element of the design, it shall be determined whether a given function is to be accomplished in hardware or software. It is recommended that Computer Software Elements (CSE) be defined during this step of the process and embedded within the SBDs. Experience shows that it is helpful to first define the top-level HWCI and/or CSCI in which a given software function is to reside before defining which candidate CSEs may accomplish the function. Additionally, as part of Section 4.5.3.7 of the Synthesis process (Physical Architecture definition), it is recommended that a given function be tracked to determine whether it has been allocated to a software alternative or a hardware alternative. Determining the appropriate level of the system hierarchy for defining CSEs is largely project dependent.

The products of this step of the SE process are a set of viable system alternatives responsive to the design goals and a series of SBDs depicting how the alternatives interrelate.

4.5.6.2 Computer-Aided Design

Modern computing hardware and software is used to convert the initial idea for a system into a detailed engineering design. The evolution involves creating geometric system models that are later manipulated, analyzed, and refined.

4.5.7 References

1. Defense Systems Management College. “Systems Engineering Fundamentals.” Fort Belvoir, VA: Defense Systems Management College Press, 1999
2. EIA Interim Standard, Systems Engineering Capability Model, EIA/IS-731.1, December 1998
3. EIA Standard, Processes for Engineering a System, EIA-632, January 7, 1999
4. Guidelines for Approval of the Provision and Use of Air Traffic Services Supported by Data Communications, RTCA/DO-264, Prepared by SC-189, December 14, 2000
5. Handbook of Systems Engineering and Management, Andrew P. Sage and William B. Rouse, ©1999

6. IEEE Standard for Application and Management of the Systems Engineering Process, IEEE Std-1220-1998
7. International Council on Systems Engineering. "Systems Engineering Handbook," Version 2.0, 2000
8. ITS Physical Architecture Physical Architecture, Lockheed Martin Federal Systems, Odetics Intelligent Transportation Systems Division, September 1998
9. KAREN Physical Architecture Physical Architecture, Version 2, Siemens Traffic Controls Limited, October 1999
10. Systems Engineering Management, Second Edition, Benjamin S. Blanchard, ©1998
11. Systems Engineering Guidebook, A Process for Developing Systems and Products, James N. Martin, ©1997

4.6 Trade Studies

Trade Studies is the System Engineering (SE) element used by multidisciplinary teams to identify the most balanced technical solutions among a set of proposed viable solutions. It is a key tool in developing designs that meet stakeholder requirements in the most cost-efficient manner possible. The application of Trade Studies prevents program/project management from committing too early to a design that may not be cost-effective or meets all system requirements. Through Trade Studies, desirable and practical alternatives that better combine cost and effectiveness may be identified, resulting in beneficial selections among the alternatives. Figure 4.6-1 depicts the Trade Studies Process-Based Management chart.

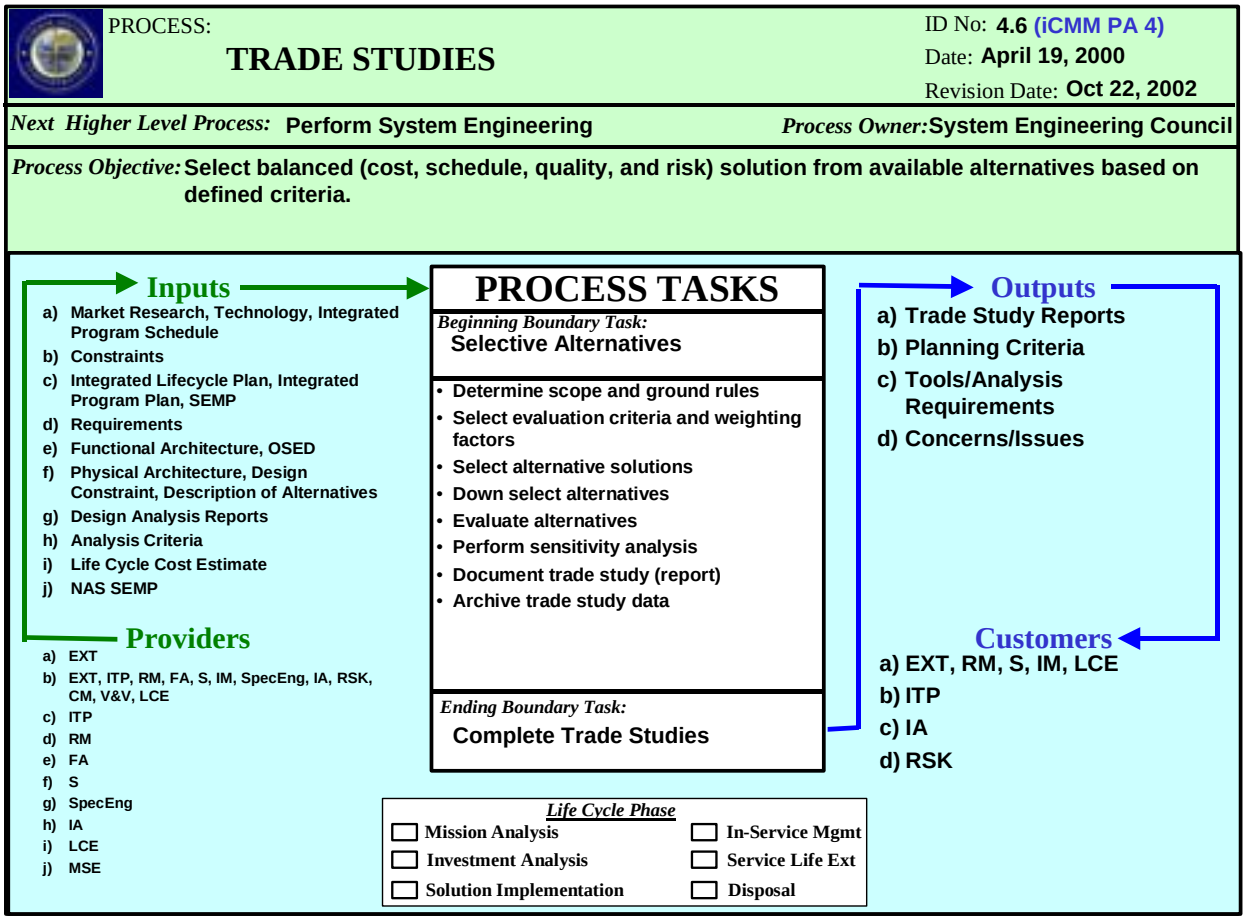


Figure 4.6-1. Trade Studies Process-Based Management Chart

Conducting Trade Studies involves evaluating two or more alternatives to select a preferred option. The Trade Studies process balances such considerations as cost, reliability, testability, supportability, survivability, compatibility, and producibility during each phase of the product development cycle.

A disciplined Trade Studies process is required to fairly evaluate alternative concepts and designs. The process requires that any affected discipline participate in the program/project to the extent needed to arrive at the best-balanced requirements solution. Typically, a Trade

Studies leader, who is not a stakeholder in any of the proposed solutions, helps to focus and coordinate the flow of information that occurs during the Trade Studies process.

Trade Studies may be formal and informal, with different emphases, depending on when in the program lifecycle they are conducted. It is appropriate to develop a Trade Studies plan (Integrated Technical Planning (Section 4.2)) for each major problem or issue for which alternatives are being considered.

This section describes the Trade Studies process as a formal decisionmaking methodology used to select among alternative concepts, designs, products, or approaches that satisfy the system implementation and to resolve any conflicts that arise during the system's lifecycle.

4.6.1 Introduction to Trade Studies

Trade Studies are conducted within and across disciplines to support decisions at any phase of the program's lifecycle. The process quantifies and/or qualifies the consequences of selecting various system alternatives in terms of metrics that are traceable to customer requirements and are declared by project management to be project objectives. They support the allocation of performance requirements and the determination of design constraints and are used in evaluating alternative functional architectures obtained from Functional Analysis (Section 4.4). In general, the results of the Trade Studies process may be quantitative or qualitative in nature.

Trade Studies may be performed at any step in the system's lifecycle, but the process begins at the Mission Analysis (MA) phase and continues through first article production. For example, the major goal of the Investment Analysis (IA) phase is to define a set of system requirements that meet the goals and objectives of a mission or a system at an affordable cost and with an acceptable level of risk. During this phase, Trade Studies may be used to select among competing sets of requirements that define alternative system concepts. In a similar manner, the Trade Studies process is used to assist SE.

The following list summarizes the use and emphasis of Trade Studies in the program's lifecycle:

MA phase:

- Define mission requirements
- Resolve conflicting high-level customer requirements
- Evaluate alternative high-level requirements to meet mission needs

IA phase:

- Compare technologies and approaches
- Evaluate concepts to meet high-level requirements
- Select alternative system configurations for further study
- Select concept for preliminary design development and conceptual layouts
- Support Functional Analysis (Section 4.4) and allocation of performance requirements (alternative architectures)
- Establish system configuration
- Support decision for new product development versus nondevelopment products

- Establish system, subsystem, and component configurations
- Select testing methods
- Determine installation locations; check for fit and compatible environment
- Detail design
- Define a best-value design solution that satisfies all system requirements
- Support detailed design analysis
- Compare manufacturing processes
- Determine best order of assembly

Solution Implementation phase:

- First article, full-scale development
- Resolve unexpected manufacturing issues, such as changing the order of assembly or revising a manufacturing process
- Select alternative designs, solutions (operations, maintenance, integrated logistic), procedures, and configurations

4.6.1.1 Trade Studies Objectives

Trade Studies are conducted at the program's different lifecycle stages to discover the best-value solution, best value to the government, and best value to a set of requirements from technical, cost, or schedules points of view. Trade Studies, also referred to as tradeoff studies or selection studies, are performed for a variety of purposes, including to:

- Choose among alternative design and implementation strategies and solutions based on architecture, performance, and cost in order to meet stakeholder requirements
- Recommend commercial-off-the-shelf (COTS) products for acquisition
- Perform make versus buy analyses, or buy versus lease analyses (Office of Management and Budget Circular a.76, Outsourcing Decision)
- Recommend a supplier for services
- Document and justify the selection of a solution for a system requirement
- Reduce risk

Trade Studies provide an objective determination of comparative metrics for various system options. An essential aspect of the analyses performed for these studies is that consistent, configuration-controlled parameters be used in the computations to ensure comparison of likely system solutions.

4.6.1.2 Participants

All elements of the project organization are responsible for Trade Studies. The process requires the participation of various interdisciplinary skills in an integrated manner with the objective of producing an optimum system design.

Design, manufacturing, test, operations, and product support perform lower-level Trade Studies that involve subsystems, components, subcomponents, and software. In the event of utilization of system-level resources contention, program/project management coordinates with the stakeholder organizations to resolve issues and establish priorities. It is recommended that Trade Studies affecting hardware and software account for system issues related to software, operations, procedures, training, and other nonmaterial-related solutions.

To determine impacts across interfaces, it is recommended that SE integrate the Trade Studies performed by various groups.

4.6.2 Inputs to Trade Studies

Inputs to the Trade Studies process may be divided into two categories: stakeholders and project. The stakeholder inputs include the operations concept, program requirements, and system requirements. The project inputs include design analysis report (DAR), Functional Architecture (Section 4.4), DAR (Section 4.8), results from Validation and Verification (Section 4.12), and Lifecycle Cost Estimates from Lifecycle Engineering (Section 4.13).

The Trade Studies process presupposes that alternatives have been identified that are evaluated as specified by the process objective. To complete this task:

- Requirements, Constraints, expectations, assumptions, goals, and regulations shall be clearly understood
- Design options, including Baseline and other criteria, shall be provided or developed
- Relevant plans and documents shall be provided

4.6.3 Trade Studies Process Tasks

The methodology to evaluate system alternatives is described in the following paragraphs. The Trade Studies process consists of the following tasks:

- Determine scope and ground rules
- Define evaluation criteria and weighting factors
- Select alternative solutions (brainstorm possible solutions), if not provided
- Down-select alternatives
- Evaluate alternatives
- Perform sensitivity analysis
- Review results and form conclusions
- Document the Trade Studies

These steps seldom are performed sequentially. Certain steps, such as definition of evaluation criteria, may be repeated several times as alternatives are defined and evaluated. Figure 4.6-2 depicts the overall Trade Studies process.

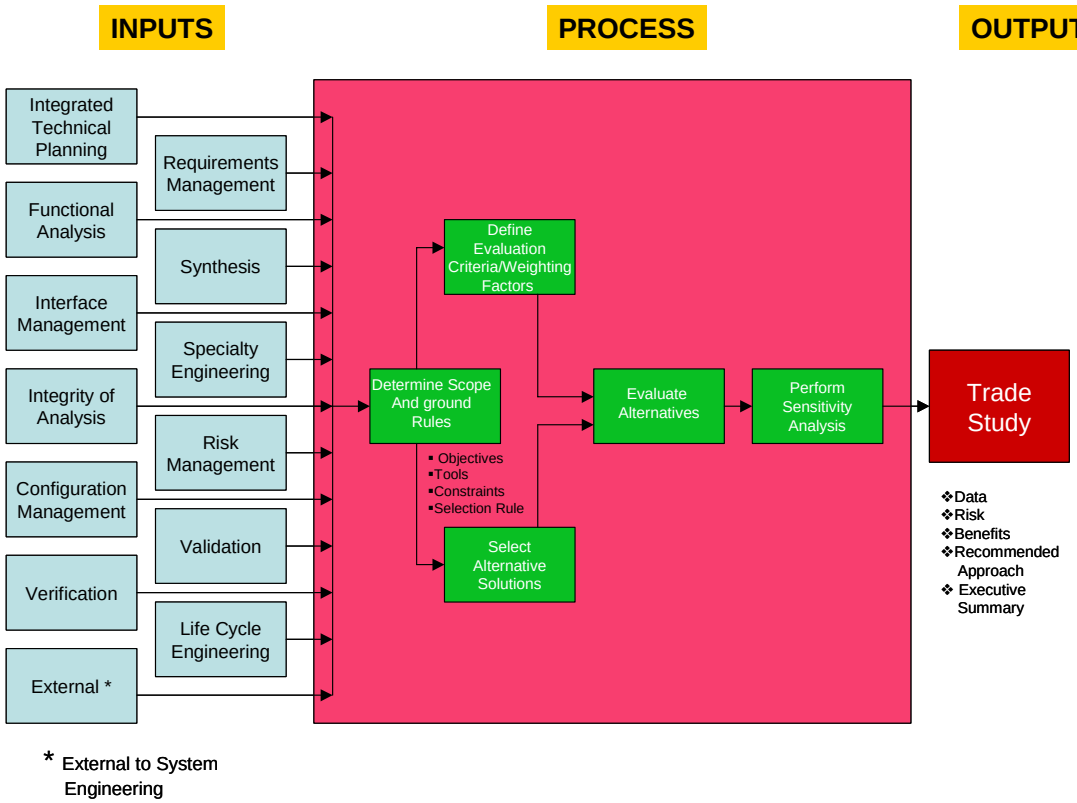


Figure 4.6-2. Trade Study Process

4.6.3.1 Task 1: Determine Scope and Ground Rules

To complete Task 1, perform/consider the following checklist of actions/issues:

- Determine the specific goals of the Trade Studies and the Requirements to be met before establishing the scope and methods of the study:
  - Consider all viewpoints of stakeholders (e.g., users, developers, managers, and operations and maintenance personnel) to accomplish this goal
  - Ensure that input is obtained from all customers associated with the study and that the stakeholders' viewpoints are clearly understood and documented
  - Understand and resolve differences between competing viewpoints and any underlying biases before continuing the evaluation process
- Use the methodology described in Requirements Management (Section 4.3) to define and analyze the Requirements for the Trade Studies:
  - Select Requirements to bound the Trade Studies into four major categories: functional, performance, operational, and programmatic
  - Base the Requirements on the goals established for the study and adjust the level of detail of the Requirements to the scope of the particular study

  - Ensure that the Requirements, which are used as a basis for criteria against which alternatives are evaluated, are accurate, unambiguous, verifiable, complete, and appropriate
  - Obtain the customer's approval on the goals and Requirements for the tradeoff study
- Define the system's goals and objectives and identify the Constraints to satisfy:
  - Recall that in the early phases of the system's lifecycle, the goals, objectives, and Constraints are usually stated in the operational terms; when the system architecture and design have been determined or established, the goals and objectives are usually stated as performance requirements
- Spend time up front clearly defining the problem and jointly coordinating with the respective internal and external customers the key Requirements that any solution needs to meet. Achieving consensus with affected team leaders regarding the real problem to be resolved saves significant time in the overall process.
- Establish a multidisciplinary team that is able to support the analysis effort from start to finish. Having expertise within each discipline ensures that alternatives are thoroughly evaluated, leading to the most accurate assessment results. Available budget and time control most studies; therefore, when equipped with this information, team members realize how far they may pursue alternatives.
- Develop an attainable schedule as well as identify major Trade Studies milestones. It is recommended that the degree to which excursions from the baseline concept are allowed also be defined. A study lacking clear boundaries easily grows far beyond the available resources.

It is recommended that the Trade Studies team leader coordinate items that influence subsystems and assess the impact on his/her area. It is also recommended that subcontractors, as well as those on the Trade Studies team, consider and identify previously developed hardware and software components, non-developmental items, and COTS hardware and software as candidates for utilization in the Trade Studies. Additional items for the team to consider and identify are common components in different parts of development to share across development groups or across configuration items.

Before the Trade Studies process is conducted, the decisionmaking body responsible for the affected baseline shall approve the Trade Studies plan.

4.6.3.2 Task 2: Define Evaluation Criteria and Weighting Factors

The definitions of measures and measurement methods for system effectiveness, system performance, and system cost are related to the definition of goals and objectives and Functional Analysis (Section 4.4) performance. These measurements are the decision criteria. Each quantitative measure shall have a defined measurement or computational method. This task initiates the analytical portion of the Trade Studies process, as it involves using quantitative methods.

The definition of evaluation criteria requires considerable engineering judgment and interaction with the stakeholder to establish the appropriate criteria, associated weights, and scoring methods. For example, supporting missions with tight schedules requires heavy weighting of schedule risk, while supporting missions with more flexible schedules generally emphasizes low

cost while accepting higher schedule risks. Sufficient comments shall be provided for each evaluation criterion to ensure evaluator and stakeholder comprehension. Stakeholder approval shall be obtained before proceeding to the next task.

The technical requirements that potential solutions need to achieve serve as the criteria against which alternative concepts are measured. The selected criteria may include limits of minimum acceptable values and desirable attributes that permit judging of candidates against each other. Trade Studies leaders are encouraged to use Quality Function Deployment (QFD) to help to define the evaluation criteria and weighting factors applicable to the Trade Studies. These criteria are defined based on the technical requirements that determine if a design is acceptable to the Stakeholder Needs.

Evaluation criteria are more meaningful if they represent measurable characteristics, which is not always possible. It is recommended that criteria on cost and programmatic risk be included. Alternatives may be evaluated based on projected fixed and variable cost using risk factors, when applicable, to derive expected costs. It is also recommended that elements not directly related to cost (e.g., weight, production cycle time) have criteria established to associate cost with changes in the elements. Trade Studies shall address these criteria.

An experienced, multidisciplinary team shall brainstorm a list of additional criteria suitable for the study's intent if all feasible alternatives are to be identified and thoroughly evaluated. Each criterion shall be described to a level of detail such that its intent is clear to all team members. This detail ensures that all participants are well aware of specified and derived Requirements affecting evaluation.

When a particular study is planned, the effort and cost of that study shall be balanced against the impact (e.g., cost, schedule, and technical risks) on the study's scope and methodology. An overly ambitious and costly study among low-impact alternatives is as serious as the failure to adequately evaluate high-impact alternatives. For a simple evaluation of several low-impact alternatives, subjective evaluation and consensus may be sufficient. For complex studies with higher impact, the following is recommended:

- Define evaluation criteria based on the Requirements analysis.
- Determine relative weights for the evaluation criteria based on the Requirements analysis.
- Prepare a scoring matrix that assigns a row for each evaluation criterion and a column for each alternative to be evaluated, with comment fields for each criterion.
- Define a method for assigning a score to each element in the scoring matrix.
- Assign a score for each criterion for each alternative:
  - Select scores in such a manner that the higher the score, the more favorable the evaluation; use an odd number of integers so that the middle score represents an average rating
  - Use small integers, typically 0 to 5, to represent scores; a range of 0 to 2 may be adequate; a range in excess of 0 to 10 is not recommended
  - Determine a method of recording items that is unable to be scored; define the scoring method to be used; recording a blank for unknown information often is useful

- Prepare a weighted score matrix that assigns a row for each evaluation criterion and its weight and assigns a column for each alternative to be evaluated. The weighted score recorded for each element in the matrix is the product of the weight for that criterion and the corresponding score in the scoring matrix.

Figure 4.6-3 is a sample decision analysis matrix.

Decision Factors / Alternatives	Decision Factor 1		Decision Factor 2		...	Decision Factor n		Total Weighted Score
	Weight = 1		Weight = 1.5		...	Weight = 2.5		
	Score	Weighted Score	Score	Weighted Score	...	Score	Weighted Score	
Alternative 1	7	21	4	6	...	8	20	47
Alternative 2	8	24	10	15	...	10	25	64
⋮	⋮	⋮	⋮	⋮	...	⋮	⋮	⋮
Alternative n	10	30	5	7.5	...	12	30	
Alternative n+1	⋮	⋮	⋮	⋮	...	⋮	⋮	⋮

Figure 4.6-3. Decision Analysis Matrix

Stakeholder approval of the proposed evaluation method shall be obtained.

Stakeholders and internal technical experts are used to establish meaningful evaluation criteria. Criteria for which all potential alternatives are equal in value are not used in the evaluation because they do not add value to the process.

Defining evaluation criteria often requires several iterations before the final criteria are determined. Evaluation criteria are defined based on the analysis of Requirements. Bias shall be avoided when evaluation criteria are established (e.g., acceptance of an existing system or product as the de facto standard for evaluation). The following evaluation criteria are applicable to a wide range of Trade Studies:

- Development cost
- Lifecycle cost
- Requirements compliance
  - Functional
  - Performance
  - Operational
  - Programmatic
- Technical risk (Maturity)

1. Reliability, Maintainability, Availability
2. System Safety
3. Quality
4. Human Factors
5. Electromagnetic Environmental Effects
6. Hazardous Materials

- Budget risk
- Schedule risk
- Operational complexity
- Vendor assessment
- System maturity
- Development support tools
- Test support tools
- Development team familiarity with candidate hardware and software
- Quality of logistics support

Evaluation criteria that apply specifically to the Trade Studies shall be selected, adding additional relevant criteria, such as security, as needed. For each evaluation criterion, established threshold values that may be used to evaluate the alternatives on a pass/fail basis shall be identified. An example criterion is: “The system MTBF [mean-time-before-failure] shall be 10,000 hours or greater." For the remaining criteria, a weight and scoring range shall be assigned for use with the weighted matrix evaluation method.

Criteria are ranked and grouped into three categories so that the assigned weights reflect their criticality. The most critical criteria are assigned large weights and flagged so that any alternative with low scores for these criteria influence any subsequent analysis. Mid-critical and noncritical criteria are assigned smaller weights; it is recommended that noncritical criteria have a negligible effect in further analysis.

4.6.3.3 Task 3: Select Alternative Solutions

Once the evaluation method is established, all available resources are used to develop viable alternatives and solutions. Trade publications, prospective bidders for service contracts, technical staff, stakeholders, and managers, as appropriate, are helpful resources in developing a set of alternatives that may potentially achieve the goals and objectives of the system (e.g., architectures, designs, COTS products).

Based on defined ground rules, the alternative development phase is intended to evaluate multiple alternatives and narrow the prospects for extensive evaluation. The importance of creativity is especially emphasized, as this task may or may not affect the alternative design solutions previously submitted.

The evaluation criteria and detailed Requirements shall be used to synthesize alternative solutions. In defining alternative approaches, developing the alternatives often requires

lower-level Trade Studies, which enables a hierarchy of design alternatives. A trade tree that reflects the complete hierarchy of trades to address when performing the top-level Trade Studies shall be drawn. The trade tree shall contain a number of high-level system architectures, which prevents focusing on a single architecture. To eliminate undesirable alternatives, for each trade item in the trade tree, the tasks in the sections above shall be repeated until a complete trade tree is generated, and the objectives, Requirements, evaluation method, and evaluation criteria are defined. Top-level objectives and Requirements are allocated to successively lower levels of Trade Studies in the trade tree. The allocated objectives and Requirements are used to define the evaluation methodology and criteria, and evaluation is performed, as described in the following paragraphs.

Each design alternative shall be thoroughly assessed. Potential design approaches for each Requirement shall be reviewed against potential approaches for other Requirements in order to identify possible interactions. It is recommended that interactions that might affect the cost of, or make one solution feasible, be documented and handled as linked decisions throughout the Trade Studies process.

Often, risk is the deciding factor in candidate selection. A complete technical analysis identifies and quantifies technical risks and develops contingency alternatives. Therefore, the technical and schedule risks associated with each candidate system are identified, and the probable gain and loss for each risk are analyzed. Also, an acceptable level of risk for a given gain is defined, and efforts are undertaken to minimize new, unproven, complex, or unusual Requirements for hardware, software, and firmware. The use of untried elements is minimized by recommending proven substitutes whenever possible.

A technical analysis of schedule risk areas is performed, and all long-leadtime items, which are the schedule drivers, are identified. How the design affects the development schedule is discovered, and all system elements and resources that may be available when needed are determined. All single-source items that may be potential risks are identified, and a recommended level of schedule contingency, as appropriate, is defined.

Expected operational scenarios for each candidate system to assess the interactions of the design alternatives are defined. Also, the expected system growth over the planned system life is determined to assess system design flexibility and expandability. Because system sizing is based on the anticipated workload, every effort to ensure an accurate workload forecast is made, as improperly sized systems result in unnecessary cost and/or insufficient capacity. Human workload and scenario definitions are used as drivers to assess performance, utilization, and capacity of the system under anticipated operational conditions. (Specialty Engineering (Section 4.8) provides guidance on this topic.)

Once a set of possible alternatives has been selected, the next task is to collect data on each to support the evaluation of the measures by the selected method. The data collection, directed by the Trade Studies leader, emphasizes the role of the disciplines, such as reliability, maintainability, integrated logistics, producibility, software, testing, operations, and costing. Figure 4.6-4 is an example of a Trade Studies table.

Criteria	Alternative 1	Alternative 2	- - -	Alternative N
Cost ▪Initial ▪Recurring	High low	Medium Low	- - -	Low Low
Performance	Low	High	- - -	New Design
Reliability Maintainability Availability	Medium	High	- - -	Medium
Risk ▪Cost ▪Technical	Low (20%) Low (25%)	Low (10%) Low (20%)	- - -	Low (10%) Medium (35%)

Figure 4.6-4. Example Trade Study Table

4.6.3.4 Task 4: Down-Select Alternatives

When numerous possible alternatives are identified, a detailed analysis of each one may not be cost-effective; therefore, down-selection of candidates is recommended. Identifying high-risk candidates and candidates with questionable feasibility or high lifecycle cost helps to reduce the number of alternatives to be studied. Screening the alternatives against the selection criteria eliminates these candidates. If one of a closely grouped set of alternatives is down-selected, it is recommended that all alternatives in that group be down-selected. Any relationship that is not the same for each down-selected alternative and the baseline becomes part of the detailed Trade Studies. Each alternative is defined to an appropriate level of detail to differentiate the alternative with respect to the technical requirements, which typically include layouts, tooling concepts, cost studies, and other detailed analysis. When only the down-select Requirements are the focus, the effort is simplified to only those Requirements that are different among the design alternatives and the baseline.

The down-selected alternatives are provided to all disciplines involved to ensure that each has the opportunity to evaluate the impacts. This process provides discrete impacts for each area used to select the preferred alternative. It is recommended that this process be performed in parallel with each discipline preparing its inputs simultaneously.

4.6.3.5 Task 5: Evaluate Alternatives

The next task in the Trade Studies process is to quantify the outcome variables by computing estimates of system effectiveness, underlying system performance or technical attributes, and system cost. If the needed data has been collected and the measurement methods (e.g., models) are in place, this step, in theory, is mechanical. In practice, considerable skill often is needed to obtain meaningful results.

Recommended Task 4 actions include the following:

- Perform a detailed evaluation of all approved viable alternatives. An individual or a small group may perform this evaluation. Record any problems or questions. If a weighted matrix method is used, finish scoring without reference to weights or flags.

- Evaluate the alternative approaches relative to the evaluation criteria when performing the Trade Studies process.
- Identify any alternatives with high-weighted scores that narrowly failed the pass/fail criteria. Discuss these alternatives with the stakeholder.
- Evaluate cost factors separately from the remaining evaluation criteria throughout the process. In some cases, none of the alternatives may satisfy all pass/fail criteria. In such cases, relax one or more pass/fail criteria, investigate additional alternatives, or report to the stakeholder that no entirely acceptable alternative has been found.

Ideally, all input values are precisely known, and models perfectly predict outcome variables. Since this case is not typical, it is recommended that the Trade Studies leader supplement point estimates of the outcome variables for each alternative with computed or estimated uncertainty ranges. For each uncertain key input, it is recommended that a range of values be estimated. Using this range of input values, the sensitivity of the outcome variables may be gauged, and their uncertainty ranges calculated. Figure 4.6-4 is an example of a Trade Studies table.

The baseline reference method, relative rank method, and cost assessment method are several methods used to evaluate alternatives and are discussed in the following paragraphs.

4.6.3.5.1 Baseline Reference Method

The baseline reference method requires a baseline or legacy design and a set of associated databases on the use of that design. Alternatives are evaluated against the baseline design or other reference using the selected evaluation criteria. If an alternative is clearly better than the baseline, it is marked as a plus (+); clearly worse than the baseline (-); same as baseline (S); and unacceptable as the baseline (U). This evaluation requires a team effort of all disciplines participating in the study, with team agreement for each rating. It is recommended that notes be maintained as to why ratings are given for each relationship. Using numbers or ++/-- may expand the sensitivity of the +/- system. However, doing so slows the evaluation process and places dangerous emphasis on the matrix as a tool that delivers answers more definitive than the process warrants. When making the +/- decision, the magnitude of the difference shall be considered; however, the process of marking an only marginally better feature as + compared to the baseline shall be avoided.

Generally, alternatives with a U relationship are eliminated, or the U condition is removed; however, there are exceptions to this rule. An exception may be when the Trade Studies process is conducted to determine whether there are sufficient benefits from an alternative to justify a request for a specification change. Also, an alternative in a study may present itself that significantly improves the overall system performance but requires a specification change. It is recommended that common sense be used when U relationships are evaluated and that the users' needs be considered.

Once relationships are defined for each alternative and technical requirement, the overall value of merit of the alternative is calculated. A value of +1 is assigned to each (+) rating, and a -1 to each (-) rating. A relative weight may also be assigned to each evaluation criterion if not all criteria are considered equal. QFD may help to determine this importance weighting.

It is recommended that the following actions be taken when the baseline reference method is used:

- Multiply the importance weighting and the evaluation and then perform the sum calculation for each alternative. No calculation is performed for the same evaluations because this method of evaluation is relative to the baseline. The overall importance rating is a figure of merit for each alternative. The higher the importance rating, the better the alternative for the given design requirement. However, this guide is only relative. Do not differentiate alternatives by closely grouped importance ratings. If, for example, three concepts fall in a range of 10-20 and the other is -30, the alternatives in the group 10-20 are basically equivalent.
- Review each alternative to gain an overall understanding of the meaning of the final importance rating. It is recommended that the team review all the alternatives with negative relationships and develop supplemental alternatives that eliminate these negatives, resulting in additional viable alternatives. Some of these alternatives use portions of the previously developed alternatives. The development and evaluation of subsequent alternatives shall follow the procedures used for initial alternative development. When supplemental alternatives are developed, low sensitivity of the +/- system is avoided. Developing supplemental alternatives is critical to a successful Trade Studies. A "zero change" option normally is included for comparison.

4.6.3.5.2 Relative Rank Method

The relative rank method uses the Kepner and Tregoe technique to evaluate alternatives. This technique evaluates each alternative against the selected criteria and establishes a ranking for each criterion. Weighting of the criteria is defined by category, while the trade options are graded in their appropriate columns according to the scaling factors over the range 0 to 4. The average ranking within each category is multiplied by the criteria weighting to determine a score. Scores are summed across the criteria for a total.

4.6.3.5.3 Cost Assessment Method

The cost assessment method is similar to the baseline reference method, with the exception that the alternatives are reduced to rough order of magnitude (ROM) estimates of fixed and variable costs. Elements that do not reduce directly to cost (e.g., weight, production cycle time) are translated to cost using common criteria described in “Task 2: Define Evaluation Criteria and Weighting Factors” (Paragraph 4.6.3.2). If risks are present, risk projections are used to calculate an expected value.

As cost is a major factor in selecting among candidate systems during system design, development, implementation, and operational costs shall be considered when the lifecycle costs of candidate system configurations are evaluated. A refinement of earlier ROM cost estimates is required to complete the information needed to select the system configuration. It is recommended that the estimate include estimates submitted by major subcontractors and vendors and contain sufficient cost detail to answer client questions.

In addition, it is recommended that the following actions be taken when the cost assessment method is used:

- Determine the relative complexity and risk of each candidate system configuration.
- Identify how each candidate system configuration proposes to handle stringent system requirements, such as response time, transaction processing time, and throughput.

- Analyze how each candidate configuration meets special system requirements for a high level of reliability and availability or for quick recovery or automatic failover.
- Highlight key factors that result in lower cost and risk. Discuss the factors with the stakeholder, including the option of analyzing a more simple system that addresses only the most critical requirements set. This type of analysis gives the stakeholder a minimum system cost benchmark to assess cost of the candidate system and functionality of each requirement.
- Include the tradeoffs among hardware, software, and manual operations as part of the cost analysis, and identify the most sensitive cost drivers of each candidate system. If the system has security requirements, also consider security cost drivers.

4.6.3.6 Task 6: Perform Sensitivity Analysis

Sensitivity analysis is used when the solutions are nearly equivalent in scoring and, in some cases, may be required even if the scoring is equivalent.

Recommended Task 5 actions include the following:

- If using a weighted matrix evaluation method, analyze all alternatives to determine if the differences between the scores are truly significant and if minor variations in the raw scores and weights might affect the selection. Reference any questions or problems noted by evaluators. For each compliant alternative, including any solution that is compliant based on redefined pass/fail criteria, determine if any weighted score or total for a group of related weighted scores is sensitive to variation of weights or scores.
- Evaluate the effect on weighted scores of varying weights. If some weights are determined by compromise, the range of reasonable values discussed during the definition of evaluation criteria (Paragraph 4.6.3.2) provides useful guidance for such variation.
- Evaluate the sensitivity of weighted scores to variation of scores. If a number of evaluators have evaluated the alternatives against a given criterion, the range of scores recorded provides useful guidance for such variation.
- Record the ranges of scores and weights evaluated for each criterion. Compute the upper and lower bound for weighted scores (and groups of weighted scores). Document the data in a matrix corresponding to the score and weighted score matrices.
- By inspection or use of a suitable statistical test, determine if any of the variations are large enough to require special attention (i.e., more detailed investigation to ensure the accuracy of the evaluation).
- Evaluate the effect on weighted score totals, including or excluding criteria flagged as noncritical.

Typical outcomes of the sensitivity analysis and review of results include the following:

- **Case 1:** One alternative emerges as the optimal choice if it meets all critical requirements, has the highest weighted score (with a range that does not overlap the range of another alternative), and has the lowest cost.
- **Case 2:** A cluster of alternatives is acceptable (i.e., each alternative in the cluster satisfies all critical requirements, its weighted scores have overlapping ranges, and its cost is competitive).

- **Case 3:** No single, entirely satisfactory alternative is found.

Case 1 is the most straightforward for the stakeholder. Case 2 may be resolved by reviewing evaluation results with the stakeholders. If a weighted matrix evaluation method is used, inspecting the score and weighted score matrices may reveal patterns that are helpful and clear in the decisionmaking process. A review of weights and criteria may indicate that weights may be modified, which may resolve the overlap. Additional factors may be identified as criteria to resolve the overlap. If the overlap of weighted scores persists, the lowest-cost alternative may be selected. Case 3 is the most difficult to resolve. A review of evaluation criteria, especially pass/fail and critical criteria, may indicate that no satisfactory alternative has been identified by the study. In this case, engineering judgment and discussions with the stakeholder shall be used to define additional alternatives or to accept a less than optimal alternative.

Figure 4.6-5 depicts typical utility curves used for sensitivity analysis.

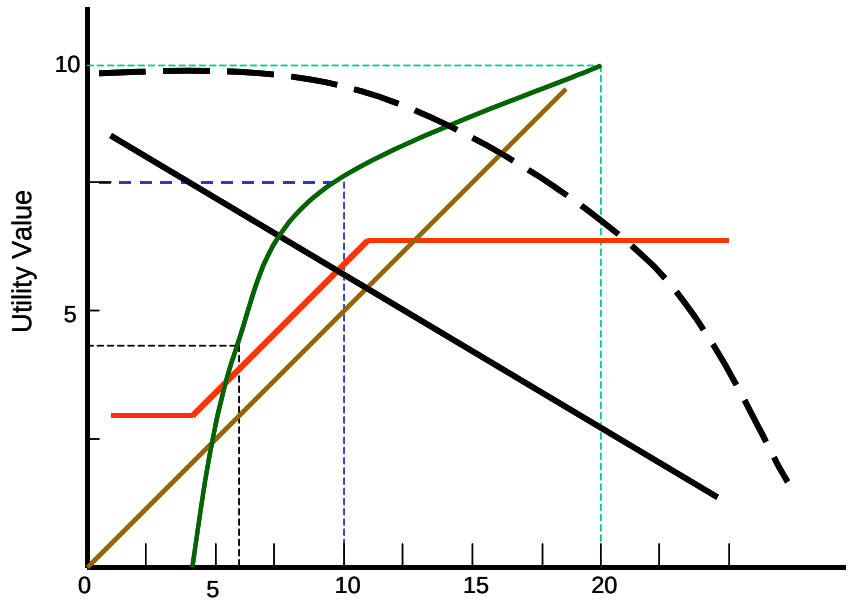


Figure 4.6-5. Example Utility Curves

4.6.3.7 Task 7: Review Result and Form Conclusions

This part of the Trade Studies process typically presents one alternative that balances the Requirements and a "zero change" option for comparison. While the defined decision authority makes the final decision, a recommendation by the Trade Studies team is essential. All results shall be reviewed, any necessary additional data obtained, and evaluations and preliminary conclusions revised as needed. Any or all parts of the study may be repeated.

If the evaluation's intent is to select a product or service, it may be useful to review preliminary conclusions with vendors to ensure that no misunderstandings have occurred. Delaying such reviews until this phase of the evaluation avoids much of the risk of biasing the overall process.

When the evaluation is completed and deemed reliable, cost estimates for each alternative shall be prepared. Weighted scores for evaluation criteria are related to benefits associated with the

evaluated alternative. The cost of an alternative divided by the total score for that alternative is a measure of the cost/benefits of that alternative.

At this point, the alternatives are now ordered based on the technical requirements and quantified impacts. It is recommended that changes from the baseline design technical performance and the decision criteria used during this evaluation be highlighted.

4.6.4 Outputs of Trade Studies

The outputs of the Trade Studies process are a report with an executive summary and a design/manufacturing decision document.

4.6.4.1 Trade Study Report

A Trade Study Report is prepared for each study. The report documents the study results and provides traceability to decisions made during the program's lifecycle. The report provides the traceability needed to substantiate design and configuration changes to the baseline design and also documents the decisionmaking process that selected one alternative over another. Additionally, it describes the effects of selecting a particular alternative among trades and clearly notes affected areas that were included in the Trade Studies assumptions, as well as affected areas that were not included in the associated trade. Once the report is completed, the Trade Studies leader is expected to coordinate the report with all affected team leaders before submitting it for approval and signature.

The Trade Study Report is prepared using a format appropriate for documenting and communicating the results, conclusions, risks, benefits, and recommendations to the decisionmaker. It is recommended that the format be standardized wherever possible to satisfy individual program needs. At a minimum, it is recommended that the following be included, but not limited to:

- Clear problem statement
- Identification of affected Requirements
- Ground rules and assumptions
- Decision criteria
- Resource requirements statement to accomplish the study
- Schedule to accomplish (proposed and actual)
- Evaluation of all potential solutions and screening matrix
- Comprehensive array of feasible alternatives
- Comparisons of alternatives using decision criteria
- Technical recommendation of the Trade Studies team
- Documentation of any decisions leading to the final technical recommendation

The following is a suggested report format. Each project may enhance the standard outline as needed by adding subsections and separately numbered items to the sections. Each project may also add sections and subsections for special topics and delete sections and subsections that are not applicable.

Table of Contents

1 Introduction
1.1 Scope
1.2 Applicable Documents
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2 Study Summary
3 Requirements Summary
4 Evaluation Criteria
4.1 Evaluation Criteria and Scoring Method
4.2 Evaluation Criteria and Changes During Study
5 Alternative Solutions
6 Results
6.1 Evaluation Approach, Scores, and Analysis
6.2 Conclusions

Appendices

List of Acronyms

References

4.6.4.2 Design/Manufacture

Once the Trade Study Report is approved, the design decision/manufacturing document is produced, outlining the impacts and actions necessary to implement the alternative recommended in the Trade Studies into the baseline configuration. In general, this document describes the rationale required to substantiate the change. The report then becomes an attachment to the design decision/manufacturing document and serves as the technical basis for the option to be implemented. The design decision document is submitted to the appropriate control authority to authorize implementation into the baseline configuration. The control authority is also required to maintain the report and the design/manufacturing decision document for the program's lifecycle.

4.6.5 Trade Studies Tools

4.6.5.1 Quality Function Deployment

QFD is a methodology used to ensure that the stakeholders' operational needs and requirements are gathered, interpreted, and deployed in developing a product or service. The primary objective of QFD is to eliminate three major problems: difficulty in gathering and interpreting stakeholder's requirements; loss of information; and different individuals and functions using varying interpretations of the same requirements. QFD provides a Trade Studies tool that screens alternatives using weighted selection criteria. QFD is recommended for use whenever:

- Stakeholder requirements are vague, ambiguous, or self-contradictory
- Multiple disciplines are involved in the collection and interpretation of the requirements
- Multiple solutions are feasible with no clear choice
- Lack of an obvious feasible solution
- Cost and/or risk appear to be unacceptably high

QFD (see http://www.shef.acu.uk/~ibberson/qfd.html) requires teamwork among the multiple disciplines that make up a program/project team to address requirements from multiple perspectives. It is recommended that QFD involve the customer, representatives from the product development and support functions, and suppliers. It is also recommended that a team attempting to conduct a QFD exercise for the first time receive training before the start of the QFD exercise and support from an experienced product-oriented QFD expert.

4.6.5.2 Modeling and Simulation

Models and simulations are standard engineering tools that represent the key features of a system and the interactions of those features with each other and the outside environment. The defining feature of any model is its purpose. In general, a model represents how the system operates in its environment. An excellent guideline to follow is to select the least complex model that provides the most visibility into the problem.

4.6.6 Trade Studies Process Metrics

Quality may be measured by the degree to which the project objectives are satisfied, as noted in “Trade Studies Objectives” (Paragraph 4.6.1.1); objectives are satisfied when they may be numerically quantified (e.g., increase of payload capability). For imprecise objectives, project management may decide on a different type of assessment (e.g., yellow/red/green).

Timeliness may be measured by compliance with the schedule. It may be measured by when the decision support provided by the studies is available for the decision to be made.

Resources consumed to reach the required decision support level may identify efficiency, which may include labor hours, computer usage, and schedule time.

Cycle time may measure the duration from the creation of system alternatives to the delivery of the decision support products discussed in “Outputs of Trade Studies” (Paragraph 4.6.4).

Process performance is measured and recorded on a regular basis. Process users (teams or equivalent functions) accumulate the following metrics, at minimum, to evaluate the performance of this process:

- Percentage of studies performed in which none of the alternatives emerged conclusively as the best solution, thereby driving a decision based on other factors
- Percentage of studies in which the recommended alternative was not subsequently selected
- Percentage of planned discipline viewpoints, as defined by the study scope, that actively participated in conducting the Trade Studies

The decisionmaker completes satisfaction assessment.

4.6.7 References

1. Blanchard, B. "System Engineering Management." 2nd Ed. New York: John Wiley & Sons, Inc., N.Y.
2. Blanchard, B., and W. Fabrycky. "Systems Engineering and Analysis." 2nd Ed. Englewood Cliffs, New Jersey: Prentice Hall.
3. Defense Systems Management College. "Systems Engineering Fundamentals." Fort Belvoir, Virginia: Defense Systems Management College Press, 1999.
4. International Council on Systems Engineering. "Systems Engineering Handbook." Version 2.0. 2000.
5. National Aeronautics and Space Administration. "NASA System Engineering Handbook." June 1995.

4.7 Interface Management *(Satisfies criteria of EIA/IS731 FA 1.5 and iCMM PA 7)*

4.7.1 Introduction to Interface Management

Interface Management, which includes identification, definition, and control of interfaces, is an element of System Engineering (SE) that helps to ensure that all the pieces of the system work together to achieve the system's goals and continue to operate together as changes are made during the system's lifecycle. Precise interface definition early in the program is crucial to a successful and timely development. As the total system is decomposed into functional areas, interfaces (functional and/or physical) between the areas are identified. These interfaces are typically characterized by functional data parameters with associated data requirements or mechanical, electrical, and space requirements. Functional and physical interface requirements are contained in the appropriate performance specifications. The Interface Management process enters the Acquisition Management System (AMS) process at the end of the first phase of Investment Analysis and continues through In-Service Management. The essential elements of the Interface Management process are illustrated in Figure 4.7-1, which lists the key inputs necessary to initiate the task, providers, process tasks, outputs required, and customers of process outputs. The beginning and ending boundary task and the intermediate tasks are detailed later in the section.

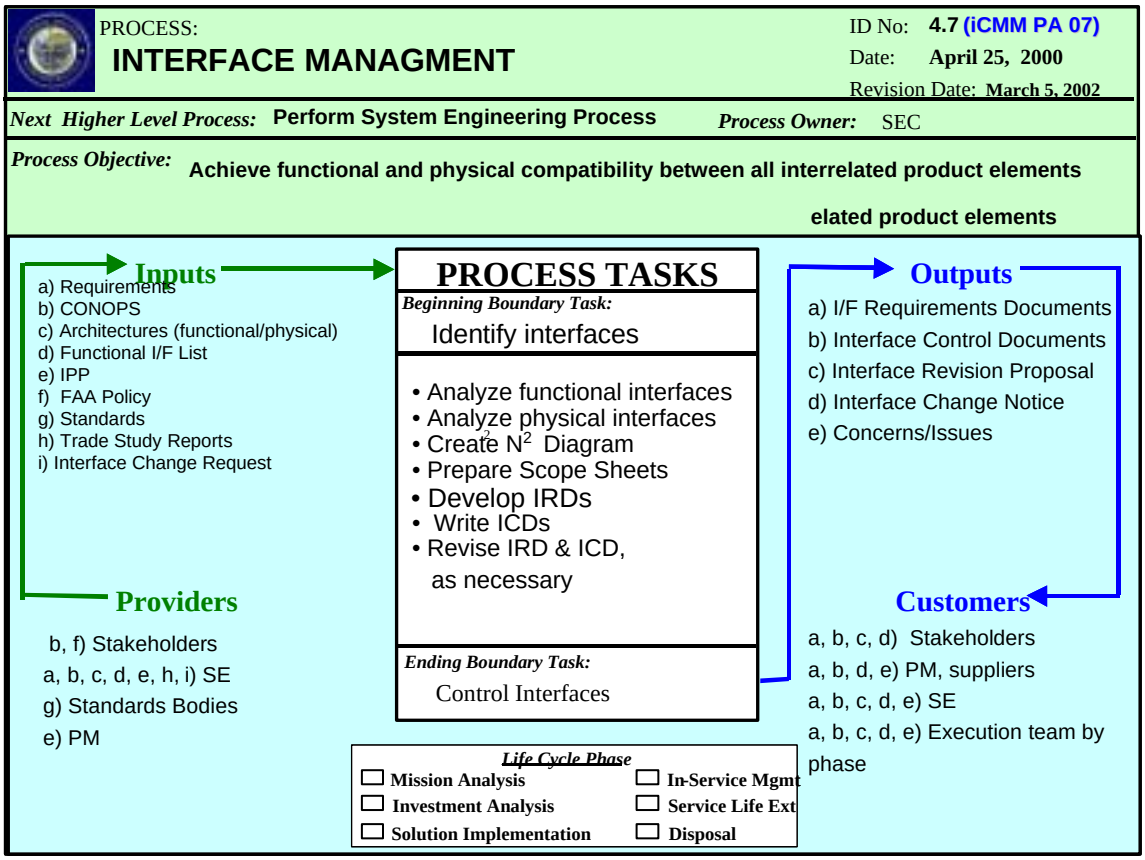


Figure 4.7-1. Interface Management Process-Based Management Chart

4.7.1.1 Interface Management Objectives

The objective of Interface Management is to identify, describe, and define interface requirements to ensure compatibility between interrelated systems and between system elements, as well as provide an authoritative means of controlling the interface design.

The Interface Requirements Document (IRD) controls interface requirements and the Interface Control Document (ICD) controls interface design. These documents:

- Define and illustrate physical and functional characteristics in sufficient detail to ensure compatibility of the interface so that this compatibility shall be determined from the information in the IRD/ICD alone
- Identify the necessary interface data and monitor submission of this data
- Control the interface requirements and design to prevent any changes to characteristics that might affect compatibility with other systems and equipment
- Communicate coordinated interface requirements and design decisions, as well as interface requirements/design changes to program participants

4.7.1.2 Types of Interfaces

An interface is any external or internal boundary between one element and another that is physical or functional. Internal interfaces are within the defined system's boundary. External interfaces are with elements outside the defined system's boundary. The external/internal interface distinction relates to the level of ownership and the verification of the requirements associated with each interface. Examples of interface types that may be encountered appear in Table 4.7-1. The 5M and SHELL Models (Figures 4.7-2 and 4.7-3, respectively) depict the types of interface elements that are recommended for consideration within most systems. Each element of the system shall be described functionally and physically. A functional description describes what the system is intended to do. It includes subsystem functions as they relate to and support the system function. (Functional Analysis, Section 4.4, provides more information on this topic.) A physical description provides information on the composition and organization of the tangible system elements. The level of detail varies with the system's size and complexity, with the end objective being adequate understanding of the system configuration and operation. (Synthesis, Section 4.5, provides more information on synthesis alternatives.)

Table 4.7-1. Examples of Interface Types

Interface Type	Interface Subtype	Examples
Functional	Mechanical	Vehicle operator increasing speed A computer sending a document to printer
Physical	Mechanical	Transmission of torque via a drive shaft Connection between computer communication port and the printer cable
Functional	Control	A control signal sent from a flight control computer through a cable to an actuator (two interfaces) A human operator selecting a flight management system

Interface Type	Interface Subtype	Examples
		mode
Physical	Control	The connection between the flight control computer and the cabling A human operator's fingers adjusting a flight management system mode switch
Functional	Aerodynamic	Pilot notification of a stall Vortices impacting on an aircraft
Physical	Aerodynamic	A stall indicator on a wing A fairing designed to prevent vortices from impacting a control surface on an aircraft
Functional	Environmental (Natural or Induced)	Maximum/minimum temperature of radar electronics The amount of rain/snow that makes a sensor reading anomalous
Physical	Environmental (Natural or Induced)	Increased volume of mercury in thermometer reaching new markers on temperature scale Wind impacting radar antenna surface
Functional	Noise	Minimum decibels required for an alert to be heard
Physical	Noise	Sound waves impacting on person's ear drum
Functional	Space	Space required to perform maintenance
Physical	Space	Inserting hardware into existing rack
Functional	Data	A cockpit visual display to a pilot Weather Message Switching Center Replacement to Weather and Radar Processor (WARP) data transfer
Physical	Data	Light from cockpit visual display impacting on pilot's retina Weather data bits moving from communications cable to communications port on WARP
Functional	Electrical	Energy from a direct current (DC) power bus supplied to an anticollision light A fan plugged into an alternating current (AC) outlet for current An electrical circuit opening a solenoid Shielding and grounding for coaxial cables
Physical	Electrical	Energy from a DC power bus supplied to the cabling connected to the anticollision light Electrical current moving from AC outlet to fan wire Current flowing through wiring Shielding material wrapped around copper wiring
Functional	Hydraulic	Pressurized fluid supplying power to a flight control actuator

Interface Type	Interface Subtype	Examples
		A fuel system pulling fuel from a tank to the engine
Physical	Hydraulic	Pressurized fluid in a hydraulic line Connection of fuel line to fuel tank
Functional	Pneumatic	An adiabatic expansion cooling unit supplying cold air to an avionics bay An air compressor supplying pressurized air to an engine air turbine starter
Physical	Pneumatic	Pressurized air in an aircraft
Functional	Electromagnetic	Radio frequency (RF) signals from a Very High Frequency Omni directional Range (VOR) A radar transmission
Physical	Electromagnetic	RF signals from a VOR vibrating radio receiver Radio waves emitted from radio transmitter
Functional	Heating, Ventilating, and Air-Conditioning (HVAC)	Amount of heating and cooling required for a facility Circuit protective devices for equipment racks
Physical	HVAC	Thermocouple contacting sensor Circuit breaker connection to power line

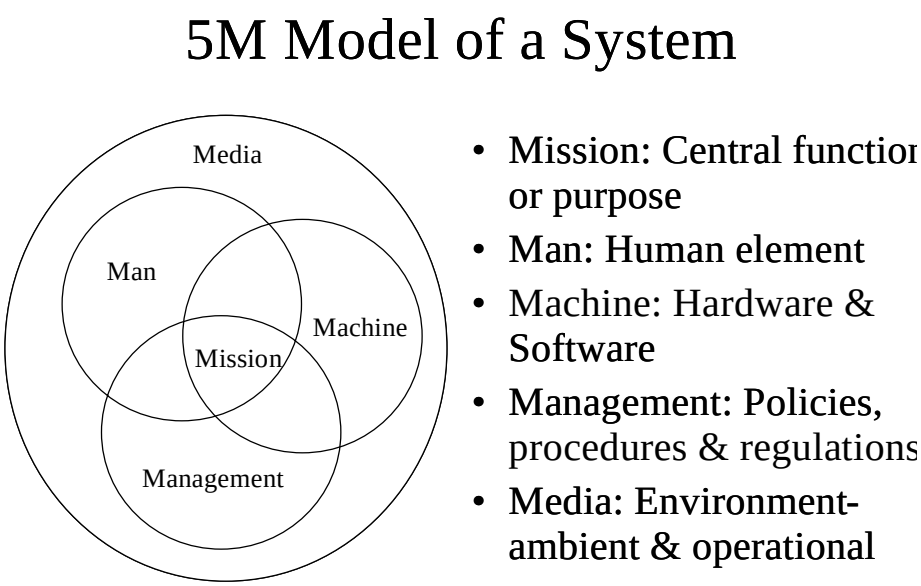


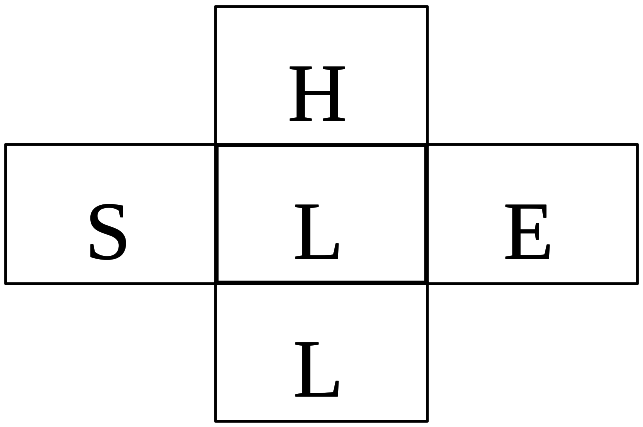
Figure 4.7-2. Depiction of 5M Interface Model

The following is a description of the 5M Interface Model:

- **Mission:** purpose or central function of the system that brings together the other elements.
- **Man:** human element of a system. If a system requires humans for operation, maintenance, or installation, this element shall be considered in the system description.
- **Machine:** hardware and software (including firmware) element of a system.
- **Management:** procedures, policy, and regulations involved in operating, maintaining, installing, and decommissioning a system.
- **Media:** environment in which a system shall be operated, maintained, and installed. This environment includes ambient and operational conditions. Ambient conditions are physical conditions involving temperature, humidity, lightning, electromagnetic effects, radiation, precipitation, and vibration. Operational environment consists of the conditions in which the mission or function is planned and carried out. Operational conditions are human-created conditions involving operations such as air traffic density, communication congestion, workload, and Instrument Flight Rules (IFR) versus Visual Flight Rules (VFR). Part of the operational environment may be described by the type of operation (e.g., air traffic control, air carrier, general aviation); phase (e.g., ground taxiing, takeoff, approach, en route, transoceanic, landing); or rules governing the operation (e.g., IFR, VFR).

In the SHELL Model, the match or mismatch of the blocks (interface) is just as important as the characteristics described by the blocks themselves. These blocks may be rearranged to describe the system as required. A connection between two blocks indicates an interface between the elements.

SHELL System Model



S= Software (procedures, symbology, etc.)
H= Hardware (machine)
E= Environment (operational and ambient)
L= Liveware (people)

Figure 4.7-3. Depiction of SHELL Interface Model

4.7.1.2.1 Functional Interfaces

Functional interfaces define the purpose of the interface. Each interface has at least two associated functions, and, because all performance requirements are traceable to functions, there shall be at least two associated interface requirements. This concept is illustrated in Figure 4.7-4, where Side A delivers some quantity (e.g., electrical power) to Side B; at the same time, Side B receives that quantity from Side A. The two implied requirements are:

- Side A shall generate the quantity
- Side B shall provide a compatible response to the quantity that Side A delivered

Interface requirements shall be expressed in verifiable terms. For example, as expressed in strict requirements terminology, "the [Side A] subsystem shall deliver electrical power at 28 volts." In this example, the element of Side B is a fan. Thus, the requirement for Side B might be as follows: "The fan [Side B] shall provide impedance, power level and timeline, while using the 28-volt power supply of the electrical system [Side A]." The interface definition includes the data and/or control functions and the way these functions are represented.

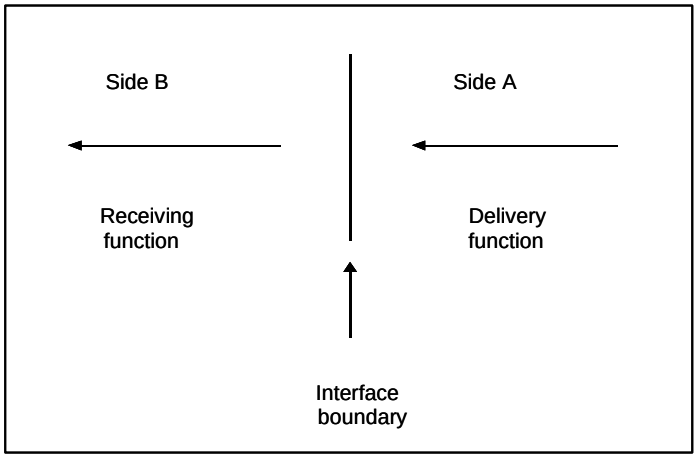


Figure 4.7-4 Example of a Simple Interface

4.7.1.2.2 Physical Interfaces

Physical interfaces are used to define and control the features, characteristics, dimensions, and tolerances of one design that affects another. Physical interfaces include material properties of the equipment that affect the functioning of mating equipment. They also include the operating environment of the system.

4.7.2 Inputs to Interface Management

The inputs required to initiate Interface Management include both program/project- and product-related data listed in Table 4.7-2. Many of these inputs are developed and refined through the continuous, iterative processes of other SE elements.

Table 4.7-2. Interface Management Process Inputs

Input	Reference
Concept of Operations (CONOPS)	Functional Analysis (Section 4.4)
Architecture	Trade Studies (Section 4.6)
Requirements MNS/iRD	Requirements Management (Section 4.3)
International Standards	System Engineering in the Acquisition Management System Program Lifecycle (Chapter 3)
FAA Order/Standards	System Engineering in the Acquisition Management System Program Lifecycle (Chapter 3)
Functional Analysis	Functional Analysis (Section 4.4)
Draft IPP	Integrated Technical Planning (Section 4.2)
Trade Study Report	Synthesis (Section 4.5)
Engineering solution actions and impacts	Trade Studies (Section 4.6)
Interface Control Plan	Integrated Technical Planning (Section 4.2)
Interface Change Request	Interface Management (Section 4.7)

4.7.3 Interface Management Process Tasks

The Interface Management process is an integrated and iterative set of activities that ensures that all functional and physical interface requirements are identified, defined, and controlled, including interfaces within the system, as well as those between the instant system and another system. Table 4.7-3 outlines the process. The paragraphs below describe the process tasks.

Table 4.7-3. Interface Management Process Inputs by Output Product

Inputs	Source Process	Initial AMS Phase	Output
Requirements Documents (MNS/iRD)	Requirements Management (Section 4.3)	Mission Analysis (MA)	
CONOPS	Functional Analysis (Section 4.4)	MA	
Architecture	Synthesis (Section 4.5)	MA	
Functional Interface List	Functional Analysis (Section 4.4)	MA	
			Scope Sheet
FAA Policy	External	Investment Analysis (IA)	
Standards	External	IA	

Inputs	Source Process	Initial AMS Phase	Output
Draft Interface Control Planning section of IPP	Integrated Technical Planning (Section 4.2)	IA	
Requirements Documents (fRD)/Changes	Requirements Management (Section 4.3)	IA	
System Requirements/Changes	Functional Analysis (Section 4.4) Synthesis (Section 4.5) Trade Studies (Section 4.6)	IA	
Physical Architecture	Synthesis (Section 4.5)	IA	
Trade Study Report	Trade Studies (Section 4.6)	IA	
			IRD
IRD		Solution Implementation (SI)	
Interface Change Request	External	SI	
Physical Architecture	Synthesis (Section 4.5)	SI	
Design Definition/Changes	Synthesis (Section 4.5)	SI	
Final Interface Control Planning section of IPP	Integrated Technical Planning (Section 4.2)	SI	
			ICD
Interface Revision Proposal			
			Revised IRD/ICD

4.7.3.1 Task 1: Identify Functional/Physical Interfaces

The first task in the Interface Management process is to identify the functional and physical interfaces, which is accomplished via N^2 diagrams. The functional interfaces are identified during the Mission Analysis phase, while the physical interfaces are identified during the Investment Analysis phase.

4.7.3.2 Task 2: Create an N^2 Diagram

The N^2 diagram is a systematic approach to identify, define, tabulate, design, and analyze functional and physical interfaces. It applies to system interfaces and hardware and/or software interfaces. The N^2 diagram is a visual matrix that requires the user to generate complete definitions of all the system interfaces in a rigid bidirectional, fixed framework. Figure 4.7-5 is a basic N^2 diagram.

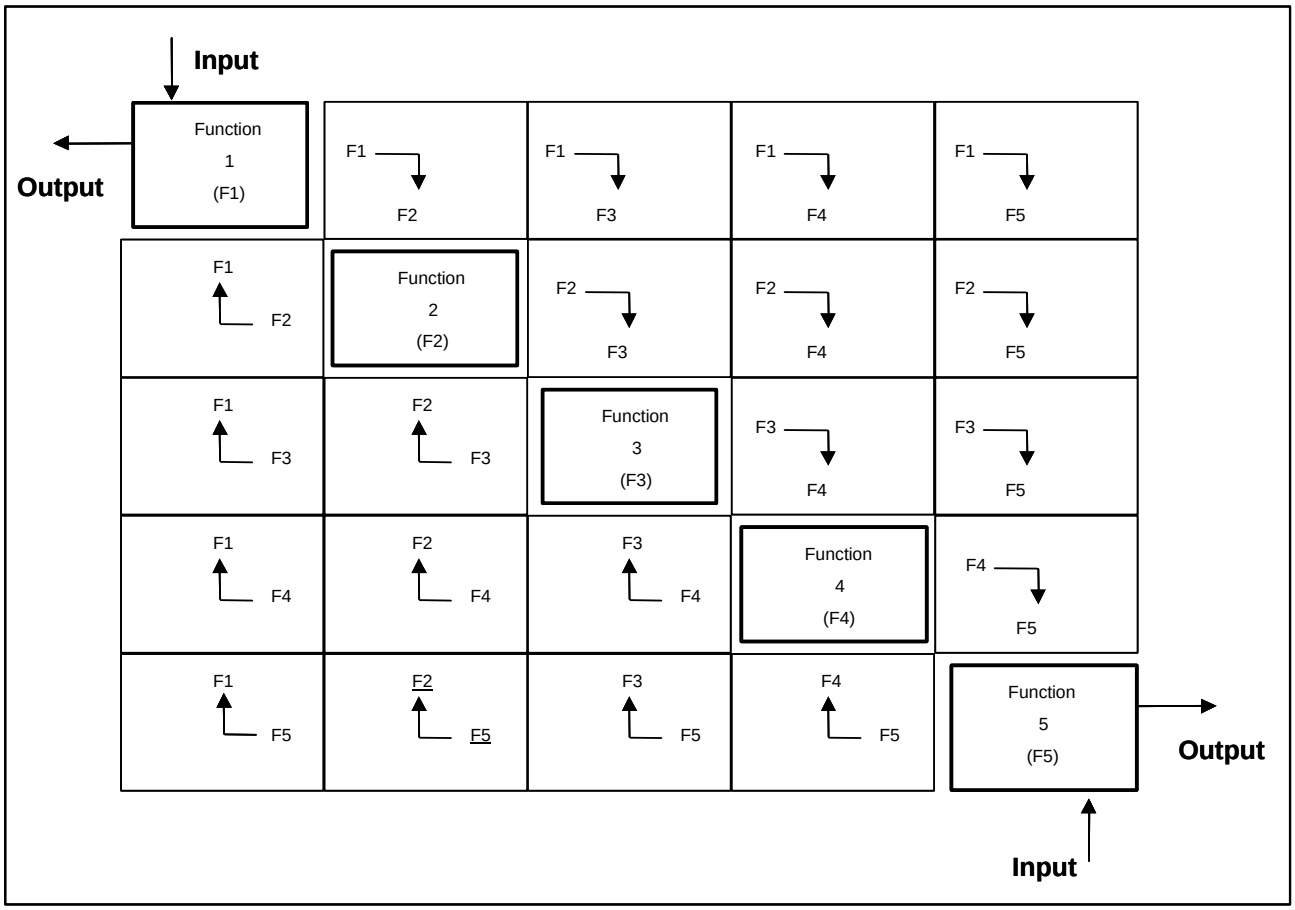


Figure 4.7-5. Generic N^2 Diagram

The following steps are recommended for creating a functional N^2 diagram:

Step 1: Identify the functional interfaces via an N^2 chart and develop functional interface list.

- Create an N^2 diagram that is N X N square, where N is the number of system functions.
- Place the system functions on the diagram's diagonal axis.
- Moving across the diagram, fill in each square with any output, moving from function F1 to any of the succeeding functions. (Interfaces between functions flow in a clockwise direction.) If there are no outputs to a succeeding function, leave the square blank. (Characteristics of the entity passing between functions may be included in the box where the entity is identified.) Continue in this fashion until the upper half of the N^2 diagram is populated.
- Moving down the diagram, fill in each square with any input, moving from function F2 to function F1, from function F3 to functions F2 or F1, and so on with succeeding functions. If there are no outputs to a succeeding function, leave the square blank. Continue in this fashion until the lower half of the N^2 diagram is populated.

- Conduct a peer review for completeness.

Step 2: Develop a functional interface list from the functional N^2 diagram.

The next action is to identify the physical interfaces via the N^2 diagram during the Investment Analysis phase using the selected Physical Architecture.

Step 3: Identify the physical interfaces via an N^2 chart and develop physical interface list.

- Create an N^2 diagram that is N X N square, where N is the number of system elements.
- Place the system elements on the diagram's diagonal axis.
- Moving across the diagram, fill in each square with any output, moving from system S1 to any of the succeeding systems. (Interfaces between systems flow in a clockwise direction.) If there are no outputs to a succeeding system, leave the square blank. (Characteristics of the entity passing between systems may be included in the box where the entity is identified.) Continue in this fashion until the upper half of the N^2 diagram is populated.
- Moving down the diagram, fill in each square with any input, moving from system 1 to system 2, from system 3 to systems 2 or 1, and so on with succeeding systems. If there are no outputs to a succeeding system, leave the square blank. Continue in this fashion until the lower half of the N^2 diagram is populated.
- Conduct a peer review for completeness.

Step 4: Develop a Physical Interface list from the Physical N^2 chart.

An example of an output from Step 3 appears in Figure 4.7-6. The N^2 diagram shall be taken down in successively lower levels to the hardware and software component levels. In addition to interface identification, another main function of the N^2 diagram is to pinpoint areas where conflicts may arise between systems and functions so that system integration occurring later in the development cycle proceeds efficiently.

	Provide electrical power	Provide environmental control	Provide surveillance
Provide electrical power		Provide power to ESC	Provide power to radar
Provide environmental control	Cool electrical components		Cool radar elements
Provide surveillance			

Figure 4.7-6. Simple N^2 Example

4.7.3.3 Task 3: Define Functional and Physical Interfaces To Prepare Scope Sheets

The third task in the Interface Management process is to define the functional and physical interfaces, which is accomplished via scope sheets and IRDs. Scope sheets are used to develop the Interface Control planning section of the Integrated Program Plan (IPP) (Integrated Technical Planning (Section 4.2)). This Interface Control planning section defines a management system of interface controls to ensure physical and functional compatibility between interfacing system elements and between systems. This section also provides the means to identify and resolve interface incompatibilities (through a program management mechanism known as the Interface Working Group (IWG)) and determines the impact of interface design changes. Source material for the Interface Control planning section includes the CONOPS, MNS, iRD, and draft IPP. The previously developed N^2 diagrams are used to complete a scope sheet for each interface, which, in turn, is used to write the required IRDs.

The following steps shall be taken when scope sheets are prepared:

- Step 1: Review scope sheet format (Figures 4.7-7 and 4.7-8)
- Step 2: Review functional and physical interface lists
- Step 3: Prepare a scope sheet for each element in the diagonal, which corresponds to internal interfaces
- Step 4: Review final Requirements Documents (fRD) to determine required external interfaces
- Step 5: Prepare scope sheets for all external interfaces
- Step 6: Enter scope sheets into Configuration Management process (Section 4.11)

- Step 7: Evaluate Scope Change Requests and update scope sheets as necessary

ICD NUMBER: REV:	DATE INITIATED: DATE:		
ICD TITLE			
PARTICIPANTS:			
SCOPE:			
EQUIPMENT RESPONSIBILITY:			
INTERFACE LOCATION (INTERFACE BLOCK DIAGRAM)			
EFFECTIVITY:			
PROGRAM REVIEWS & AUDITS:			
RELATED ICDs			
APPROVALS:			
Participant	Date	Participant	Date
IWG Secretariat	Date	IWG Chairman	Date

Figure 4.7-7. Format of Scope Sheet for Interface Management

ICD NUMBER: 25-DR010M REV: 1	DATE INITIATED: June 25, 3032 DATE: December 6, 3033
ICD TITLE	Interface Control – Surveillance Radar Product Generator (RPG) – Weather System Processor (WSP) - Electrical Installation Envelope, Mechanical, Environmental, and Data
PARTICIPANTS:	Raytheon/Lockheed Martin
SCOPE:	This IRD/ICD controls and documents all interface requirements for the RPG to WSP interface. Interface definition is described to the extent necessary to assure compatibility of the RPG to WSP interfacing hardware when used with the specified constraints. The interface consists of mechanical installation of the WSP for cabling, mounting, environmental cooling, and data requirements. Mechanical interfaces include location, orientation, mounting provisions, and power supply. Envelope interfaces include installation, removal, connector, and cable clearances. Environmental interfaces include temperature and humidity constraints. The data interface includes Airport Surveillance Radar (ASR) 27 data (RF, control, data, and timing signals) and WSP data (control and status signals).
EQUIPMENT RESPONSIBILITY:	1. Raytheon – ASR-27 radar product generator 2. Lockheed Martin – WSP module (hardware and software)

INTERFACE LOCATION (INTERFACE BLOCK DIAGRAM)

EFFECTIVITY:	PK/RG (TYPE VIII)
PROGRAM REVIEWS & AUDITS:	WSCE IRR September 3032, WSCE SER December 3032, WSCE PDR March 3033
RELATED ICDs	
APPROVALS:	

Raytheon	Date	Lockheed Martin	Date

IWG Secretariat	Date	IWG Chairman	Date

Figure 4.7-8. Example Scope Sheet

4.7.3.4 Task 4: Develop Interface Requirements Documents

The next task in the Interface Management process is to develop IRDs, which, in turn, are used to develop ICDs. The designated custodian shall prepare the detailed IRD. FAA-STD-025 provides a checklist for IRD content. Several commonly used FAA standards appear in Table 4.7-4. (Note: This is not necessarily a complete list.)

The following steps shall be undertaken when IRDs are developed:

- Step 1: Review the inputs listed in Table 4.7-2
- Step 2: Prepare the detailed IRD in accordance with (IAW) FAA-STD-025
- Step 3: Review the IRD for compliance with the fRD
- Step 4: Coordinate the revised draft IRD with all affected organizations
- Step 5: Enter the IRD into the Configuration Management process (Section 4.11)

Table 4.7-4. Checklist for Interface Requirements Document Standards (In Accordance With FAA-STD-025)

Standard	Title
FAA-STD-025	Preparation of Interface Documentation
FAA-STD-002	Facilities Engineering Drawing Preparation
FAA-STD-005	Preparation of Specification Documents
FAA-STD-019	Lighting Protecting, Grounding, Bonding, and Shielding Requirements for Facilities
FAA-STD-020	Transient Lighting Protecting, Grounding, Bonding, and Shielding Requirements for Equipment
FAA-STD-023	Microfilming of Engineering and Electrical Drawings
FAA-STD-029	Selection of Telecommunications Standards
FAA-STD-032	Design Standards for National Airspace System (NAS) Physical Facilities
FAA-STD-039	NAS Open Systems Architecture and Protocols
FAA-STD-042	NAS Open System Interconnection (OSI) Naming and Addressing
FAA-STD-043	NAS OSI Priority
FAA-STD-044	NAS OSI Directory Services
FAA-STD-045	NAS OSI Security Standard
FAA-STD-047	NAS OSI Conformance Testing

Standard	Title
FAA-STD-048	NAS OSI Interoperability Testing
FAA-STD-049	FAA Standard for Fiber Optic Telecommunications Systems and Equipment
FAA-G-2100	Electronics Equipment, General Requirements
MIL-STD-005	Engineering Drawing Practices
ISO 8648-1988	Information Processing Systems – OSI Internal Organization of the Network
ISO/IEC 96467:1998	Information Technology – OSI – Conformance Testing Methodology and Framework: Implementation Conformance Statements
ISO/IEC TR 1000-1-1998	Information Technology – Framework and Taxonomy of International Standardization Profiles – Part 1: General Principles and Documentation Framework
IEEE 315 – 1975	Graphic Symbols for Electric and Electronics Diagrams (including reference class designations letters)
IEEE 315A – 1986	Graphic Symbols for Electric and Electronics Diagrams (supplement to Institute of Electrical and Electronics Engineers, Inc. (IEEE) and standard 315-1975)

4.7.3.5 Task 5: Write Interface Control Documents

During this task, the detailed ICD/Interface Control Notice is prepared, and an analysis is performed to confirm completeness and accuracy of the interface definition. These documents shall be reviewed for compliance with the defined scope sheets and coordinated. A record of these actions shall be maintained.

FAA-STD-025 provides a checklist for ICD content.

- Step 1: Review the inputs listed in Table 4.7-2
- Step 2: Prepare the detailed ICD IAW FAA-STD-025
- Step 3: Review the ICD for compliance with IRD
- Step 4: Coordinate the revised draft ICD with all affected organizations
- Step 5: Enter the ICD into the Configuration Management process (Section 4.11)

4.7.3.6 Task 6: Revise Interface Requirements Documents and Interface Control Documents

It may be necessary to request changes to the IRD/ICD as changes to Requirements or design definition occur.

- Step 1: Review the IRD for any required changes when design modifications occur or new requirements are added to the system RD to determine if changes are required.
- Step 2: Review the ICD to determine if changes are also required.
- Step 3: Prepare the change request IAW FAA-STD-025 and provide the following information:
  - Description of the problem and the proposed change
  - Analysis showing how the change solves the problem
  - Analysis of how the change impacts system performance, effectiveness, and lifecycle costs
  - Analysis to ensure that the proposed solution does not introduce new problems
  - Description of resources and an estimate of the costs associated with implementing the change
  - Statement of impact to system
- Step 4: Provide change request to IWG, which shall determine if the authorized Interface Change Request (ICR) is within the scope. In-scope ICRs shall be returned to the ICR originator and the custodian of the IRD/ICD for preparation and release of an interface requirement. Out-of-scope ICRs shall be forwarded to program manager.
- Step 5: Coordinate the draft IRD/ICD with all affected organizations.
- Step 6: Enter the changed IRD/ICD into the Configuration Management process (Section 4.11).
- Step 7: Determine if IRD changes affect the system RD and, if so, update the RD also.

4.7.4 Outputs of Interface Management

The outputs of the Interface Management process appear in Table 4.7-5. When documented and approved, the IRD is provided to all applicable organizations, while the ICD is provided to technical disciplines responsible for meeting its interface requirements, to customer and program management for coordination, and to the respective test and quality assurances organizations.

Table 4.7-5. Process Outputs and Destination Process

Outputs	Destination Process(es)
IRDs	Requirements Management (Section 4.3) Configuration Management (Section 4.11) Synthesis (Section 4.5) Validation and Verification (Section 4.12)
ICDs	Requirements Management (Section 4.3) Configuration Management (Section 4.11) Synthesis (Section 4.5) Validation and Verification (Section 4.12)
Interface Change Proposal	Configuration Management (Section 4.11)

4.7.5 Interface Management Tools

The functional flow diagram (FFD):

- The FFD family is a group of analyses that depicts functional (input-function-output) relationships between functions. This family includes the Department of Defense standard FFDs, N^2 diagrams, Integrated Definition for Function Modeling tools, and the Unified Modeling Language (UML). The FFD is a multi-tier, time-sequenced, step-by-step diagram of the system's functional flow. Typically, FFDs are prepared to define the detailed, step-by-step, operational and support sequences for systems, but they may also be used effectively to define processes in developing and producing systems. In this method, the functions are organized and depicted by their logical inputs and outputs. Each function is shown in relation to the other functions by how the inputs and outputs feed and are fed by the other functions. Each function is depicted as a node labeled with the function name. (Naming criteria are described in "Introduction to Functional Analysis" (Paragraph 4.4.1).) Arrows leading into the function depict inputs, while arrows leading out of the function depict outputs. If the output of function F0 is an input to F1, then an arrow is shown leaving F0 and going into F1 ("Functional Flow Relationship" (Figure 4.4-12)).

The N^2 Diagram

- The N^2 diagram (Figure 4.7-5) ensures that all functions identified in the Functional Analyses are reflected in functional interfaces. Each node in the N^2 diagram indicates a possible functional interface. Note that in the example (Figure 4.7-6), "Provide Electrical Power" supplies power to other functions, and "Provide Environmental Control" supplies cooling to the other functions. However, the "Provide Surveillance" function does not provide any quantity to the other functions.

4.7.6 Interface Management Process Metrics

Table 4.7-6 lists the Interface Management process metrics.

Table 4.7-6. Interface Management Process Metrics

Quality Metrics	Cycle Time Metrics	Cost* Metrics
Scope Sheet in Compliance with Requirements (% “Yes”)	Time from iRD to IRD Approval	Cost to implement IRDs
IRD in Compliance with Requirements (% "Yes")	Time from IRD Approval to ICD Release	Cost to implement ICDs
ICD/Interface Requirement Compliance with Interface Requirements (% "Yes")	Time from ICR Approval to Interface Requirement Release	Cost to implement ICRs
Design Compliance with ICD/Interface Requirement Requirements (% "Yes")		
Number of interfaces discovered after initial release of ICD		
*NOTE: Cost is only direct program costs.		

4.7.7 Terms and Definitions

Interface Requirements: All interface requirements are classed as functional and physical requirements, as well as constraints that exist at a common boundary between two or more functions, system elements, configuration items, or systems.

IRD: The IRD defines requirements associated with external physical and functional interfaces between the particular system and other associated system(s). The IRD is one of the two basic products of the interface task. In its final form, the IRD is primary documentation of the interface requirements.

ICD: The ICD is one of the two basic products of the interface task. In its final form, the ICD is a ”design” document that describes the detailed ”as built” implementation of the requirements contained in the IRD. The vendor usually develops it.

Interface Control Planning Section of IPP: The Interface Control planning section of the IPP documents the formal management system of interface controls that ensures physical and functional compatibility between interfacing hardware, software, and facilities. The plan provides the means for identifying and resolving interface incompatibilities and for determining the impact of interface design changes. This Interface Control planning guides the management, control, and documentation of all system functional and physical interfaces. The Interface Control planning section also contains interface requirements and templates for preparing, revising, and processing ICDs unique to the program. The Interface Control planning section addresses supplier participation in the interface process. (Integrated Technical Planning (Section 4.2) provides detailed instructions on this topic.)

IWG: The IWG is established through the IPP (and System Engineering Management Plan). The IWG is the forum for discussing interface issues. IWG meetings serve two purposes: to ensure effective, detailed definition of interfaces by all cognizant parties, and to expedite baselining of initial IRDs, ICDs, and subsequent drawing changes by encouraging resolution of interface issues. The IWG shall consist of IWG Chair, IRD/ICD Custodian(s), and management personnel from associated teams. (Integrated Technical Planning (Section 4.2) provides detailed instructions on this topic.)

4.7.8 References

1. Blanchard, Benjamin S., System Engineer Management, John Wiley & Son, 603 Third Ave., New York, N.Y., 10158-0012, 1998.
2. Buede, Dennis M., The Engineering Design of Systems, John Wiley & Son, 603 Third Ave., New York, N.Y., 10158-0012, 2000.
3. EIA 731.1, Systems Engineering Capability Model, January 1999.
4. Grady, Jeffery O., Systems Requirements Analysis, McGraw-Hill, March 1999.
5. NASA Systems Engineering Handbook, SP-6105, June 1995
6. System Engineering Fundamentals, DSMC, Defense Acquisition University Press, Ft. Belvoir, VA, 1999.

4.8 Specialty Engineering

Specialty Engineering is a subset of System Engineering (SE) that defines and evaluates specific areas, features, and/or characteristics of a system. Specialty Engineering supplements the acquisition process by defining these characteristics and assessing their impact on the program. SE relies on specialty domain expertise to define and characterize specific requirements. SE's function in this process is to integrate the design engineer and specialty engineer's activities, coordinate and open communication lines between the design engineer and specialty engineer, and focus the engineering effort toward the common goal of satisfying the customer—not to perform detailed Specialty Engineering work.

Analysis of the system is a primary means of conducting Specialty Engineering. These analyses are categorized under Specialty Engineering because they require specialized engineering skills. These specialized skill areas include system safety engineering (SSE); Reliability, Maintainability, and Availability (RMA); Human Engineering (human factors); Electromagnetic Environmental Effects (E^3); quality Engineering; Information Security Engineering; and Hazardous Materials Management/Environmental Engineering. Engineers in these disciplines perform analyses throughout the system's lifecycle. The results are used to derive, validate, and verify requirements; evaluate system design progress and technical soundness; and manage risk. At a minimum, analysis results are available at standard design milestones, including the design, acquisition, and program reviews. The results are communicated via reports. In the case of supplier involvement, deliverables are in accordance with contract requirements. The general process for performing Specialty Engineering is depicted in Figure 4.8-1, which lists the key inputs necessary to initiate the task, providers, process tasks, outputs required, and customers of process outputs.

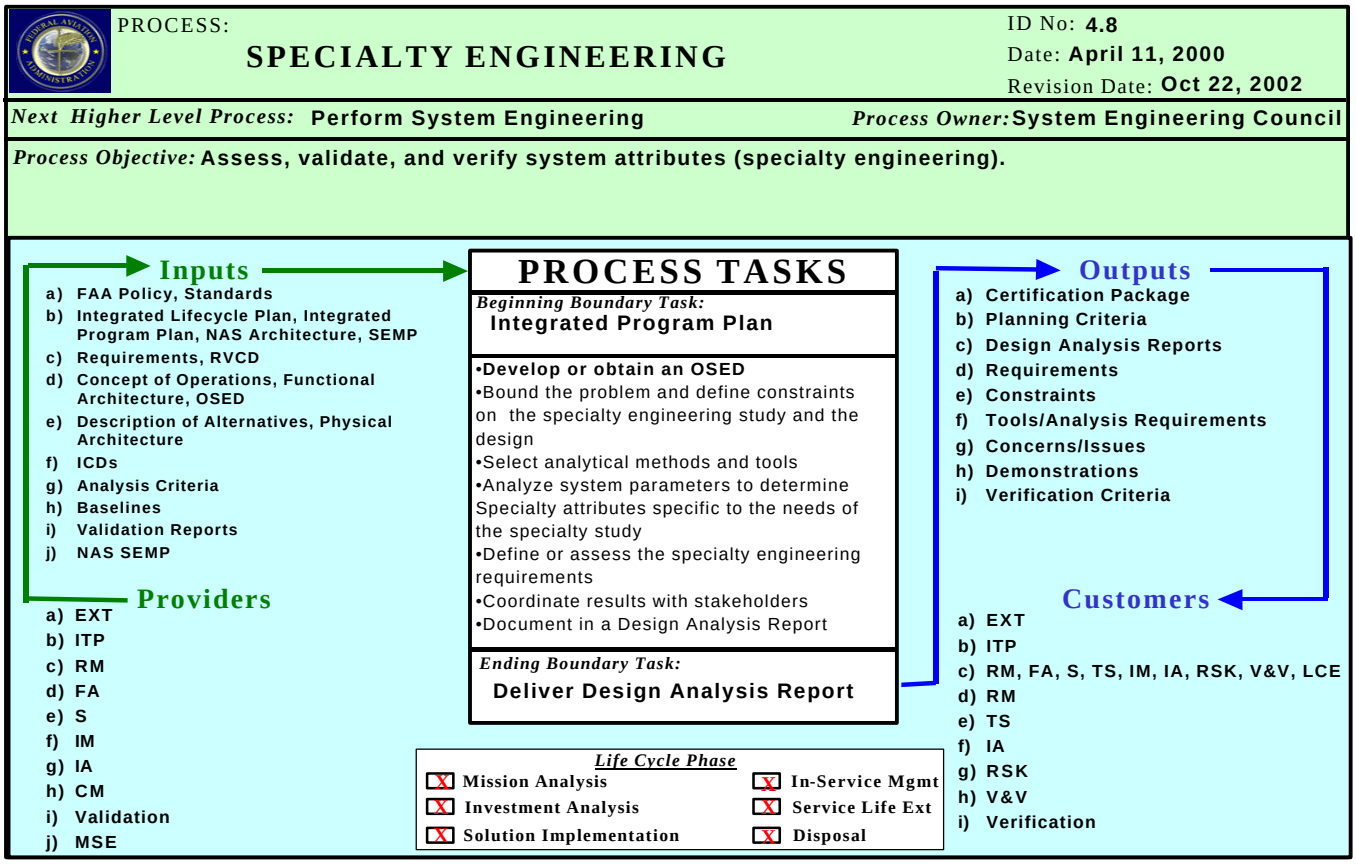


Figure 4.8-1. Specialty Engineering Process-Based Management Chart

4.8.0 Introductory Material

4.8.0.1 Introduction to Specialty Engineering

Specialty Engineering is conducted throughout the system's lifecycle. Specialty Engineering analyses are conducted early to derive and validate requirements. In addition, the Specialty Engineering disciplines support the Trade Studies (Section 4.6), Synthesis (Section 4.5), and Functional Analysis (Section 4.4) efforts in selecting and designing solutions to requirements. Later in the lifecycle, after requirements at all levels are validated, these analyses provide support in verifying the requirements by describing and assessing the characteristics of the design and/or operations. As early as possible in the lifecycle, the Specialty Engineering disciplines find and resolve potential program risk. Finding and controlling risk early assists in seeking the lowest possible cost and increases the probability of program success and operator acceptance of the product.

This section contains a description of the functions, objectives, and products of the various disciplines included in Specialty Engineering.

4.8.0.1.1 Description of Specialty Engineering Disciplines

Specialty Engineering analyses provide characteristics of the system from a specific technical perspective. Table 4.8-1 provides a general description of the Specialty Engineering disciplines.

Table 4.8-1. Specialty Engineering Disciplines

Specialty Engineering Discipline	Description
SSE	Evaluation and management of the safety risk associated with a system using measures of safety risk identified in various hazard analyses, fault tree analyses, safety risk assessments, and hazard tracking and control.
RMA	Quantitative and qualitative analyses of the attributes of the system to perform reliably. Quantitative assessments are in the form of probabilistic, mean, and/or distribution assessments. Qualitative analyses are in the form of failure mode assessments. Evaluation of the design's ability to meet operational readiness requirements through preventive and corrective maintenance.
Human Factors Engineering	Human factors is a multidisciplinary effort to generate and compile information about human capabilities and limitations and apply that information to: – equipment, systems, facilities – procedures, jobs, environments – staffing – training – personnel and organizational management for safe, comfortable, and effective human performance.
E^3	Analysis of the system for susceptibility and/or vulnerability to electromagnetic fields or capability to generate such fields that might interfere with other systems, identify sources of interference, and means for correction within the levels prescribed by law, program requirements, spectrum management, or recognized standards. E^3 is composed of Electromagnetic Interference (EMI) and Electromagnetic Compatibility (EMC)
Quality Engineering	Evaluation of a system's ability to meet its requirements and to mitigate product defects.
Information Security Engineering (ISE)	Applies scientific and engineering principles to manage and control system security risk to the enterprise and its mission. Risk identification includes identifying system vulnerabilities and threats. ISE applies effective and suitable technical, procedural, physical,

Specialty Engineering Discipline	Description
	and administrative controls to mitigate these risks to an acceptable level. ISE combines control measures for prevention, detection, and recovery from security attacks that would compromise confidentiality, integrity, and/or availability of information technology assets (including information).
Hazardous Materials Management/Environmental Engineering	Determination of environmental impacts at deployment sites and during operations, including both environmental impacts on the system and system impacts on the environment during all phases of the product life.

In addition to resolving problems and defining requirements early, Specialty Engineering supplies information to the other SE functions, including Requirements Management (Section 4.3), Risk Management (Section 4.10), Configuration Management (Section 4.11), and Validation and Verification (Section 4.12). The major relationships between Specialty Engineering and other SE processes are depicted in Figure 4.8-2.

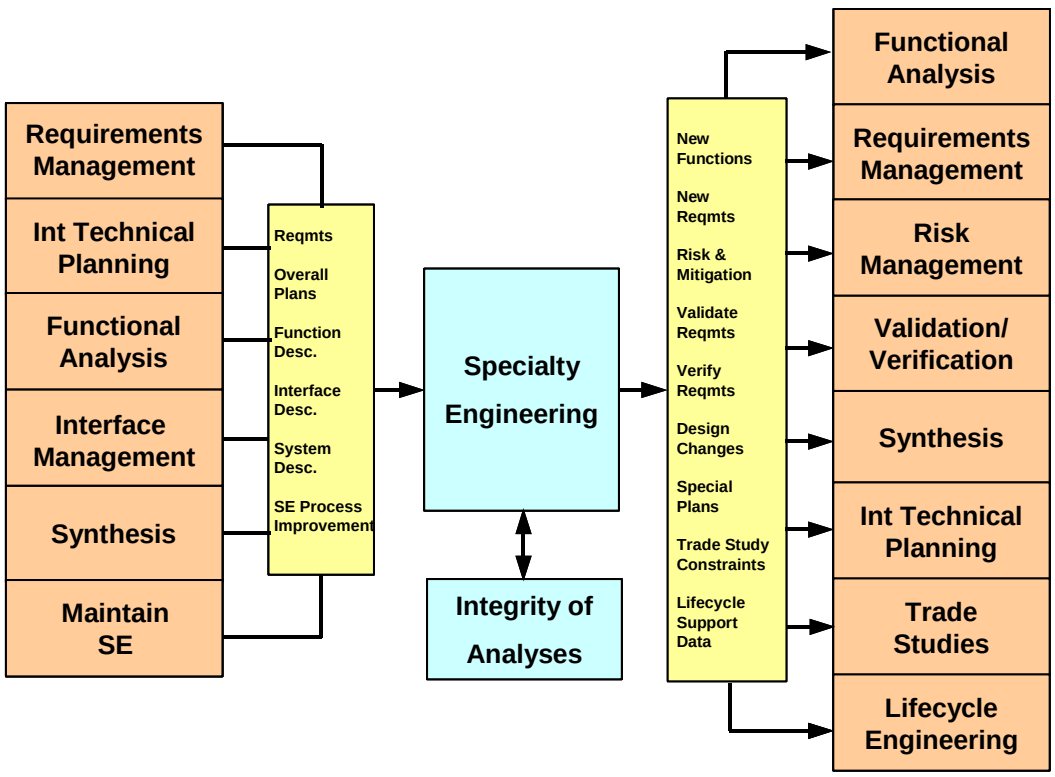


Figure 4.8-2. Major Relationships Between System Engineering Elements and Specialty Engineering

The relationships depicted in Figure 4.8-2 are further described in Table 4.8-2.

Table 4.8-2. Major Effects of Specialty Engineering on Other System Engineering Processes

Affected SE Process	How Affected
Integrated Technical Planning (Section 4.2)	The Integrated Technical Planning process feeds Specialty Engineering. Integrated Technical Planning produces the plans for Specialty Engineering, SE, and all other SE processes. The plans detail what is to be done, who is to do it, the standards of performance, and when each task is to be performed.
Requirements Management (Section 4.3)	The Requirements Management process both feeds and is fed by Specialty Engineering. The system under study is described in order to perform Specialty Engineering analyses. Requirements are a key component of any description and they are an output of the Requirements Management process. Specialty Engineering studies often find characteristics that create a need for new or different requirements. Sometimes, the Specialty Engineering disciplines find areas of conflict between two or more requirements. In either case, the Specialty Engineering function develops the new or changed requirements and these are an input to the Requirements Management process.
Functional Analysis (Section 4.4)	The Functional Analysis process both feeds and is fed by Specialty Engineering. To execute a Specialty Engineering analysis, the specialist shall have a thorough understanding of the system functions. This understanding is a result of performing a Functional Analysis of the system.
Interface Management (Section 4.7)	Specialty Engineering both feeds and is fed by Interface Management. The system under study is described in order to perform Specialty Engineering analyses. Interface Requirements Descriptions (IRD) are key components of any system description and are an output of the Interface Management process. Specialty Engineering studies often find characteristics that create a need for new or different interface requirements or descriptions. Sometimes, the Specialty Engineering disciplines find areas of conflict between two or more interfaces. In either case, the Specialty Engineering function develops the new or changed requirements, which are inputs to the Interface Management process.
Risk Management (Section 4.10)	Specialty Engineering feeds the Risk Management process. Specialty Engineering studies and analyses are designed to find and assess potential problem areas of a design as early as possible. When a potential problem is found, the information becomes an input to the Risk Management process for mitigation and control.
Configuration Management (Section 4.11)	Specialty Engineering outputs are inputs to the Configuration Management process. During the execution of Specialty Engineering analyses, it may be discovered that additional or changed design features are required, or changes to operating, maintenance, or installation procedures are needed. When these discoveries occur, the proposed changes become inputs to the Configuration Management process.

Affected SE Process	How Affected
Validation and Verification (Section 4.12)	Specialty Engineering outputs feed the Validation and Verification process. Early in the program's lifecycle, Specialty Engineering is used to validate requirements, which is accomplished by comparing the requirements defined in early Specialty Engineering analyses to those defined in current/later analyses. If the Specialty Engineering analyses find a need for an existing requirement, then the requirement may be considered validated. Specialty Engineering feeds Verification Criteria to the Verification process. Specialty Engineering is also used to verify requirements later in the system's lifecycle. Verification may be accomplished either by test or SE Assessment. Specialty Engineering is a form of assessment and may be used to demonstrate verification.

4.8.0.2 Inputs and Providers to Specialty Engineering

Table 4.8-3 depicts the inputs needed to conduct Specialty Engineering analyses.

Table 4.8-3. Specialty Engineering Process Inputs

Process Input	Input Purpose/Description	From Process
FAA Policy and Standards	Policy and standards, such as the Acquisition Management System (AMS), define what is expected and how well it needs to be done.	AMS and FAA Orders
Integrated Lifecycle Plan	The Integrated Lifecycle Plan provides planning information necessary to support the system throughout its lifecycle.	Integrated Technical Planning (Section 4.2)
Integrated Program Plan (IPP)	The IPP provides information on the overall plan for conducting the program. It provides information on program constraints, system constraints, and Specialty Engineering plans. Each specific program maintains the IPP. It is an aggregate plan that includes and integrates all the program specific plans. The IPP details what tasks are to be performed, who is to do them, and when the tasks are to be performed.	Program's IPP Integrated Technical Planning (Section 4.2)
National Airspace System (NAS) Architecture	The NAS Architecture is the technical blueprint for NAS Modernization and guides the Federal Aviation Administration (FAA) on what systems are planned for modernizing the NAS.	Synthesis (Section 4.5)

Process Input	Input Purpose/Description	From Process
System Engineering Management Plan (SEMP)	The SEMP defines the plan for conducting SE in the AMS and the program.	System Engineering in the Acquisition Management System Program Lifecycle (Chapter 3)
Requirements	Requirements provide information about the system's required characteristics, specifications, performance, and requirements. They assist in developing the system description. System requirements are documented in the initial Requirements Documents (iRD), final Requirements Documents (fRD), and system specification(s). The execution teams and SE develop and maintain the requirements documents.	Requirements Management (Section 4.3)
Requirements Verification Compliance Documents (RVCD)	The RVCD records the verification status of all requirements.	Requirements Management (Section 4.3)
Concept of Operations (CONOPS)	The CONOPS is a user-oriented document that describes system functional characteristics for a proposed system from the user's viewpoint. It explains the existing system, current environment, users, interactions among users and the system, and organizational impacts. The CONOPS document is written in order to communicate overall quantitative and qualitative system characteristics to the user, buyer, developer, and other organizational elements.	Functional Analysis (Section 4.4)
Functional Architecture	The Functional Architecture identifies, analyzes, and describes the functions of a system. It provides information required for a system description and assists in the definition of requirements. Functional Analysis is the process of turning a need or system requirement into a description and an architecture of functions (system behaviors or behavior descriptors). The execution teams and/or SE perform and maintain the Functional Architecture.	Functional Analysis (Section 4.4)

Process Input	Input Purpose/Description	From Process
Operational Services and Environmental Description (OSED)	The OSED is a comprehensive, holistic Communications, Navigation, and Surveillance (CNS)/Air Traffic Management (ATM) system description. It describes the services, environment, functions, and mechanizations that form a system's characteristics.	Functional Analysis (Section 4.4)
Description of Alternatives	Description of Alternatives is described as Physical Architectures. When performing Trade Studies (Section 4.6), a number of alternatives shall be competitively evaluated.	Synthesis (Section 4.5)
Physical Architecture	Physical Architecture identifies and defines the system and its components, including the physical interfaces among products, subsystems, humans, lifecycle processes, and external interfaces to higher-level systems or interacting systems.	Synthesis (Section 4.5)
Interface Control Document (ICD)	The ICD contains and documents the "as built" interface design derived from the IRD.	Interface Management (Section 4.7)
Analysis Criteria	Criteria for specialty engineering analyses are specified to establish the degree of validation required for the analyses and associated tools, the methods to use to ensure that the data is of the proper quality and range, and the level of documentation required.	Integrity of Analysis (Section 4.9)
Baselines	When the requirements and design have reached sufficient maturity, they are baselined to facilitate management of the configuration.	Configuration Management (Section 4.11)
Validation Reports	Validation Reports document the results of the Validation effort. They report requirements that are validated and those that are considered nonconforming.	Validation (Section 4.12)
NAS SEMP	The NAS SEMP describes the overall SE used in the FAA.	Manage System Engineering (Section 4.14)

4.8.0.3 General Specialty Engineering Process Tasks

Most, if not all, Specialty Engineering disciplines follow a similar process during the conduct of associated analyses. The following paragraphs provide general guidance on performing Specialty Engineering in the FAA. These processes are depicted in Figure 4.8-1. The process tasks are:

- Describe the system in physical and/or functional terms. This task has to be completed before the specialists may begin; if not, the specialists may perform this task, as long as it is performed according to the guidance in Functional Analysis (Section 4.4) and Interface Management (Section 4.7)).
- Bound the problem and define Constraints on the Specialty Engineering study and the design.
- Select analytical methods and tools.
- Analyze system parameters to determine specialty attributes specific to the views of the Specialty Engineering study.
- Define or assess the Specialty Engineering Requirements.
- Coordinate results with stakeholders.
- Document the analysis in a Design Analysis Report (DAR).

The following paragraphs detail the process tasks depicted in Figure 4.8-1.

4.8.0.3.1 Task 1: Obtain or Develop an Operational Services and Environmental Description

The first task in performing a Specialty Engineering analysis is to understand and describe the system under study at an appropriate level. The OSED is an excellent source of this information; it is a system description that is developed in the Functional Analysis process (Section 4.4).

It is recommended that the specialty engineer use the existing descriptions to frame the Specialty Engineering analysis. However, there are times when the existing system descriptions are insufficient in detail for the specialist. In these cases, the specialty engineer develops the system description. When developing the system description, the specialty engineer shall comply with the guidance in Functional Analysis and Interface Management (Section 4.7).

Functional Analysis describes the desired behaviors of a system. These behaviors provide critical insight into how the system is intended to perform and, therefore, are a critical input to any Specialty Engineering analysis. To perform an assessment of a system, the engineer is required to understand the functions of that system and be able to relate the specialties to these functions. Normally, the Functional Analysis is completed before the Specialty Engineering process begins, and all that is required of the specialty engineer is to obtain and review the Functional Analysis and use it to enhance or complete the system description. In some cases, either because the engineers failed to perform it or because it is too early in the design process, the Functional Analysis is not available. In these cases, the specialty engineer shall refer to guidance in Functional Analysis and perform the Functional Analysis independently.

4.8.0.3.2 Task 2: Bound the Problem and Define Constraints on the Study and Design

Every system problem or analysis has breadth and depth. The breadth of a system analysis refers to the system boundaries. Boundaries limit the system to elements of the system model that affect or interact with each other in order to accomplish the central mission(s) or function. Depth refers to the level of detail in the description. The level of detail in an analysis varies inversely with the breadth of the system. For a system as broad as the NAS, the description

and analysis are general in nature with little detail on individual components. On the other hand, a simple system, such as a valve in a landing gear design, includes significant detail to support the assessment.

Constraints on the design play an important role in the conduct of the analysis and the credibility of the results. It is essential to identify the Constraints before the analysis to account for their influence on the methods used and the alternatives chosen. As part of determining the Constraints, the scope of the analysis, the ground rules, and assumptions are identified. Identifying the customer(s) for the analysis is important with respect to defining the scope. The analysis may be subject to contractual restraints if it is a deliverable; therefore, it is necessary to consider these restraints when defining the scope of the effort. The project schedule and budget may also impose limits on the analysis, which may affect the assumptions and ground rules. The analysis team and the recipients of the report shall be aware of all the scope limitations, ground rules, assumptions, and guidelines that apply to the assessment and product design. The following sources are used to identify Constraints:

- CONOPS defined via Functional Analysis (Section 4.4)
- Contract Statement of Work (SOW), including referenced standards and procedures
- Compliance documents that apply to the analysis methods and report
- Customer-specified requirements on cost, schedule, and product performance
- Management-imposed business goals and Constraints
- Functional, performance, and interface requirements derived from the design concept
- Functional, performance, and interface requirements imposed by the use of commercially available or preexisting hardware and software
- Operational constraints imposed by the user
- Environmental constraints imposed by the physical and operational environment
- Constraints imposed by the production or Verification process (Section 4.12)
- Design constraints imposed by standard practices that are defined by the government or standards-setting bodies
- Federal, Department, and FAA policies, standards, and guidelines

4.8.0.3.3 Task 3: Select Analytic Methods and Tools

To ensure Integrity of Analyses (Section 4.9), the engineer selects analytic methods and tools that meet the program phase; the system analysis needs; and cost, schedule, and skill constraints. It is important to select methods and tools that match the analysis objectives within the resource limitations of the effort.

4.8.0.3.4 Task 4: Analyze System Parameters To Determine System Attributes

In this step, the attributes of the design are determined by using the methods and tools appropriate to the Specialty Engineering discipline. The appropriate guidelines and handbooks for each Specialty Engineering discipline are listed in Table 4.8-4. The AMS FAA Acquisition System Toolset (FAST) often contains guidelines for these activities. For example, it is recommended that the team, if conducting a safety assessment, consult the FAA System Safety

Handbook (SSH) and the NAS System Safety Management Plan (SSMP) found in the FAST. For some analyses, it is recommended that the results include programmatic attributes, such as cost and schedule impacts, as appropriate to the analysis.

In addition, the SE or project team, as part of this process, conducts technical or peer reviews of the analysis and its results. The technical community conducts this independent evaluation before the Specialty Engineering DARs are submitted.

The results of Specialty Engineering analyses confirm design attributes necessary for acceptable product performance, cost, schedule, and risk. When an attribute is not confirmed, the analysis and/or the baseline shall be revised.

Revision may be implemented through changes in scope, ground rules, assumptions, and analytic methods. The analysis process is reactivated with the intent of determining an alternative result that is acceptable and valid. Alternatively, the results of the analysis may drive revision of the Requirements or design Baseline. This revision is accomplished by preparing appropriate change proposal documentation for input to the Configuration Management process (Section 4.11).

Table 4.8-4. Guidelines and Handbooks for Conducting Specialty Engineering

Phase	Analysis	Guidance/Reference
Mission Analysis	E^3 EMC requirements	FAST. (2000). Environment/Energy/ Safety/Health. http://fast.faa.gov/ FAST. (2000). Radio Spectrum Management. http://fast.faa.gov/
	Environmental Requirements Analysis	FAST.[1] Environment/Energy/Safety /Health. http://fast.faa.gov/
	Human Factors Functional Analysis	FAST. Human Factors. http://fast.faa.gov/
	Human Factors System (Mission) Analysis	FAST. Human Factors. http://fast.faa.gov/

[1] Federal Aviation Administration, Federal Acquisition System Tools (FAST), Office of Research and Acquisitions (ARA), [On-line] Available: http://fast.faa.gov.

Phase	Analysis	Guidance/Reference
	Maintainability Requirements Analysis	FAST. Sustainment and Maintenance. http://fast.faa.gov/
	Operational Safety Assessment (OSA)	FAST. System Safety Management. http://fast.faa.gov/ FAA SSH[2], Chapter 4. NAS SSMP[3], Chapters 3 and 4.
	Reliability Requirements Analysis	(Reserved)
	Information Security Engineering	Preliminary Risk Assessment, Guidance/Reference: FAA ISS Handbook 1370.82
Investment Analysis	Comparative Safety Assessment (CSA)	FAST. System Safety Management. http://fast.faa.gov/ FAA SSH, Chapter 4 NAS SSMP
	EMC Control Plan	FAST. (2000). Environment/Energy/ Safety/Health. http://fast.faa.gov/ FAST. (2000). Radio Spectrum Management. http://fast.faa.gov/
	Human Factors Function Allocation	FAST. Human Factors. http://fast.faa.gov/
	Human Factors Program Plan	FAST. Human Factors. http://fast.faa.gov/
	Maintainability Plan	FAST. Sustainment and Maintenance. http://fast.faa.gov/
	Preliminary Hazard Analysis (PHA)	FAST. System Safety Management. http://fast.faa.gov/ FAA SSH, Chapter 8 NAS SSMP
	Quality Engineering Plan	FAST. Quality Assurance. http://fast.faa.gov/
	Reliability Program Plan	(Reserved)

[2] U.S. Federal Aviation Administration, "FAA System Safety Handbook," FAA Office of System Safety (ASY), Washington, DC (2000).

[3] U.S. Federal Aviation Administration, "NAS Modernization System Safety Management Plan," FAA Office of Architecture and SE (ASD), Washington, DC (2000).

Phase	Analysis	Guidance/Reference
	Specialty Engineering Support of Trade Studies or Alternatives Analysis	FAST. Investment Analysis. http://fast.faa.gov/ Synthesis of Alternatives (Section 4.8)
	System Safety Program Plan (SSPP)	FAST. System Safety Management. http://fast.faa.gov/ FAA SSH, Chapter 5 NAS SSMP
	Information Security Engineering	Updated Risk Assessment, Guidance/Reference: FAA ISS Handbook 1370.82
Solution Implementation	Environmental/ Hazardous Material Analysis	FAST. Environment/Energy/Safety /Health. http://fast.faa.gov/
	Failure Modes and Effects Analysis (FMEA)	(Reserved)
	Failure Modes and Effects Criticality Analysis (FMECA)	(Reserved)
	Failure Reporting Analysis and Corrective Action System (FRACAS)	(Reserved)
	Failure Review Board	(Reserved)
	Hazard Tracking and Risk Resolution	FAST. System Safety Management. http://fast.faa.gov/ FAA SSH, Chapter 3 NAS SSMP
	Human Factors Demonstrations, Models, and Mockups	(Reserved)
	Human Factors Error Analysis	(Reserved)
	Human Factors Operational Sequence Diagrams	(Reserved)
	Human Factors Operator Task Analysis	(Reserved)
	Human Factors Timeline Analysis	(Reserved)
	Human Factors Workload Analysis	(Reserved)

Phase	Analysis	Guidance/Reference
	Maintainability Analysis	FAST. Sustainment and Maintenance. http://fast.faa.gov/
	Maintainability Demonstration	FAST. Sustainment and Maintenance. http://fast.faa.gov/
	Maintainability Modeling	FAST. Sustainment and Maintenance. http://fast.faa.gov/
	Maintenance Task Analysis	FAST. Sustainment and Maintenance. http://fast.faa.gov/
	Operating and Support Hazard Analysis (O&SHA)	FAST. System Safety Management. http://fast.faa.gov/ FAA SSH, Chapter 8 NAS SSMP
	Reliability Centered Maintenance (RCM)	(Reserved)
Solution Implementation	Reliability Development Growth Testing (RDGT)	(Reserved)
	Reliability Modeling	(Reserved)
	Sneak Circuit Analysis	(Reserved)
	Subsystem Hazard Analysis (SSHA)	FAST. System Safety Management. http://fast.faa.gov/ FAA SSH, Chapter 8 NAS SSMP
	System Hazard Analysis (SHA)	FAST. System Safety Management. http://fast.faa.gov/ FAA SSH, Chapter 8 NAS SSMP
	Information Security Engineering	Analysis supporting Certification and Authorization, Guidance/Reference: FAA ISS Handbook 1370.82

4.8.0.3.5 Task 5: Define and Document Specialty Engineering Requirements

The Specialty Engineering products described in “Task 4: Analyze System Parameters to Determine System Attributes” (Paragraph 4.8.0.3.4) result in the definition and assessment of Specialty Engineering-related Requirements. These Requirements shall meet the standards for requirements definition and documentation described in Requirements Management (Section 4.3). In addition, these Requirements shall be validated and verified, as described in Validation and Verification (Section 4.12).

4.8.0.3.6 Task 6: Coordinate Results With Stakeholders

The results of the Specialty Engineering process (particularly the DARs and Requirements) shall be coordinated with the project/program stakeholders. This coordination is conducted in both formal and informal forums. The informal forums include peer reviews and working groups.

The formal forums include Acquisition Reviews and Design Reviews, as described in Integrated Technical Planning (Section 4.2).

4.8.0.3.7 Task 7: Document the Specialty Engineering Analysis in a Design Analysis Report

The primary output of any Specialty Engineering function is the DAR, which documents the results of the specific analysis with rationale. Each DAR shall contain the following results:

- Description of the system's special characteristics
- List of existing Requirements that were either validated or verified in the analysis
- Residual risks
- Candidate Requirements found as a result of the analysis

These Requirements are inputs to the Requirements Management process (Section 4.3) and shall be considered for inclusion in iRD and fRD. The rationale includes the scope, ground rules, assumptions, constraints, methods, and tools applicable to the analysis.

The Specialty Engineering outputs are often used to validate and/or verify requirements. In addition, change proposal documentation is produced if the conclusions of the analysis call for a revision to the Requirements or design Baseline. This revision is an input to the Configuration Management process (Section 4.11) for authorization to change the Baseline as the analysis indicates.

Requirements for contents and format may be applicable to the DAR as specified by the contract. Figure 4.8-3 provides a sample outline of the contents of the DAR.

1.0 Executive Summary
2.0 Introduction
3.0 Summary of results
4.0 Summary of conclusions (including residual risks)
5.0 Recommendations (including mitigation)
6.0 System Description
    6.1 Summary
    6.2 Operational Services and Environment Description (OSED)
    6.3 Functional Analysis (if applicable)
    6.4 Requirements (if applicable)
7.0 Description of system special characteristics (detailed analysis worksheets or data)
8.0 List of candidate requirements
9.0 List of requirements that were validated and/or verified with rationale
10.0 Analysis methodology with rationale

Figure 4.8-3. Sample Outline of a Design Analysis Report

4.8.0.4 Outputs of Specialty Engineering

The following paragraphs describe the outputs of Specialty Engineering. The outputs are:

- Certification Package
- Planning Criteria
- DARs (specific to the Specialty Engineering study)
- Specialty Engineering Requirements
- Constraints
- Tools/Analysis Requirements
- Concerns/Issues
- Demonstrations
- Verification Criteria

4.8.0.4.1 Certification Package — Reserved

4.8.0.4.2 Planning Criteria

Any Planning Criteria necessary for performing Specialty Engineering throughout the remainder of the program's lifecycle need to be provided to the Integrated Technical Planning process (Section 4.2)

4.8.0.4.3 Design Analysis Report

The DAR is the means of documenting and reporting the methods and results of the Specialty Engineering analyses. Figure 4.8-3 provides a sample outline of a DAR.

4.8.0.4.4 Specialty Engineering Requirements

In the course of performing an analysis, the specialty engineer typically defines, validates, or verifies Requirements. Occasionally, the specialist discovers characteristics of the system that are not adequately specified in the existing Requirements or specification documents. If this occurs, the specialist defines those necessary Requirements consistent with the specialist's area of expertise and the requirements standards described in Requirements Management (Section 4.3).

4.8.0.4.5 Constraints

Constraints necessary for performing Specialty Engineering throughout the remainder of the program's lifecycle need to be provided to the Trade Studies process (Section 4.6).

4.8.0.4.6 Tools/Analysis Requirements

Tools/Analysis Requirements for performing Specialty Engineering throughout the remainder of the program's lifecycle need to be provided to the Integrity of Analyses process (Section 4.9).

4.8.0.4.7 Concerns/Issues

Appendix D contains guidance on Concerns/Issues as a product of Specialty Engineering.

4.8.0.4.8 Demonstrations

Demonstrations are often used to verify compliance with Requirements in servicing, reliability, maintainability, transportability, and human factors engineering. Demonstrations are used to verify what is accomplished by operating, adjusting, or reconfiguring items performing their design functions under specific scenarios. The items may be instrumented and quantitative limits of performance monitored; however, only check sheets are required rather than recordings of actual performance data. This method is used when actual demonstration techniques may be used to verify compliance with a Requirement. Observations made by engineers or instrumentation are compared with predetermined responses based on the requirements. An example of this verification method is the demonstration of installing and uninstalling an aircraft engine in a required amount of time.

Demonstrations may also be used to validate unstable Requirements. If there is a risk inherent to a Requirement, Demonstrations may be used to determine the correct characteristics needed.

"Test and Evaluation Verification" (Paragraph 4.12.2.2.1,Verification by Demonstration) has more information on Demonstrations.

4.8.0.4.9 Verification Criteria

The specialist may be called upon to define specific verification requirements, as described in "Step 3: Develop Verification Approach" (Paragraph 4.12.2.5.2.2.3). The Verification Criteria or requirements are added to the Verification Requirements Traceability Matrix (VRTM).

4.8.0.5 Specialty Engineering Tools

The tools used in Specialty Engineering are often unique to each Specialty Engineering discipline. They include databases, drawing tools, requirements and Functional Analysis tools, word and document processors, and spreadsheets. The selection of specific tools depends on criteria established by the particular program. These tools are identified and controlled as documented in individual Specialty Engineering plan sections of the IPP.

4.8.0.6 Specialty Engineering Process Metrics

The schedule completion of Specialty Engineering analyses measured against the plan is a measure of the degree to which these analyses are being effectively managed. The effectiveness of Specialty Engineering analyses may be measured by the rework of analyses or incompatibility with measured performance as an indication that these analyses are reaching inaccurate conclusions.

Of the seven general measurement categories discussed in this section, the five that are applicable to Specialty Engineering are Schedule and Progress, Resources and Cost, Process Performance, Customer Satisfaction, and Product Quality. These measures, along with other candidate measures for Specialty Engineering, are provided in Table 4.8-5. It is recommended that each effort tailor these measures and add other applicable project-specific measures to ensure the contribution of necessary information to the decisionmaking processes.

Table 4.8-5. Candidate Measures for Specialty Engineering*

Schedule and Progress	Resources and Cost	Product Size and Stability	Product Quality	Process Performance	Technology Effectiveness	Customer Satisfaction
Achievement of specific milestone dates	Total effort compared to plan	Documentation of special engineering characteristics	Technical performance	Process productivity	Technology impact on product	Customer survey results
Test status	Resource utilization	Requirements	Defects	Process activity cycle time	Baseline changes	Performance rating
Percent of analysis studies completed (schedule and progress)		Percent of requirements derived from specialty analyses	Standards compliance	Depth of the specialty analyses as a percentage versus the target depth		

*NOTE: The measures above are only general examples to indicate the type of information that might be included in the individual section measurement matrix.

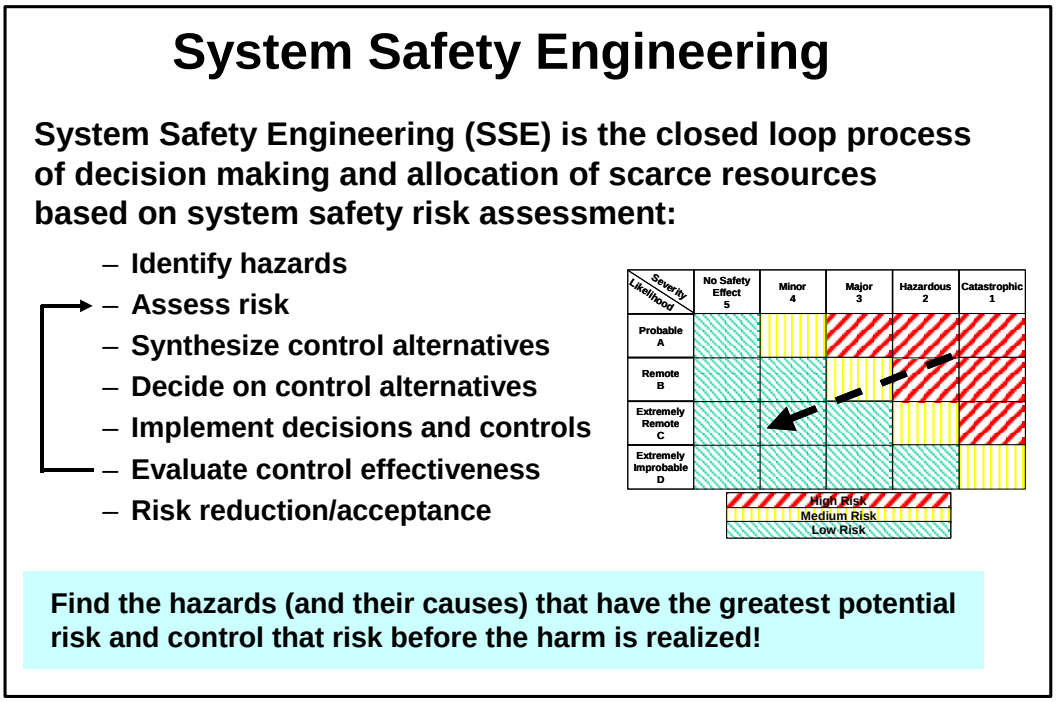
4.8.1 System Safety Engineering

SSE (also called Safety Risk Management) is a Specialty Engineering discipline within SE. It is recommended that system/safety engineers and program managers refer to the FAA SSH and the NAS Modernization SSMP for detailed information regarding the planning and conduct of SSE. The following paragraphs describe how system safety is integrated into a system's overall SE.

4.8.1.1 What Is System Safety Engineering?

SSE is the application of engineering and management principles, criteria, and techniques to optimize the safety of a system within the program's operational and programmatic constraints. These engineering and related management tools are used to identify, evaluate, and control hazards associated with a system. A hazard is a real or likely event that has the potential to harm people or damage the system. SSE's goal is to identify the hazards in a system early and continuously to assess the risk (severity and likelihood) of each hazard and to actively control the highest risk hazards. The NAS Modernization SSMP, Figure 4.2-1 (Risk Assessment Matrix) under the Safety Risk Management hyperlink in the FAST (http://fast.faa.gov/toolsets/index.htm), provides more information on this topic, as do Table 4.2.1 (Severity Definitions) and Table 4.2-2 (Likelihood or Probability Definitions).

As illustrated in Figure 4.8-4, the SSE process is a closed-loop method of Risk Management



(Section 4.10).

Figure 4.8-4. Closed-Loop Nature of System Safety Engineering

To conduct SSE in the AMS, the program performs hazard analyses, as described in the NAS SSMP, Chapters 4 and 5 (http://fast.faa.gov/toolsets/index.htm), and the SSH, Chapter 8 (http://fast.faa.gov/toolsets/index.htm). Figure 4.8-5 shows what safety analyses are performed relative to the phases and decisions of the Integrated Product Development System of the AMS. These safety analyses are timed to best support the phased needs and decisions in the overall AMS process.

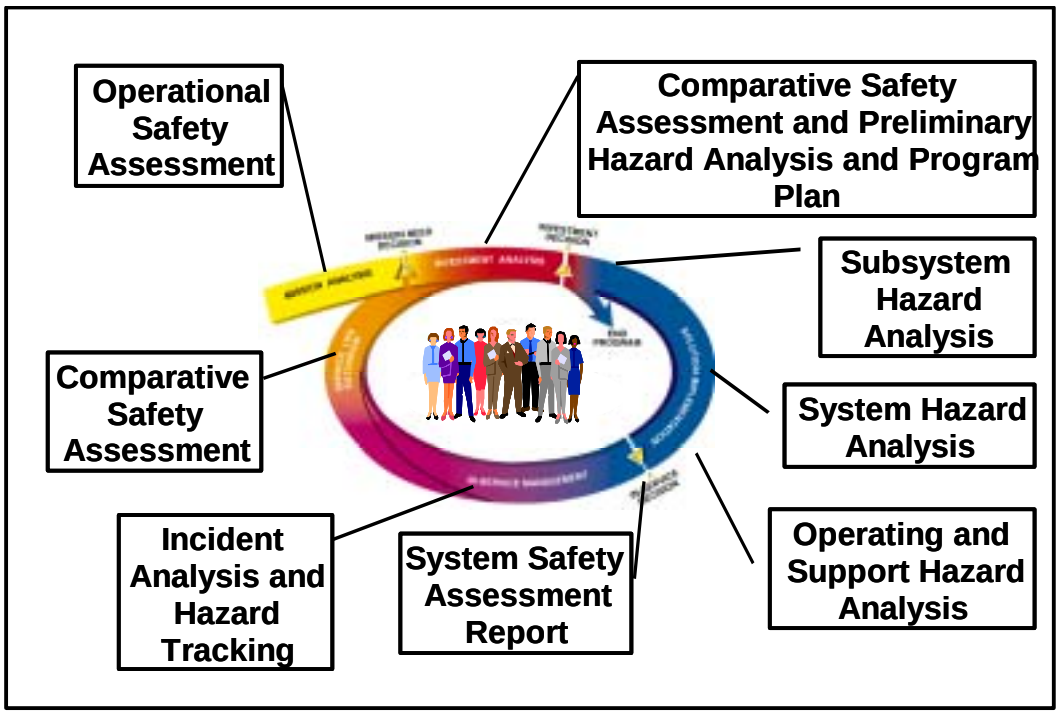


Figure 4.8-5. Types of Safety Hazard Analyses and Their Relative Position in the Acquisition Management System

4.8.1.2 Why Perform System Safety Engineering?

There are two basic reasons for performing SSE on a program:

- To comply with FAA Orders and AMS direction (e.g., FAA Order 8040.4 and AMS, Paragraph 2.9.13)
- To reduce total cost of development and improve program integration

The FAA's primary role is to ensure the safety of the NAS. In performing this role, the FAA has issued FAA Order 8040.4 (http://fast.faa.gov/toolsets/index.htm), which directs all FAA organizations to employ safety risk management in decisionmaking. The AMS was amended to

comply with FAA Order 8040.4. The AMS now requires programs to execute system safety and to brief the system safety program status at all Joint Resources Council (JRC) meetings and Acquisition Reviews. The SSH, Chapter 2 (http://fast.faa.gov/toolsets/index.htm), the SSMP, Chapter 6 (http://fast.faa.gov/toolsets/index.htm), and the AMS provide more information on this subject. For example, AMS Paragraph 2.9.13 reads:

> *System Safety Management shall be conducted and documented throughout the acquisition management lifecycle. Critical safety issues identified during mission analysis are recorded in the Mission Need Statement; a system safety assessment of candidate solutions to mission need is reported in the Investment Analysis Report; and Integrated Product Teams provide for program-specific safety risk management planning in the Acquisition Strategy Paper.*

Each line of business involved in acquisition management shall institute a system safety management process that includes, at minimum, the following:

- Hazard identification
- Hazard classification (severity of consequences and likelihood of occurrence)
- Measures to mitigate hazards or reduce risk to an acceptable level
- Verification that mitigation measures are incorporated into product design and implementation
- Assessment of residual risk

Status of system safety shall be presented at all JRCs. The FAST provides detailed guidelines for system safety management (http://fast.faa.gov/toolsets/SafMgmt/IndexStart.htm).

The second reason for conducting safety risk management is that it reduces cost and improves system integration and SE overall.

- System safety looks for programmatic risks that may impact system performance, schedule, and costs.
- System safety finds problems early. As Figure 4.8-6 shows, the earlier in the lifecycle a problem is found and managed, the easier and less expensive it is to correct.

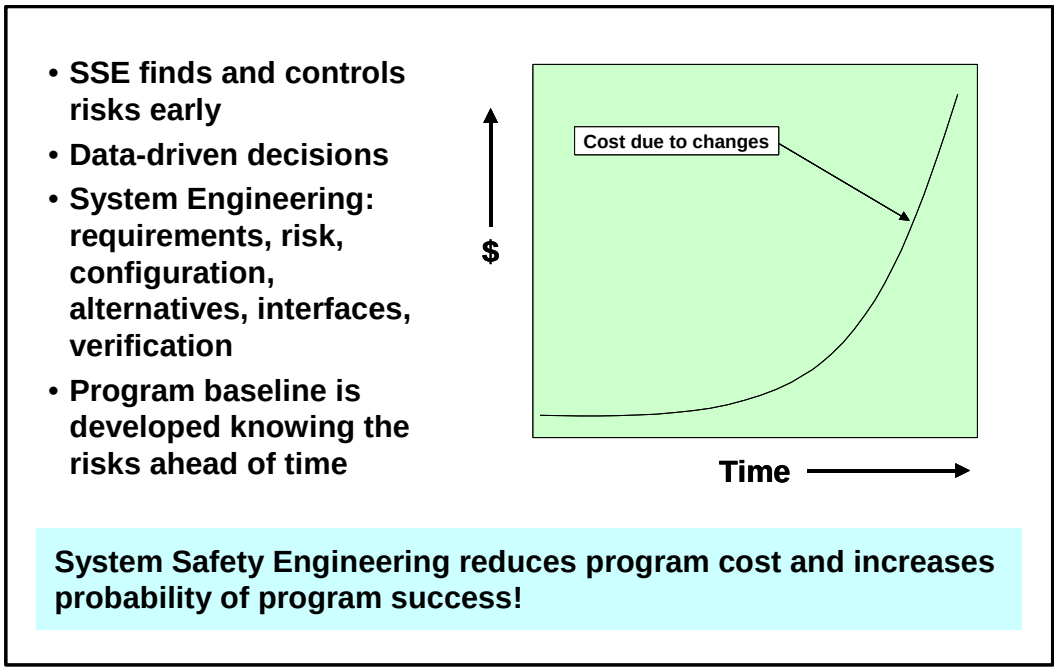


Figure 4.8-6. Benefits of System Safety Engineering

- The outputs of the system safety process feed other SE processes, improving the overall SE of the system (Figure 4.8-7).

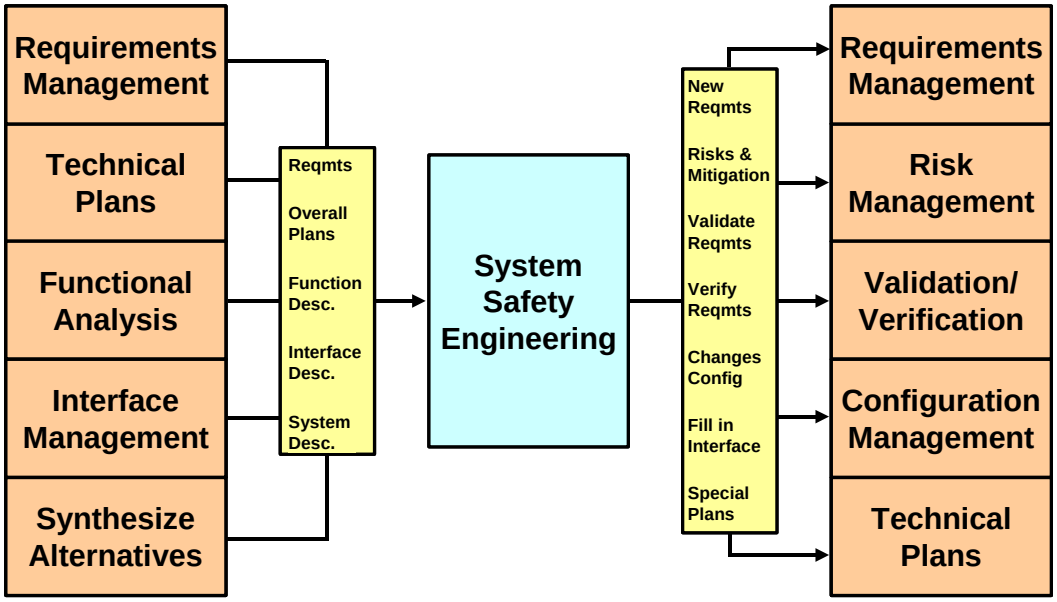


Figure 4.8-7. System Safety Engineering's Relationship to Other System Engineering Processes

4.8.1.3 System Safety Engineering Process Tasks

SSE follows the process tasks outlined in "General Specialty Engineering Process Tasks" (Paragraph 4.8.0.3).

4.8.1.4 System Safety Engineering Outputs/Products

The following products are outputs of SSE.

4.8.1.4.1 Program Planning

Each program is required to have an SSPP. The NAS Modernization SSMP (http://fast.faa.gov/toolsets/index.htm) is the overall plan for conducting safety risk management in the AMS. It is recommended that individual programs consult the SSMP when developing a program-specific SSPP that meets the NAS SSMP requirements. The FAA SSH, Chapter 5 (http://fast.faa.gov/toolsets/index.htm), also provides guidance on this topic.

4.8.1.4.2 Analysis Products

Table 4.8-6 lists the products of SSE. Detailed directions for how to develop these products are referenced in the table.

Table 4.8-6. Products of System Safety Engineering

System Safety Process Products	How To Reference
Operational Safety Assessment (OSA)	FAA SSH, Chapters 2 and 4 (http://fast.faa.gov/toolsets/index.htm) NAS SSMP, Section 5.2.1 (http://fast.faa.gov/toolsets/SafMgmt/section5.htm#5.2.1)
Comparative Safety Assessment (CSA)	FAA SSH, Chapters 2 and 4 NAS SSMP, Section 5.2.2 (http://fast.faa.gov/toolsets/SafMgmt/section5.htm#5.2.2)
Preliminary Hazard Analysis (PHA)	FAA SSH, Chapter 8 NAS SSMP, Section 5.2.3 (http://fast.faa.gov/toolsets/SafMgmt/section5.htm#5.2.3)
System Safety Program Plan (SSPP)	FAA SSH, Chapter 5 NAS SSMP, Section 5.2.4 (http://fast.faa.gov/toolsets/SafMgmt/section5.htm#5.2.4)
Subsystem Hazard Analysis (SSHA)	FAA SSH, Chapter 8 NAS SSMP, Section 5.2.5 (http://fast.faa.gov/toolsets/SafMgmt/section5.htm#5.2.5)
System Hazard Analysis (SHA)	FAA SSH, Chapter 8 NAS SSMP, Section 5.2.6 (http://fast.faa.gov/toolsets/SafMgmt/section5.htm#5.2.6)
Operating and Support Hazard Analysis (O&SHA)	FAA SSH, Chapter 8 NAS SSMP, Section 5.2.7 (http://fast.faa.gov/toolsets/SafMgmt/section5.htm#5.2.7)
Health Hazard Assessment (HHA)	FAA SSH, Chapter 8 NAS SSMP, Section 5.2.8 (http://fast.faa.gov/toolsets/SafMgmt/section5.htm#5.2.8)
System Safety Assessment Report (SSAR)	NAS SSMP, Section 5.2.9 (http://fast.faa.gov/toolsets/SafMgmt/section5.htm#5.2.9)
Safety Requirements Verification Table (SRVT)	NAS SSMP, Section 5.2.11 (http://fast.faa.gov/toolsets/SafMgmt/section5.htm#5.2.11)
Hazard Tracking System	FAA SSH, Section 2.2.3

System Safety Process Products	How To Reference
Hazard Tracking System (HTS)	NAS SSMP, Section 5.2.10 (http://fast.faa.gov/toolsets/SafMgmt/section5.htm#5.2.10)

4.8.2 Reliability, Maintainability, and Availability

4.8.3 Human Factors Engineering

4.8.4 Electromagnetic Environmental Effects

4.8.5 Quality Engineering — Reserved

4.8.6 Information Security Engineering

4.8.7 Hazardous Materials Management/Environmental Engineering

4.8.2 Reliability, Maintainability, and Availability Engineering

This section guides system engineers in facilitating and managing coordination of RMA efforts, which ensure operationally acceptable RMA characteristics in fielded systems.

4.8.2.1 What Is Reliability, Maintainability, and Availability Engineering?

Simply defined:

- *Reliability* quantifies a system's ability to perform without failure
- *Maintainability* quantifies a system's ability to recover from failure
- *Availability* quantifies a system's ability to perform when needed

RMA Engineering applies engineering and management principles, criteria, and techniques to optimize the RMA performance of a system within the program's operational and programmatic constraints. These engineering and related management tools are used to identify, evaluate, and control RMA characteristics associated with a system. Thus, the primary purpose of RMA Engineering is to minimize the probability of system failure and any potential losses stemming from such failure. RMA accomplishes this by establishing RMA requirements, assessing system RMA attributes, and analyzing solutions developed to meet established RMA requirements within realistic cost constraints.

4.8.2.1.1 Reliability, Maintainability, and Availability Detailed Definitions

These detailed RMA definitions provide background and context for the subsequent RMA Engineering discussions.

4.8.2.1.1.1 Reliability

Reliability is the probability that a system or constituent piece may perform a required function under specific conditions for a stated period of time. Reliability is calculated by the formula in Equation 1.

$$R = e^{-\frac{t}{m}}$$

Equation 1. Reliability Formula

where:

- *t is the mission time for which reliability is be calculated*
- *m is the mean-time-between-failure (MTBF),*
- *e is the natural antilogarithm of* $-\frac{t}{m}$.

MTBF is the basic measure of reliability for repairable systems or constituent pieces. MTBF is the mean number of life units during which all parts of the system or constituent pieces perform within their specified limits, during a particular measurement interval under stated conditions. MTBF is calculated according to Equation 2.

$$MTBF = \frac{T}{F}$$

Equation 2. MTBF Formula

where:

- *T is the length of the measurement interval*
- *F is the number of failures that occurred during the measurement interval*

4.8.2.1.1.2 Maintainability

Maintainability is the measure of the ability of a system or constituent piece to be retained in, or restored to, its fully operational status. It is generally characterized by the Mean-Time-To-Restore (MTTR), which is the total elapsed time from initial failure to resumption of operation. MTTR includes *all* "downtime"—not just the ease and speed with which a system may be repaired and returned to operational status following a failure. It is expressed as the sum of corrective diagnosis and maintenance times, divided by the total number of failures of a system or constituent piece Thus, the MTTR includes (and is thus greater than) the Mean-Time-To-Repair (see Equation 3). MTTR is usually expressed in hours.

$$MTTR = \sum_{t=1}^{F_T} \frac{\text{Diagnosis}_t + \text{Maintenance}_t}{F_T}$$

Equation 3. MTTR Formula

where:

- *t is an integer representing an occurrence requiring corrective diagnosis and associated corrective maintenance*
- *T is the length of the measurement interval*
- F_T *is the number of failures that occurred during the measurement interval*
- Diagnosis_t *is the time to perform corrective diagnosis*

- Maintenance_t *is the time to perform corrective maintenance*

Maintainability requirements generally pertain to inherent characteristics of the hardware design, such as the ability to isolate, access, and replace the failed component. These characteristics are generally fixed for commercial-off-the-shelf (COTS) components but may be specified, provided they do not conflict with the policy to employ COTS hardware whenever practical.

4.8.2.1.1.3 Availability

Availability is the probability that a system or constituent piece may be operational during any randomly selected instant of time or, alternatively, the fraction of the total available operating time that the system or constituent piece is operational. Measured as a probability, availability may be defined in several ways, which allows a variety of issues to be addressed appropriately, including:

- **Inherent Availability**. This availability is based solely on the MTBF and the MTTR characteristics of the system or constituent piece and the level of redundancy, if any, provided. For systems or constituent pieces employing redundant elements, perfect recovery is assumed. Downtime occurs only if multiple failures within a common timeframe result in outages of the system or one or more of its pieces to the extent that the need for redundant resources exceeds the level of redundancy provided. Inherent availability represents the maximum availability that the system or constituent piece is theoretically capable of achieving.

- **Equipment and Service Availability**. This availability includes all causes of unscheduled downtime (i.e., does not include scheduled downtime). This type of availability takes into account additional downtime incurred during the failover to redundant systems or downtime incurred by other practical issues associated with unscheduled outages.

- **Operational Availability**. This availability includes all sources of downtime, both scheduled and unscheduled.

The inherent availability represents the theoretical maximum availability that may be achieved by a system or constituent piece if automatic recovery is 100 percent effective. It strictly represents the theoretical availability based only on reliability (MTBF) and maintainability (MTTR). It does not include the effects of scheduled downtime, shortages of spares, unavailable service personnel, or poorly trained service personnel.

The availability requirement associated with the highest criticality service supplied by the system being procured is used to specify the inherent availability of the system. The only purpose for imposing an inherent availability requirement is to ensure that proposed constituent pieces of the system are *theoretically* capable of meeting a higher-level requirement, based on the reliability and maintainability characteristics of these constituent pieces and the redundancy provided.

Compliance with this requirement may be verified by using straightforward combinatorial availability models. The inherent availability of a single system or single constituent piece of the system is based on Equation 4.

$$A_{Single} = \frac{MTBF}{MTBF + MTTR}$$

Equation 4. Availability of a Single Element

Equation 5 gives the inherent availability of a string of system pieces that shall be up for the system to be operational.

$$A_{String} = A_1 A_2 A_3 \cdots A_n$$

Equation 5. Availability of a String of System Pieces

The right side of Equation 5 is the product of all terms in the sequence.

Figure 4.8-8 illustrates the inherent availability of a two-element system, which is considered operational if both elements are up—or if the first is up and the second is down, or if the first is down and the second is up (i.e., the system is available if either S1 or S2 is up and running)—and is expressed by Equation and Equation 7.

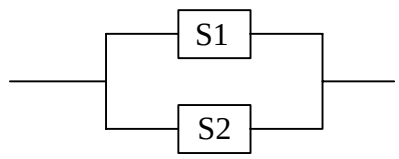


Figure 4.8-8. Inherent Availability of a Two-Element System

$$A_{Two-Element} = (A_1 A_2 + A_1 \overline{A}_2 + \overline{A}_1 A_2)$$

Equation 6. Availability of a Two-Element System

or

$$A_{Two-Element} = (1 - \overline{A}_1 \overline{A}_2)$$

Equation 7. Availability of a Two-Element System

where $\overline{A} = (1 - A)$ *, or the probability that an element is not available*

The above equations may be combined to model more complex architectures. However, it is recommended that the overriding goal for verifying compliance with the inherent availability requirement be *kept simple*.

4.8.2.2 Why Perform Reliability, Maintainability, and Availability Engineering?

Reliability, maintainability, and availability directly impact both operational capability and lifecycle costs and, therefore, are important considerations in any system engineering effort. A system's ability to successfully fulfill its mission need directly depends on its ability to perform its required function under specific conditions for a given period of time without failure (reliability). Likewise, a system's operational success also depends on its ability to recover from a failure in a timely and efficient manner (maintainability). Operational success also depends on the system being ready to accomplish its mission as needed (availability). It is widely recognized and accepted that a system's RMA characteristics directly impact its overall lifecycle costs. Operational and support costs for a system are predominant variables of its overall lifecycle cost. A major driver in operational and support costs is the quality of a system's RMA characteristics; thus, it is imperative that programs apply sound engineering and management principles, criteria, and techniques to ensure operationally acceptable RMA characteristics in fielded systems. As indicated in Equation 6, using redundancy is the simplest way to increase availability. When redundancy is used to increase system availability, the overall system lifecycle costs increases.

A system engineer—to effectively and successfully coordinate RMA Engineering efforts and, therefore, optimize the quality of a system's RMA characteristics—shall focus on the following RMA objectives, which are to be achieved throughout the lifecycle of a system:

- Identify all of the system's RMA functions, to include all operational and maintenance support drivers, in order to:
  - Comprehensively incorporate RMA principles into the system's requirements and design
  - Minimize and control the system's lifecycle costs
- Measure, predict, assess, and report system trends, throughout its lifecycle to continuously meet or exceed RMA performance requirements
- Achieve RMA performance objectives at all system levels
- Emphasize continuous RMA improvement

4.8.2.2.1 FAA Background on Reliability, Maintainability, and Availability

For the last 20 years, FAA specifications have focused primarily on availability requirements instead of the more traditional reliability and maintainability requirements.

Availability is appropriate as a top-level operational requirement because it is a quantitative and consistent way of summarizing the need for continuity of NAS services. Use of availability requirements may facilitate FAA system engineers' comparison and assessment of architectural alternatives. . Availability is also useful as a performance metric for operational systems.

However, using availability as the primary RMA requirement in contractual specifications presents many practical problems. The fundamental concept of availability seems to imply a tradeoff between reliability and maintainability. In other words, a 1-hour interruption of a critical service that occurs annually is apparently equivalent to 240 15-second interruptions of the same

service, since both scenarios provide the same availability. However, short interruptions lasting seconds are less likely to affect air traffic control operations than long interruptions lasting an hour or more, which may have a significant impact on traffic flow and operational safety.

In addition, availability cannot be measured during system development and may only be predicted by using highly artificial models. It is also impractical to measure the availability of a developed system before its operational deployment.

For these reasons, it is necessary to perform RMA Engineering to establish detailed RMA requirements that may be monitored and verified during development. Well-written RMA requirements ensure that the FAA understands what is to be received and that the supplier understands what shall be delivered.

4.8.2.2.2 Reliability, Maintainability, and Availability Policy

The Integrated Logistics Support (ILS) section of the FAA's AMS policy implies that the products of RMA Engineering are a fundamental key in achieving the ILS objective. ILS provides the required level of service to the end user at minimal lifecycle cost to the FAA. Thus, not only is it sound system engineering practice that drives programs to perform RMA Engineering (as stated in the sections above), but it is also a necessity to properly adhere to AMS policy.

4.8.2.3 Reliability, Maintainability, and Availability Inputs

Inputs to the RMA Engineering process include requirements, descriptions of alternatives, and functional architectures and physical architectures, as well as specific measurements and other data that may be used to analyze system performance in the interrelated RMA areas. (See Figure 4.8-1 for a list of possible inputs.) The inputs used within the RMA Engineering process shall be sufficient to enable computation of the two defining RMA characteristics (i.e., MTBF and MTTR) and comprehensive enough to conduct the appropriate analysis.

4.8.2.4 Reliability, Maintainability, and Availability Process Tasks

RMA Engineering follows the process tasks outlined in General Specialty Engineering Process Tasks (Paragraph 4.8.0.3).

4.8.2.5 Reliability, Maintainability, and Availability Outputs

Figure 4.8-1 lists the various outputs that may result from performing Specialty Engineering. The following subsections detail some of these outputs as they relate to RMA Engineering.

4.8.2.5.1 Planning Criteria

The application of an RMA program generally follows the steps described below. These steps shall be considered in providing planning criteria input to SE Integrated Technical Planning (Section 4.2).

4.8.2.5.1.1 STEP 1: Identify Desired RMA Program Objectives

This step includes identifying and documenting unambiguous and measurable objectives based on the mission need.

4.8.2.5.1.2 STEP 2: Select Metrics

Establishing metrics (see Paragraph 4.8.2.6) sets the stage for later evaluations. Metrics provide a level of program continuity in determining progress toward meeting RMA program objectives.

4.8.2.5.1.3 STEP 3: Establish Plans for Performance Monitoring

Monitoring plans shall be established and implemented early in the program. It is recommended that an RMA data system be incorporated early in the system's lifecycle to permit monitoring and assessment of RMA performance and to ensure that all RMA data recorded are appropriately disseminated, analyzed, and evaluated.

In conjunction with an effective RMA data system, it is recommended that a closed loop problem/failure reporting and corrective system be established to support problem detection, assessment, and correction. Such a system allows implementation of design improvements and corrections as part of the system development process as well as provides a tool for monitoring progress toward meeting system requirements, which obviously includes subset of the RMA requirements. The data collected supports tracking the root cause of the problem, which thus facilitates overcoming hurdles that may be hindering achievement of specific RMA requirements.

It is recommended that the corrective action system continue to be used during in-service operations to support upgrading system RMA performance in conjunction with a Reliability Growth Program (see Paragraph 4.8.2.5.1.3.1), if necessary. Operations truly demonstrate the system's actual capability to meet RMA requirements. Operations also provides a unique opportunity to continue evaluating and upgrading the system's RMA performance with the dual benefit of ensuring that the RMA performance meets and maintains intended capabilities and produces lower lifetime costs. It is recommended that the corrective action system developed and implemented early in the system's lifecycle continue to be used to support upgrading RMA performance.

Using a structured and controlled performance data acquisition process provides the information to perform trend analysis on the behavior of the system and to support root cause analysis. The application of RMA tools (see Paragraph 4.8.2.7) is extremely data-dependent and the root of oversight/insight into program behavior, validation decisions made earlier during initiation, and identification of modifications/actions to sustain the program. For example, if Reliability Centered Maintenance were incorporated early in the system's lifecycle, operations would provide the opportunity to validate or revise the maintenance decisions that were previously made during design. The most essential ingredient that helps guarantee the success of any RMA program is management's continuing commitment and support.

4.8.2.5.1.3.1 Reliability Growth Program

A Reliability Growth Program is usually necessary because a formal reliability demonstration test, in which the system is either accepted or rejected based on the test results, is not feasible. For a formal reliability demonstration, the test time required to obtain a statistically valid sample would be prohibitive, and the large number of software failures encountered in any major software development program would virtually ensure failure to demonstrate compliance with the requirements. Establishing "pass-fail" criteria for a major system acquisition is not a viable alternative.

Reliability growth testing is an ongoing process of testing, and correcting failures. Reliability growth was initially developed to discover and correct hardware design defects. Statistical methods were developed to predict the system MTBF at any point in time and to estimate the additional test time required to achieve a given MTBF goal.

Reliability growth testing applied to automation systems is a process of exposing and correcting latent software defects. The hundreds of software defects exposed during system testing, coupled with the stringent reliability requirements for these systems, preclude using statistical methods to accurately predict the test time to reach a given MTBF before system deployment. There is no statistically valid way to verify compliance with reliability requirements at the FAA's William J. Hughes Technical Center (WJHTC) before field deployment. This is because it is not possible to obtain enough operating hours at the WJHTC to reduce the number of latent defects to the level needed to meet the reliability requirements.

The inescapable conclusion is that it may be necessary to field systems that lack RMA requirements verification. The large number of additional operating hours accumulated by multiple system installations may increase the rate at which software errors are found and corrected, as well as the growth of the system MTBF.

To be successful, the reliability growth program shall address two issues. First, the contractor shall be aggressive in promptly correcting software defects. The contractor shall be given a powerful incentive to keep the best people on the job through its completion, instead of moving them to work on new opportunities. In the Host program, for example, a process called "expunging" accomplished this. The system MTBF was computed by dividing the operating hours by the number of failures. However, if the contractor demonstrated that the cause of the failure had been corrected, and then the failure was "expunged" from the list of failures. If a failure is not repeated within 30 days, it is also expunged from the database. Thus, if all Program Trouble Reports (PTRs) were fixed immediately, the computed MTBF would be infinite even if the system were failing daily.

This measure is statistically meaningless as a true indicator of the system MTBF. It is, however, a useful metric for assessing the responsiveness of the contractor in fixing the backlog of accumulated PTRs. Since government representatives decide when to expunge errors from the database, they have considerable leverage over the contractor by controlling the value of the MTBF reported to senior program management officials. There may be other or better metrics that could be used to measure the contractor's responsiveness in fixing PTRs; the important thing is that there shall be a process in place to measure the success of the contractor's support of reliability growth.

The second issue that shall be addressed during the reliability growth program is the acceptability of the system to field personnel. Since the system may be deployed to field sites before it has met the reliability requirements, it is recommended that field personnel be involved in the reliability growth testing at the WJHTC and concur in deciding when the system is sufficiently stable to warrant sending it to the field.

4.8.2.5.1.4 STEP 4: Report Results

Results of the performance-monitoring effort are reported to support assessment of the progress toward meeting requirements and meeting RMA program objectives. This includes comparing predicted and demonstrated RMA versus requirements and evaluating system RMA demand throughout the system's operational life.

4.8.2.5.1.5 STEP 5: Use Results for Planning, Managing, and Budgeting

Assessing progress toward meeting requirements and meeting RMA program objectives provides the feedback needed to adjust program planning, managing, and budgeting. The results may also be used to support related analyses, such as safety and logistics, and in emphasizing improvements in succeeding systems.

4.8.2.5.2 Design Analysis Reports

There are various types of RMA analyses conducted and eventually documented within a Design Analysis Report. A discussion of some of the more common RMA-related analyses follows.

4.8.2.5.2.1 Failure Modes and Effects Analysis

FMEA is an evaluation process for analyzing and assessing the potential failures in a system. The objective is to determine the effect of failures on system operation, identify the failures critical to operational success and personnel safety, and assess each potential failure according to the effects on other portions of the system. In general, these objectives are accomplished by itemizing and evaluating system composition and functions.

This type of analysis is a systematic method of identifying the failure modes of a system, constituent piece, or function and determining the effects on the next higher level of the design. The detection method (if any) for each failure mode may also be determined. An FMEA may be a quantitative or qualitative analysis and may be performed on all types of systems (e.g., electrical, electronic, or mechanical). If a quantitative FMEA is being performed, a failure rate is determined for each failure mode. The results of an FMEA may be used to generate the Failure Modes and Effects Summary (FMES), Figure 4.8-10, and are normally used to support the other analysis techniques of the System Safety Assessment (SSA) process, such as Fault Tree Analysis (FTA), Dependence Diagram (DD), or Markov Analysis (MA). Combinations of failures are not usually considered as part of the FMEA.

An FMEA is performed at a given level (system, subsystem, element, etc.) by postulating the ways the chosen level's specific implementation may fail. The effect of each failure mode is determined at the given level and usually the next higher level for each operating mode of the equipment. Sometimes, an FMEA may be focused toward a specific operating scenario as required to support a top-down FTA, DD, or MA.

The FMEA shall account for all safety-related effects and any other effects identified by the requirements. In cases where it is not possible to identify the specific nature of a failure mode, the worst-case effect shall be assured. If the worst case is unacceptable for the fault tree, the failure modes shall be examined at the next lower level. That is, if the FMEA is being conducted at the functional level, drop to the piece-part level and exclude components with no effect on the event under consideration. If the analysis is being conducted at a piece-part level, drop to consider specific failure mechanisms within the part. Another option is to redesign to improve redundancy or add monitoring.

Regardless of the level to which the FMEA is to be performed, the major steps of an FMEA include preparation, analysis, and documentation.

4.8.2.5.2.1.1 FMEA Preparation

Preparing an FMEA includes determining the FAA's requirements, obtaining current documentation, and understanding the operation of the function. It is important to know the FAA's expectations and requirements for the FMEA before beginning. If the FMEA requirements are not known, the FMEA may not meet the needs of the requester and may have to be redone.

FMEA requirements usually originate from a Preliminary Hazard Analysis activity such as an FTA, DD, or MA. The analyst needs to know the analysis level (functional versus piece-part), safety-related effects, other failure effects, and operational modes of interest. An FMEA is used to support the safety assessment process by providing failure rates to quantify the basic events of the FTA, DD, or MA. An FMEA may also be used to support verification of the FTA by comparing the FMEA failure modes with the basic events of the fault tree.

The final step before beginning to perform the analysis is to obtain the following information, which may be necessary to complete the analysis, or which may simplify the analysis activity:

- FMEA requirements, including safety-related and requested failure effects and specific operating modes of interest
- Specifications
- Current drawings and schematics
- Parts lists for each system or constituent piece
- Functional block diagrams
- Explanatory materials, including the theory of operation
- An applicable list of failure rates
- The FMEA on the previous generation or similar function
- Any design changes and revisions that have not yet been included on the schematic (**Note:** Designs may change frequently, and having the most up-to-date material reduces FMEA updates.)
- Preliminary list of component failure modes from previous FMEA, if applicable

  (**Note:** For FMEA performed early in the design stage, some of the above information may not be available, and assumptions or estimates may have to be made. Detailed documentation of these assumptions shall be maintained for traceability and to simplify future updates.)

4.8.2.5.2.1.2 Performing the Analysis

The analyst needs to review and understand the information gathered during preparation stage previously described. The analyst may also find it useful to understand the functions that the design being analyzed performs within the next higher level. After gaining sufficient knowledge,

the analyst identifies failure modes. Every feasible hardware failure mode is postulated at the level of the design being analyzed. Consideration is given to failure modes of the components or functions that make up the given level. Information to aid in determining the failure modes of the functions or components is provided in functional FMEA and piece-part FMEA (see Paragraphs 4.8.2.5.2.1.2.1 and 4.8.2.5.2.1.2.2).

Every identified failure mode is analyzed to determine its effect on the given level and usually on higher levels as well. Failure-effect categories are created for each different type of effect, and a code may be assigned to each effect category. Defining these codes simplifies the FMEA worksheet Figure 4.8-9 by moving the description of each effect from the worksheet to the body of the report. The FMEA worksheet provides a list of failure modes, effects, and rates. Each effect category shall have only one higher-level effect; otherwise, the effect categories need to be defined in more detail. For example, if the effect category is originally defined as “causes signal xyz to be out of specification,” but an out of specification high condition causes a different effect from an out of specification low condition, then the effect category may be split to “…out of specification high” and “…out of specification low.” Similarly, if the failure mode is found to cause two higher-level effects (e.g., “Loss of signal A” and “Loss of signal B”), then these two need to be combined to form a new effect category, “Loss of both signal A and B.”

The means by which the failure is detected is usually determined and documented within the FMEA worksheets. Examples of detection methods include detection by hardware or software monitors, power-up tests, and maintenance checks.

For a quantitative FMEA, a failure rate is assigned to each failure mode. It is recommended that whenever possible, failure rates be determined from failure data or similar equipment already in field use. Industry sources of failure rates (including MIL-HDBK-217, MIL-HDBK-338, RAC “Nonelectronic Parts Reliability Data” (NPRD), and GIPED (Government Industry Data Exchange Program), MIL-HDBK-978, and Rome Laboratory’s “Reliability Engineer’s Toolkit”) may also be used. The total failure rate for each failure effect category may be detailed in a summary sheet or summarized in the FMES.

There are two basic types of FMEAs: functional and piece-part. Functional FMEAs are typically performed to support the safety analysis effort; piece-part FMEAs are performed as necessary to provide further refinement of the failure rate. Piece-part FMEAs are typically done when the more conservative failure rates from a functional FMEA prevent the system or constituent piece from meeting the FTA probability of failure budget. A piece-part FMEA may also be useful for systems that rely on redundancy, since a functional FMEA may not reveal single component failures affecting more than one redundant element. Piece-part FMEAs are also useful for safety analysis of mechanical items and assemblies.

4.8.2.5.2.1.2.1 Functional FMEA

A functional FMEA may be performed at any indenture level. The appropriate level of subdivision is determined by the complexity of the system and the objectives of the analysis. If the required analysis is on a section of circuitry or mechanical devices larger than a particular function, it is recommended that it be broken down into functional blocks. This may mean defining each replaceable unit or item into many blocks. The FMEA task is simplified in each block and has as few outputs as possible. Once the functional blocks have been determined, a functional block diagram is to be created and each block labeled with its functional name. For each functional block, it is recommended that internal and interface functions are analyzed relative to system operation.

The next step is postulating the failure modes for each functional block. Determine the failure modes by thinking about the intent of the functional block and trying to determine how that function might fall regardless of the specific parts used. The analyst shall know the operation of the functional block well enough to be positive that no significant failure modes have been overlooked, including single component failures that could affect more than one redundant functional block. Given a clear description of the block's function, analysts often find many of the failure modes to be apparent.

Following is a simple example of functional failure modes:

The power supply circuitry that generates the 5 volts may be called a functional block. Some examples of functional failure modes include:

- Loss of 5 volts
- Voltage less than 5 volts
- Voltage greater than 5 volts
- Noise on 5 volts
- Short-to-ground or other voltage

There may be other failure modes based on circuit implementation.

The effect of each failure mode is determined by considering how the function fits into the overall design. Failure-effect categories are generally created for each effect type, and a failure-effect category code is assigned. All failure modes that cause this identical effect are assigned to the effect category. The effect category code may then be entered into the FMEA worksheet for each failure. Software and fault monitoring shall be considered when failure effects and means of detection are determined. As part of this analysis, the analyst shall also verify that the monitoring is able to detect the failure mode. To properly perform this analysis, the analyst shall have detailed knowledge of the system requirements and software design, including internal fault management techniques as applicable.

If a quantitative analysis is being performed, a failure rate is assigned to each failure mode. One technique is to perform a failure rate prediction for each block and apportion the failure rate across the various failure modes based on past experience of similar functions or other sources, allowing determination of probability of occurrence.

The analyst records the functional FMEA results in the worksheet. The example below may be modified to meet program needs. Different requirements may result in addition or deletion of some of the information. The analyst needs to ensure that the FMEA form and content meet the specific needs of the requester before beginning the analysis.

As the analysis progresses, it is recommended that the analyst informally record the following information for future FMEA maintenance and to assist in resolving FMEA questions.

- Justification of each failure mode
- Rationale for the assigned failure rate

- Rationale assigning a particular failure-to-a-failure effect category
- Documentation of any assumptions made

This documentation is usually not included in the FMEA report, but is retained for reference.

4.8.2.5.2.1.2.2 Piece-Part FMEA

A piece-part FMEA is similar to a functional FMEA, except that instead of analyzing at the functional or block diagram level, analysts assess the failure modes of each individual component contained in the item or function. A piece-part FMEA may be used to determine the failure effects of potential electrical, electronic, or mechanical failures. For example, the effect of failures of a resistor or motor shaft may be considered as part of a piece-part FMEA. Piece-part FMEAs on electronic equipment are usually performed only as necessary, when the more conservative results of a functional FMEA may not allow the item to meet the FTA probability of failure budget. This is due in part to the difficulty in determining the failure modes for complex components.

The first step in a piece-part FMEA is to create a list of all components to be covered by the FMEA. The next step is to determine the failure modes of each component type. This is the most difficult part of the piece-part FMEA, particularly FMEAs performed on electronic items containing complex integrated circuits. Determining all the failure modes of any but the simplest components, where industry data is available, is extremely difficult and sometimes impossible. When in doubt, make the worst-case assumptions of part failure modes.

Failure Modes and Effects Analysis (FMEA)							
System:					FMEA Description:		Date:
Subsystem of Unit:							Sheet_____ of _____
Component:					FTA or DD References:		File No.:
					Prepared by:		Revision:
Function Names	Function Code	Failure Mode	Mode Failure Rate	Failure Phase	Failure Effect	Detection Method	Comments

Figure 4.8-9. Functional FMEA Worksheet

Failure Modes and Effects Summary (FMES)									
Project No.:					FMES No.:		Date:		
Contract No.:					Supplier:		Sheet_____ of _____		
System:					Suppliers Part No.:		Revision:		
Subsystem of Unit:					Suppliers Dwg. Ref.:		Prepared by:		
Ref.	Failure Mode	Failure Rate	Phase	Effects on System	Symptoms 1) Controllers 2) Ground Crew 3) Maintenance	1) Causal Failure 2) Remarks	Causal Failure Ref.	Check Ref.	Failure Condition Ref.

Figure 4.8-10. Functional FMES Worksheet

4.8.2.5.2.2 Failure Modes and Effects Criticality Analysis

FMECA identifies potential design weaknesses through a systematic analysis approach. The approach considers all possible ways in which a component may fail (the modes of failure); the possible causes for each failure; the likely frequency of occurrence; the criticality of failure; the effects of each failure on systems operation (and on various system components); and any corrective action that may be initiated to prevent (or reduce the probability of) the potential problem from occurring in the future.

Essentially, an FMECA is generated from an FMEA by adding a criticality figure of merit. More information on performing an FMECA appears in Section 9.7 of the FAA's System Safety Handbook.

4.8.2.5.2.3 Fault Tree Analysis

Details on FTA contents and the steps involved in performing an FTA appear in Section 9.3 of the FAA's System Safety Handbook.

4.8.2.5.3 Requirements

The following subsections provide general guidelines in developing candidate RMA requirements that may arise as a result of RMA Engineering analysis efforts.

4.8.2.5.3.1 Reliability, Maintainability, and Availability Requirements

For systems that are to become direct replacements of existing systems, it is recommended that the RMA Engineering practitioner do the following:

- Locate the system being replaced within the higher-level architecture
- Identify the service thread or threads that the system supports
- Determine the criticality level of the service thread; if more than one service thread is supported, use the service thread with the highest criticality level
- Use the availability associated with the service thread with the highest criticality level as the basis for the system-level availability requirement

For systems that are not to become replacements of existing systems, it is recommended that the RMA Engineering practitioner do the following:

- Identify the criticality of the system according to the provided requirements
- Ensure that the requirements are consistent with the higher-level requirements and the associated NAS Architecture implementation plan being addressed

The primary objectives to be achieved in preparing the RMA provisions for a procurement package are as follows:

- Provide the specifications, including a system-level specification, defining the RMA requirements for the delivered system
- Define the effort required to provide the necessary documentation, engineering, and testing required to support monitoring of the design and development effort, risk management, design validation, and reliability growth testing activities
- Provide guidance concerning the design and data required to facilitate the technical evaluation of fault-tolerant design approaches, as well as programs for risk management, software fault avoidance, and reliability growth

The system-level specification serves as the basis for defining the design characteristics and performance that are expected of the system. From the standpoint of RMA characteristics, it is necessary to define the quantitative RMA and performance characteristics of the automatic fault detection and recovery mechanisms. It is also necessary to define the operational requirements

needed to permit FAA facilities personnel to perform real-time monitoring and control and manual recovery operations as well as diagnostic and support activities.

4.8.2.5.3.2 Monitor and Control Requirements

In addition to the requirements directly related to RMA, there are complementary requirements in the area of Monitor and Control (M&C). The requirements are complementary because M&C capabilities deal with functions related to monitoring and controlling RMA performance. These capabilities include such functions as the ability to monitor the status of system hardware and software; run diagnostics; reconfigure system hardware and software; and download software releases. M&C requirements are typically either local to the system site location or remotely away from the system site location. Types of M&C requirements include:

- **System Monitoring.** The critical user requirements for system monitoring are the number of parameters and events that need to be monitored and the allowable latency between the time an event occurs and the time that it is reported at the M&C console. These requirements determine design parameters, such as the frequency of polling of remote devices or the periodicity of their reporting. The number of parameters to be monitored and the frequency of reporting impose a steady-state communications and processing load on the system. A requirement for immediate notification of status changes or failures may cause excessive peak loads that may overwhelm the monitor and control processor.

- **System Control**. The primary system control requirement concerns the types of commands to be provided and the time between entering and executing a command.

- **M&C Computer-Human Interface.** Specifying the M&C Computer-Human Interface (CHI) requirements is a particularly challenging task. General statements such as “an effective user interface must be provided” only creates controversy over what constitutes “effective.” Attempts to provide detailed requirements for the CHI may stifle innovation or rule out COTS solutions; but if detailed specifications are not provided, there is a risk that the design may be deemed unacceptable. Both the RMA Engineering process and the Human Factors Engineering process (Section 4.8.3) are involved in defining M&C CHI requirements.

- **System Data Recording.** Data-recording requirements concern the number and types of data to be recorded and the sampling rates. Some of the data to be recorded may be error reports and status changes that occur asynchronously. Data-recording issues are similar to those for system monitoring. The requirements drive steady-state processing and communications overhead, and peak traffic from asynchronous events may overload the system.

  Estimating the load imposed by system recording is complicated by the fact that FAA systems typically allow selection of the data items to be recorded (e.g., for monitoring normal operations or for diagnosing specific problems). Unless specific recording scenarios are provided, the data-recording load may be indeterminate.

- **Data Reduction and Analysis.** These requirements apply to the offline analysis capabilities that are provided to process recorded data. The analysis capabilities to be provided depend on the characteristics of the specified system.

- **Startup/Startover**. These requirements apply primarily to computer systems. Since most computer systems being acquired are based on COTS hardware, these requirements are likely to be closely tied to the characteristics of the selected hardware and operating system.

- **Software Loading and Cutover**. These requirements concern the methods for obtaining a new version of software (either electronically or on some form of media); loading the new software into the machines; and cutting over to the new software version. These requirements also greatly depend on the specific system design.

- **Certification**. Certification requirements relate to both offline capabilities for verifying that an individual subsystem has been restored to operation and to online capabilities for verifying that an entire system is continuing to operate satisfactorily.

- **Transition**. Transition requirements define the temporary capabilities that allow transition safely from an existing system to a new system and reversion quickly to the old system if problems occur with the new system. The transition capabilities allow new systems to be safely introduced into a 24/7 environment. Transition requirements are typically for temporary switching systems that are removed once the new system has proven to be reliable.

- **Training Systems**. Training requirements refer to requirements for any separate equipment and systems that are needed for training, as well as the capability to partition the system so that the part used for training activities is isolated from the operational system.

4.8.2.6 Reliability, Maintainability, and Availability Metrics

At a minimum, RMA metrics are based on the system's MTBF (i.e., reliability), MTTR (i.e., maintainability), and availability (see Paragraphs 4.8.2.1.1 and 4.8.2.5.1.2 for further details).

4.8.2.7 Reliability, Maintainability, and Availability Tools

The following tables list the RMA tools.

4.8.2.7.1 Reliability Analysis Tools

Table 4.8-7. Reliability Analysis Tools

Activity	What Is Done	Why It Is Done	When It Is Called For	When It Is Performed
Alert Reporting	Document significant problem and nonconforming item data for exchange between the FAA and GIDEP.	Identifies potential problems.	Used throughout a program (extends beyond just RMA).	As close to problem identification as possible.

Activity	What Is Done	Why It Is Done	When It Is Called For	When It Is Performed
Human Error Risk Assessment	Identify risks to design, equipment, procedures, and tasks as a result of human error.	Identifies candidate designs to support both risk and maintainability goals.	Appropriate for all programs.	Initially early in design and iteratively as the design matures.
Human Factors Task Analysis	Analyze and list all the things people may do in a system, procedure, or operation with details on: (a) information requirements; (b) evaluations and decisions that shall be made; (c) task times; (d) operator actions; and (e) environmental conditions.	Identifies influence factors that drive design for maintainability.	Appropriate for all programs.	Initially early in design and iteratively as the design matures.
Failure Mode and Effects (and Criticality) Analysis (FMEA/FMECA)	Perform a systematic analysis of the local and system effects of specific component failure modes. Under FMECA, also evaluate the mission criticality of each failure mode.	Identifies potential single failure points requiring corrective action. Identifies critical items and assesses system redundancy.	Recommended for consideration for all systems.	When a system block diagram is available. Update throughout system design.
Fault Tree Analysis (FTA)	Systematically identify all possible causes leading to system failure or an undesirable event or state	Permits systematic, top-down, penetration to significant failure mechanisms.	Apply to critical (especially safety-critical) systems.	During system design.
Problem/Fail	Provide a closed	Ensures that	All programs	Throughout

Activity	What Is Done	Why It Is Done	When It Is Called For	When It Is Performed
Pure Reporting and Corrective Action System (PRACA/ FRACAS)	loop system for documenting hardware and software anomalies, analyzing their impact on RMA, and tracking them to their resolution. (Root Cause Analysis)	problems are systematically evaluated, reported, and corrected.	may benefit from some type of formal, closed-loop system.	system lifecycle.
Problem/ Failure Reporting Plan	Document the process for closed-loop problem/failure identification, reporting, and resolution.	Shows what problems exist within the program, what has been done to correct them, and the effectiveness of the remedial action.	At the outset of a program.	Throughout system lifecycle.
Process Failure Modes and Effects Analysis	Analyze an operation/process to identify the kinds of errors that humans could make in carrying out the task.	Ensures a method to deduce the consequences for process failures and the probabilities of those consequences occurring.	To assist in the control of critical processes.	Early in process definition.
Reliability Assurance Plan	Identify the activities essential in ensuring reliable performance, including design, production, and product operation.	Ensures that design risks are balanced against program constraints and objectives through a comprehensive effort calculated to contribute to system reliability over the mission lifecycle.	For all programs with reliability performance requirements.	During program planning.
Reliability Modeling	Perform prediction, allocation, and	Aids in evaluating the reliability of competing designs.	Most hardware programs benefit where	Early in design.

Activity	What Is Done	Why It Is Done	When It Is Called For	When It Is Performed
(Prediction/ Allocation)	modeling tasks to identify inherent reliability characteristics.	competing designs.	failure rates are needed for tradeoff studies, sparing analysis, etc.	
Redundancy Switching Analysis	Perform a rigorous failure modes, effects, and criticality analysis (FMECA) at the part level for all interfacing circuits of redundant equipment.	Verifies that the failure of one of two redundant functions does not impair the ability to transfer to the second function.	Recommended for consideration for redundant equipment.	Early in design.
Reliability Tradeoff Studies	Compare all realistic alternative reliability design approaches against cost, risk, schedule, and performance impacts.	Aids in deriving the optimal set of reliability performance requirements, architecture, baselines, or designs.	Performed at some level on all systems. Predictive techniques may be used.	Investment Analysis and Solution Implementat ion.
Reliability Growth Test	Conduct repetitive test and repair cycles to disclose deficiencies and verify that corrective actions may prevent recurrence.	Provides gradual evolution of a system to a state of higher reliability through repeated failure and repair.	Appropriate for all hardware and software systems.	Beginning with design and throughout the product lifecycle.
Sneak Circuit Analysis	Methodically identify sneak conditions (unexpected paths or logic flows) in circuits.	Identifies design weaknesses that could inhibit desired functions ort initiate undesired functions.	Generally used only for the most safety-critical equipment.	Early in design.
Trend Analysis	Evaluate variation in data with the	Provides a means of assessing the	Used to track failures,	Throughout the

Activity	What Is Done	Why It Is Done	When It Is Called For	When It Is Performed
Analysis	ultimate objectives of forecasting future events based on examination of past results.	status of a program or the maturity of a system or equipment and predicting future performance.	anomalies, quality processes, delivery dates, etc.	program.

4.8.2.7.2 Maintainability Analysis Tools

Table 4.8- 8. Maintainability Analysis Tools

Activity	What Is Done	Why It Is Done	When It Is Called For	When It Is Performed
Link Analysis	Arrange the physical layout of instrument panels, control panels, workstations, or work areas to meet specific objectives (e.g., increased accessibility).	Provides as assessment of the connection between (a) a person and a machine or part of a machine; (b) two persons; or (c) two parts of a machine.	During design for maintainability.	During Mission Analysis and Investment Analysis.
Maintainability Modeling (Prediction/ Allocation)	Perform prediction, allocation, and modeling tasks to estimate the system mean-time-to-restore requirements.	Determines the potential of a given design for meeting system maintainability performance requirements.	Whenever maintainability requirements are designated in the design specification.	Early in Solution Implementation.
Maintenance Concept	Describe what, how, and where preventive and corrective maintenance is to be performed.	Establishes the overall approach to maintenance for meeting the operational requirements and the logistics and maintenance objectives.	Performed for any system where maintenance is a consideration.	During Mission Analysis and revise throughout the lifecycle.
Maintenance	Describe the	Provides the basis	A Maintenance	Begins

Activity	What Is Done	Why It Is Done	When It Is Called For	When It Is Performed
Engineering Analysis	planned general scheme for maintenance and support of an item in the operational environment.	for design, layout and packaging of the system and its test equipment and establishes the scope of maintenance resources required to maintain the system.	Plan may be substituted on smaller programs in which maintainability prediction and analysis are not required.	during design and iterated through develoment.
Maintenance Plan	Detail how the support program is to be conducted to accomplish the program goals.	Identifies the desired long-term maintenance characteristics of the system and the steps for attaining them.	Appropriate for all hardware programs.	Prepare during Investment Analysis and update throughout the life of program.
Reliability Centered Maintenance (RCM)	Determine the mix of reactive, preventive, and proactive maintenance practices to provide the required reliability at the minimum cost.	Minimizes or eliminates more costly unscheduled maintenance and minimizes preventive maintenance.	Appropriate for all hardware programs. Generally called for as part of the maintenance concept.	During Solution Implementat ion.
Testability Analysis	Assess the inherent fault detection and failure isolation characteristics of the equipment.	Improves maintainability in response to operational requirements for quicker response time and increased accuracy.	Applicable to all hardware systems; however, especially appropriate where maintenance resources are available but restrained.	Early in design.
Tradeoff Studies	Compare realistic alternative maintainability design approaches	Determines the preferred support system or maintenance approach in	Performed where alternate support approaches or	Complete early in the acquisition cycle (see Section

Activity	What Is Done	Why It Is Done	When It Is Called For	When It Is Performed
	against cost, schedule, risk, and performance impacts.	accordance with risk, performance, and readiness objectives.	maintenance concepts involve high-risk variables.	4.6).

4.8.2.8 References

1. Aerospace Recommended Practice, ARP4761 “Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment.” Issued 1996-12. Society of Automotive Engineers, Inc.

2. “Guide to the Assessment of Reliability" 89/97714—Guide to the Assessment of Reliability of Systems Containing Software," British Standards Institution, 12 September 1989.

3. “System Safety Handbook,” Federal Aviation Administration, 30 September 2000.

4.8.3 Human Factors Engineering

4.8.3.1 What Is Human Factors Engineering?

Human factors engineering is a multifaceted discipline that generates information about human requirements and capabilities and applies it to the design and acquisition of complex systems (see Figure 4.8-11). Human factors engineering provides the opportunity to: (1) develop or improve all human interfaces with the system; (2) optimize human/product performance during system operation, maintenance, and support; and (3) make economical decisions on personnel resources, skills, training, and costs. Embedding and integrating human factors engineering activities into the acquisition of systems and equipment lower lifecycle costs, improves overall performance, and reduces technical risk. Failure to apply the disciplines of human factors engineering has consistently resulted in development of systems that do not satisfy the needs of the workforce and often result in costly delays and extensive rework.

Human factors engineering is a multidisciplinary effort to generate and compile information about human capabilities and limitations and apply that information to:

- **Equipment, Systems, Software, Facilities**
- **Procedures, Jobs, Organizational Design, Environments**
- **Training, Staffing, Personnel management**

To produce safe, comfortable, and effective human performance.

Figure 4.8-11. Definition of Human Factors Engineering

4.8.3.2 Why Perform Human Factors Engineering?

Experience has proven that when people think of acquiring a system, they tend to focus on the hardware and the software. Individuals often fail to visualize that people operate and maintain the hardware/software. These people have different aptitudes, abilities, and training and operate system under various operating conditions, organizational structures, procedures, equipment configurations, and work scenarios. The total composite of these elements and the human component determines the performance, safety, and efficiency of the system in the NAS. To produce an effective human factors engineering program for any acquisition, it is recommended that the definition of the system include not only the *hardware, software, facility, and services*, but also the *users* (*operators and maintainers)* and the *environment* in which the acquisition is used.

Applied early in the lifecycle acquisition management process, human factors engineering enhances the probability of increased performance, safety, and productivity; decreases lifecycle staffing and training costs; and becomes well-integrated into the program's strategy, planning, cost and schedule baselines, and technical tradeoffs. Changes in operational, maintenance, or design concepts during the later phases of an acquisition are expensive and entail high-risk program adjustments. Identifying lifecycle costs and human performance components of

system operation and maintenance during investment analysis and requirements definition decreases program risks and long-term operations costs. These benefits are applicable to COTS and non-developmental items (NDI) as well as to developmental programs.

4.8.3.3 Inputs to the Human Factors Engineering Process

The FAA Human Factors Job Aid guidelines are in the FAA Acquisition System Toolset (FAST). These guidelines contain extensive information regarding the integration of human factors engineering activities into the acquisition management process. It is recommended that IPTs be familiar with this information and embed human factors engineering principles into their acquisition programs. The Human Performance Interfaces in Systems Acquisition (Table 4.8-9) identify and define the many classes of human interfaces the IPT may need to consider as it plans and implements equipment/system acquisition programs. Analysis of these interfaces may provide a basis for determining the inputs to the human factors engineering process tasks. These inputs may include new or previously conducted human factors research, studies, and analyses; human factors standards and guidelines; human factors technical methods and techniques; human performance data criteria; or other human-system interaction information.

Table 4.8-9. Human Performance Interfaces in Systems Acquisition

Human Interface Class	Performance Dimension	Performance Objective
Functional Interfaces: For operations and maintenance - role of the human versus automation; functions and tasks; manning levels; skills and training	Task performance	Ability to perform tasks within time and accuracy constraints
Information Interfaces: Information media, electronic or hardcopy; information characteristics, and the information itself	Information handling/processing performance	Ability to identify, obtain, integrate, understand, interpret, apply, and disseminate information
Environmental Interfaces: Physical, psychological, and tactical environments	Performance under environmental stress	Ability to perform under adverse environmental stress, including heat and cold, vibration, clothing, illumination, reduced visibility, weather, constrained time, and psychological stress
Operational Interfaces: Procedures, job aids, embedded or organic training, and online help	Sustained performance	Ability to maintain performance over time

Human Interface Class	Performance Dimension	Performance Objective
Organizational Interfaces: Job design, policies, lines of authority, management structure, organizational infrastructure	Job performance	Ability to perform jobs, tasks, and functions within the management and organizational structure
Cooperation Interfaces: Communications, inter personal relations, team performance	Team performance	Ability to collectively achieve mission objectives
Cognitive Interfaces: Cognitive aspects of human-computer interfaces (HCI), situational awareness, decision-making, information integration, short-term memory	Cognitive performance	Ability to perform cognitive operations (e.g., problem-solving, decision making, information integration, situational awareness)
Physical Interfaces: Physical aspects of the system with which the human interacts (e.g., HCI, controls and displays, workstations, and facilities)	Operations and maintenance performance	Ability to perform operations and maintenance at workstations and worksites, and in facilities using controls, displays, equipment, tools, etc.

Addressing the human performance limitations and capabilities would seem to be a daunting task unless the task were divided into its many components and unless human factors is described in some descriptive taxonomy of issues. Thus, the potential human factors risks and areas of interest may be reflected as elements of the human factors issue areas listed in Table 4.8-10.

Table 4.8-10. Human Factors Issue Areas

Human Factors Issue Areas
1. **Allocation of Function** — System design reflecting assignment of those roles/functions/tasks for which the human performs better, or assignment to the equipment that it performs better while maintaining the human's awareness of the operational situation. 2. **Anthropometrics and Biomechanics** — System design accommodation of personnel (e.g., from the 1st through the 99th percentile levels of human physical characteristics) represented in the user population. 3. **Communications and Teamwork** — System design considerations to enhance required user communication and teamwork. 4. **Computer Human Interface (CHI)** — Standardization of CHI to access and use common functions employing similar and effective user dialogues, interfaces, and procedures.

Human Factors Issue Areas
5. **Displays and Controls** — Design and arrangement of displays and controls to be consistent with the operator's and maintainer's natural sequence of operational actions and provide easily understandable supporting information. 6. **Documentation** — Preparation of user documentation and technical manuals in a suitable format of information presentation, at the appropriate reading level, easily accessible, and with the required degree of technical sophistication and clarity. 7. **Environment** — Accommodation of environmental factors (including extremes) to which equipment is to be subjected and the effects of environmental factors on human-system performance. 8. **Functional Design and Operational Suitability** – Use of a human-centered design process to achieve usability objectives and compatibility of equipment design with operation and maintenance concepts and legacy systems. 9. **Human Error** — Examination of unsafe acts, contextual conditions, and supervisory and organization influences as causal factors contributing to degradation in human performance, and consideration of error tolerance, resistance, and recovery in system operation. 10. **Information Presentation** — Enhancement of operator and maintainer performance through use of effective and consistent labels, symbols, colors, terms, acronyms, abbreviations, formats, and data fields. 11. **Information Requirements** — Availability of information needed by the operator and maintainer for a specific task when it is needed and in the appropriate sequence. 12. **Input/Output Devices** — Design of input and output devices and methods that support performing a task quickly and accurately, especially critical tasks. 13. **Knowledge, Skills and Abilities (KSA)** — Measurement of the knowledge, skills, and abilities required to perform job-related tasks. Necessary to determine appropriate selection requirements for operators. 14. **Procedures** — Design of operational and maintenance procedures for simplicity and consistency with the desired human-system interface functions. 15. **Safety and Health** — Reduction/prevention of operator and maintainer exposure to safety and health hazards. 16. **Situation Awareness** — Consideration of the ability to detect, understand, and project the current and future operational situations. 17. **Skills and Tools** — Considerations to minimize the need for unique operator or maintainer skills, abilities, or characteristics. 18. **Staffing** — Accommodation of constraints and opportunities on staffing levels and organizational structures. 19. **Subjective Workload** — The operator's or maintainer's perceived effort involved in managing the operational situation. 20. **Task Load** — Objective determination of the numbers and types of tasks that an operator performs.

Human Factors Issue Areas
21. **Training** — Consideration of the acquisition and decay of operator and maintainer skills in the system design and capability to train users easily, and design of the training regimen to result in effective training. 22. **Visual/Auditory Alerts** — Design of visual and auditory alerts (including error messages) to invoke the necessary operator and maintainer response to adverse and emergency situations. 23. **Workspace** — Adequacy of workspace for personnel and their tools and equipment, and sufficient space for movements and actions they perform during operational and maintenance tasks under normal, adverse, and emergency conditions.

4.8.3.4 Human Factors Engineering Process

The process of integrating human factors engineering into acquisition programs entails numerous technical and management activities. Many of these activities are conducted iteratively through several phases of the acquisition and often in a nonlinear sequence. While the process flow is described below in 15 activities (listed in Table 4.8-11), other subordinate activities (e.g., critical task analysis, target audience analysis, cognitive analysis, human-in-the-loop simulation, and CHI prototyping) are also required. A description of these subordinate tasks are in the FAA Human Factors Job Aid or in more detailed human factors engineering reference manuals.

Table 4.8-11. Human Factors Engineering Process Activities

Human Factors Engineering Process Activities
1. Incorporate Human Factors Opportunities and Constraints into the MA and Mission Need Statement (MNS) 2. Incorporate Human Factors Requirements in Requirements Document 3. Incorporate Human Factors Assessment in the Investment Analysis 4. Incorporate Human Factors Parameters in the Acquisition Program Baseline (APB) 5. Designate Human Factors Coordinator for the PT 6. Establish Human Factor Working Group 7. Incorporate Human Factors Strategy into the ASP 8. Incorporate Human Factors Tasks into the IPP 9. Develop Integrated Human Factors Plan 10. Incorporate Human Factors Requirements into System Specifications and Statement of Work 11. Include Human Factors in Source Evaluation Criteria 12. Conduct Human Factors Engineering Analyses 13. Apply Human Factors Engineering to System Design 14. Test System Against Human Performance Requirements 15. Conduct In-Service Review for Human Factors

4.8.3.5 Human Factors Engineering Process Tasks

The following process flow provides an outline and overview of key activities in the human factors engineering process.

Activity 1: Incorporate Human Factors Opportunities and Constraints Into the Mission Analysis and Mission Need Statement			
Responsible Agent	**Product**	**Approval Authority**	**Tools and Aids**
Mission Analysis and MNS Sponsor	Human factors input on opportunities and constraints to the MNS	Mission Analysis Manager MNS Sponsor	Guidance on developing human factors input to the MA and MNS

Description:

Using the results from the mission analysis, human factors engineering inputs to the MNS identify the human performance constraints and issues that need to be addressed or resolved. This information may come from operations and maintenance concepts, similar systems or components, and other documents that may provide insights into the effects of human factors engineering constraints and limitations on system performance. Since most acquisitions are evolutionary, important human factors engineering information may be obtained from predecessor systems or their component subsystems. Analyses and tradeoff studies may be required to determine the effects of constraints and issues on system performance. It is recommended that the existing literature and lessons learned databases be reviewed.

Activity 2: Incorporate Human Factors Requirements in the RD			
Responsible Agent	**Product**	**Approval Authority**	**Tools and Aids**
Requirements Sponsor	Human factors requirements in the iRD or fRD	IRT Lead	Guidance on developing human factors requirements for the RD

Description:

The initial RD contains generic performance and supportability requirements that do not prescribe a specific solution. The RD defines the essential performance capabilities and characteristics, including those of the human component. Human factors engineering inputs to the RD identify requirements for human performance factors that impact system design. Broad cognitive, physical, and sensory requirements for the operator, maintainer, and support personnel that contribute to or constrain total system performance are established. It is recommended that any safety, health hazards, or critical errors that reduce job performance or system effectiveness be defined, and that staffing and training concepts, including requirements for training devices, embedded training, and training logistics, also be described.

Activity 3: Incorporate Human Factors Assessment in the Investment Analysis			
Responsible Agent	**Product**	**Approval Authority**	**Tools and Aids**
Investment Analysis Sponsor	Human factors input to the IA Plan Human Factors Assessment (including risk, cost, and benefits) for the IA	IAT Lead	Guidance on developing Human Factors Assessments for the IA

Description:

Human factors engineering inputs to the IAR address, for each alternative being evaluated, the full range of human performance and interfaces (e.g., cognitive, organizational, physical, functional, and environmental) necessary to achieve an acceptable level of performance for operating, maintaining, and supporting the system. It is recommended that the analysis provide information on what is known and unknown about human performance risks in meeting minimum system performance requirements. Human factors engineering areas of interest relevant to the investment analysis include:

- Human performance (e.g., human capabilities and limitations, workload, function allocation, hardware and software design, decision aids, environmental constraints, team versus individual performance)
- Training (e.g., length of training, training effectiveness, retraining, training devices and facilities, embedded training)
- Staffing (e.g., staffing levels, team composition, organizational structure)
- Personnel selection (e.g., aptitudes, minimum skill levels, special skills, experience levels)
- Safety and health hazards (e.g., hazardous materials or conditions, system or equipment safety design, operational or procedural constraints, biomedical influences, protective equipment, required warnings and alarms)

Activity 4: Incorporate Human Factors Parameters in the APB			
Responsible Agent	**Product**	**Approval Authority**	**Tools and Aids**
APB Sponsor	Human factors performance parameters in the APB	IAT Lead	Guidance on developing human factors parameters for the APB

Description:

The APB is established at the Investment Decision and reflects the solution selected by the JRC for implementation. Based on the solution selected, human factors engineering inputs to the APB are those human performance requirements needed to achieve the required level of system performance. These inputs are derived from those identified in the Requirements Document and reflect a refinement that provides increased definition, greater granularity, and more specificity of relevant human-system performance characteristics. It is recommended that constraints, limitations, and unique or specialized training requirements, staffing levels, or personnel skill requirements be identified.

It is recommended that, to the degree possible, the required level of human performance be based on practical measures of operational effectiveness and suitability and be stated in quantifiable terms (e.g., time to complete a given task, level of accuracy required, number of tracks to be processed per unit time).

Activity 5: Designate Human Factors Coordinator for the PT			
Responsible Agent	**Product**	**Approval Authority**	**Tools and Aids**
PT Leader	Human Factors Coordinator	System Engineer	Guidance on developing a human factors program

Description:

The Product Team Leader designates a Human Factors Coordinator to develop, direct, and monitor human factors engineering activities during system acquisition. It is recommended this designation occur as early as during Investment Analysis to ensure human considerations are an integral element of market surveys, tradeoff analyses, and the definition of requirements for candidate solutions to mission need. The Human Factors Coordinator:

- Defines human impacts and constraints during Investment Analysis and determination of requirements
- Evaluates human-system interfaces during market surveys, tradeoff analyses, and prototypes
- Prepares and updates human factors engineering portions of program planning documents, procurement packages, performance criteria and measures, and data collection efforts
- Develops and analyzes operational scenarios and human-system modeling for operators and maintainers
- Reviews and assesses human factors engineering concepts and designs
- Coordinates human factors engineering efforts and workgroup activities
- Coordinates human factors engineering with other disciplines

Activity 6: Establish Human Factor Working Group			
Responsible Agent	Product	Approval Authority	Tools and Aids
Human Factors Coordinator	Human factors Working Group	Systems Engineer	Guidance on human factors working groups

Description:

The Human Factors Coordinator may establish and chair a Human Factors Working Group (HFWG) to facilitate accomplishment of human factors engineering tasks and activities. The composition of the HFWG is tailored to the needs of the acquisition program. Membership typically consists of Product Team members, with outside members participating as needed.

Activity 7: Incorporate Human Factors Strategy Into the ASP			
Responsible Agent	Product	Approval Authority	Tools and Aids
PT systems engineering specialist with assistance from the Human Factors Working Group	Human factors strategy in the ASP	PT Lead	Guidance for developing HF strategy for the ASP

Description:

The human factors strategy depends on the size, cost, and complexity of the system to be acquired, as well as the nature and complexity of the human-product interface. It is recommended that the human factors engineering strategy address such factors as:

- Scope and level of human factors engineering required from the systems contractor
- Human factors engineering roles and responsibilities of organizations and contractors
- Means for evaluating the human-machine interface and achieving user buy-in
- Data sources and facilities needed
- Distribution of funding and resources
- Timing and scope of human factors engineering activities
- Relationship of human factors engineering with other program elements.

The HFWG may assist in developing strategies appropriate for different types of acquisition programs, such as those that procure NDIs, COTS products, or fully developed new systems.

Activity 8: Incorporate Human Factors Tasks Into the IPP			
Responsible Agent	Product	Approval Authority	Tools and Aids
PT systems engineering specialist with assistance from the Human Factors Working Group	Human factors tasks in the Integrated Program Plan	System Engineer	Guidelines for developing HF tasks for the IPP Human Factors Strategy Human Factors Requirements

Description:

The human factors section of the Integrated Program Plan defines the individual human factors engineering work tasks that shall be done during program implementation. For each task, the IPP assigns the responsible person and organization, identifies any output and the approval authority, specifies when the task is to be completed, and allocates resources. As the program progresses through Solution Implementation, the human factors section of the IPP is updated to reflect changes in program strategy or execution and to provide more planning detail as it is developed.

Activity 9: Develop Integrated Human Factors Plan			
Responsible Agent	Product	Approval Authority	Tools and Aids
Human Factors Coordinator	Integrated Human Factors Plan	PT Lead	Template for Integrated Human Factors Plan

Description:

For complex system acquisition programs, the Product Team may wish to prepare an Integrated Human Factors Plan. (See Table 4.8-12 for an outline of the content.) Tasks associated with this plan include:

- Defining the operational concept and support concept
- Describing the target population
- Defining human / system interfaces
- Defining human impacts of the system
- Defining the human factors engineering strategy
- Defining human factors engineering implementation activities

Table 4.8-12. Integrated Human Factors Plan Content and Format

Headings		Content
Background	Program Summary	• Briefly describe the program • Describe concept of operation and maintenance
	Program Schedule	• Provide overview of system acquisition schedule
	Target Population	Identify: • Operator and maintainer • Demographics • Biographical data • Previous training • Aptitudes • Task-related experience • Anthropometric data • Physical qualifications • Organizational relationships • Workspace requirements
	Guidance	• Summarize any guidance received
	Constraints	• State if additional staffing is required by the new system • State whether an existing job series is to be used or a new one created • Post limits on the amount of time that may be afforded for training • Establish standards on the working conditions that are to be acceptable when the new system is fielded • Describe limitations imposed by maintenance policy • Develop requirements as a result of union agreements
Issues and Enhancements	Issue Description	Describe the issue or problem background, importance, and consequences or task to be done to support the acquisition

Headings		Content
	Objectives	• Identify Human Factors Program objectives • Provide performance measures and criteria in terms of time and accuracy to perform tasks to evaluate resolution of issue • When human performance thresholds are known, identify tasks for the developer to be done early enough in the acquisition to influence requirements and system engineering • Identify the actions to be taken to resolve each issue • Show the current status of each issue
	Actions	• Identify actions to be taken to resolve issues • Show current status of each action
Activities	Activity Description	• Identify any tasks, studies, or analyses that shall be performed to resolve the issues (e.g., contractor's Human Engineering Program Plan per MIL-HDBK-46855, Functional Analysis to support equipment versus people allocation of functions, Task Analysis to produce a specific operator, and maintainer task list)
	Activity Schedule	• By acquisition phase, describe the human factors tasks in terms of who, what, when, and how (resources) • Identify feeds to and dependencies on ILS, training, and test and evaluation programs
Strategy	Goals and Requirements	• Derive Strategy from the major concerns, issues, schedule, tasks, guidance, constraints, objectives, and approach for the Human Factors Program • Answer the question, "What objectives does the government wish to achieve?" • Answer the question, "How is the government to accomplish these objectives?"
	Approach	• Identify who is to be responsible for the Human Factors Program • Set out the extent of contractor support required • Define how human factors resources are to be organized and managed to support the system acquisition

Headings		Content
	References	• Identify relevant references needed for a full understanding of the Human Factors Program
Review	Review	• Identify administrative handling procedures • Identify update schedule and procedure • Identify review procedures

Activity 10: Incorporate Human Factors Requirements Into System Specification and Statement of Work			
Responsible Agent	Product	Approval Authority	Tools and Aids
PT systems engineering specialist and human factors specialist	- Human factors requirements in the System Specification - Human Factors tasking in the Statement of Work - Human Factors data items in the Contractor Deliverable Requirements List (CDRL) - Human Factors data item descriptions	PT Lead	- Guidance on formulating human factors requirements in the System Specification - Guidance on defining human factors tasking in the Statement of Work - Data Item Descriptions for human factors

Description:

The System Specification and Statement of Work are the mechanisms for translating human performance requirements and appropriate human factors engineering work tasks to the contractor in a clear, unambiguous, and contractually binding document. The System Specification addresses the following elements to ensure that required human performance influences system design effectively:

- staffing constraints
- required operator and maintainer skills
- training time and cost for formal, informal, and on-the-job skill development

- acceptable levels of human and system performance when operated and maintained by the training population.

The Statement of Work shall contain all human factors tasking to be imposed on the contractor, as well as define data deliverables in the CDRL and associated Data Item Descriptions (DID).

Activity 11: Include Human Factors in Source Evaluation Criteria			
Responsible Agent	Product	Approval Authority	Tools and Aids
PT systems engineering specialist with assistance from the Human Factors Working Group	Human factors source evaluation criteria	PT Lead	Guidance for specifying human factors in source selection

Description:

It is recommended that human performance be a candidate as a major evaluation factor in source selection. By providing vendors a clear indication that the government attributes significant weight to how operators and maintainers perform with the system, the agency sends a strong message that operational suitability and effectiveness are of utmost importance.

Activity 12: Conduct Human Factors Engineering Analyses			
Responsible Agent	Product	Approval Authority	Tools and Aids
Contractor (or other performing agent) conducts analyses	Appropriate data as specified in the CDRL and DIDs (or other designated documentation)	Appropriate official as designated in the CDRL (or other designated documentation)	Human Factors Design Standard Human Factors Data Item Descriptions

Description:

The Product Team oversees, monitors, and reviews human factors engineering analyses conducted by the system contractor or other performing agent. These analyses may involve:

- Defining and allocating system functions
- Analyzing information flow and processing
- Estimating operator and maintainer capabilities
- Defining and analyzing tasks and workloads

Activity 13: Apply Human Factors Engineering to System Design			
Responsible Agent	Product	Approval Authority	Tools and Aids
Contractor designs system PT Human Factors Coordinator oversees and reviews	Integration of Human factors requirements into system design	System Engineer	Guidance for integrating human factors during detailed design

Description:

Human factors engineering is applied to system design activities to optimize human-system interfaces and ensure that human performance requirements are satisfied. Human factors engineering is applied to the full scope of system design, including experiments, tests, and studies; engineering drawings; work environment, crew station, and facility design; performance and design specifications; procedure development; software development; and manuals. The following are used effectively in defining human-product interfaces during system design:

- Prototypes and computer models
- Three-dimensional mockups
- Scale models
- Dynamic simulation

Activity 14: Test System Against Human Performance Requirements			
Responsible Agent	Product	Approval Authority	Tools and Aids
Contractor and government conduct testing PT Human Factors Specialist oversees and evaluates	Test results on human performance requirements	System Engineer System Test Official	Guidance on human factors engineering activities during test and evaluation

Description:

Compliance of the system with human performance requirements is tested as early as possible in system development. Human factors engineering findings from design reviews, prototype reviews, mockup inspections, demonstrations, and other early engineering tests are used in planning and conducting later tests. Human factors engineering testing focuses on verifying that user personnel in the intended operational environment are able to operate, maintain, support, and control the system.

Activity 15: Conduct In-Service Review for Human Factors			
Responsible Agent	Product	Approval Authority	Tools and Aids
Human Factors Coordinator	Assessment of the acceptability of the human-machine interface Post-Deployment Human Factors Assessment Plan	System Engineer	Guidance on conducting human factors assessments In-Service Management Review (ISR) Checklist

Description

Operational suitability and effectiveness are major evaluation factors that are considered in making the decision to place a new capability into operational service. Satisfactory human performance is an integral element of operational suitability and effectiveness. The broad range of human factors engineering issues is addressed during this activity. Also, a plan is formulated to assess and monitor the human-system performance of the new capability following its deployment to the operational environment.

4.8.3.6 Human Factors Engineering Process Outputs/Products

Efforts to manage the human factors engineering program, establish requirements, conduct system integration, and test and evaluate human factors engineering compliance may result in many major and minor human factors engineering outputs and products. These products include human factors input to the primary acquisition documentation (e.g., requirements documents, investment analyses, acquisition program baselines, integrated program plans, specifications, and statements of work) as well as human factors research, studies, and analyses that support program and design decisions and documentation (e.g., human factors risk analyses, human factors benefits analyses, criteria for performance evaluation, prototype designs, and critical task analyses). The human factors engineering activities and their resultant products are described in more detail in the FAA Human Factors Job Aid (and other human factors engineering manuals), but are reflected in five key components of program planning and implementation.

4.8.3.6.1 Human Factors Engineering Planning

Human factors engineering planning involves developing concepts, tasks, completion dates, levels of effort, methods to be used, strategy for development and verification, and an approach to implementing and integrating with other program planning.

4.8.3.6.2 Human Factors Engineering Analysis

Human factors engineering analysis involves identifying the best allocation of function to personnel, equipment, software, or combinations to meet the acquisition objectives. It includes the dissecting functions to specific tasks, analyzing tasks to determine human performance parameters, quantifying task parameters to permit evaluation of human-system interfaces in relation to total system operation, and the identifying high-risk human factors engineering areas.

4.8.3.6.3 Human Factors Engineering Design and Development

Human factors engineering design and development involves converting mission, system, and task analyses data into (a) detail designs and (b) development plans to create human-system interfaces that operate within human performance capabilities, meets system functional requirements, and accomplishes mission objectives.

4.8.3.6.4 Human Factors Engineering Test and Evaluation

Human factors engineering test and evaluation involves verifying that systems, equipment, software, and facilities may be operated and maintained within intended user performance capabilities and is compatible with overall system requirements and resource constraints.

4.8.3.6.5 Human Factors Engineering Management and Coordination

Human factors engineering management and coordination involves coordinating with RMA engineering; system safety; risk management; facilities systems engineering; integrated logistic support; and other human factors engineering functions, including biomedical, personnel, and training.

4.8.3.7 References:

1. FAA Order 9550.8, Human Factors Policy (October 1993).
2. FAA Human Factors Design Standard (May 2003).
3. FAA Human Factors Job Aid (March 1999).
4. MIL-HDBK-759C, Human Engineering Design Guidelines (July 1995).
5. MIL-HDBK-1908, Definitions of Human Factors Terms (August 1999).
6. MIL-HDBK-46855A, Human Engineering Program Process and Procedures (May 1999).
7. Boff, K., & Lincoln J. (Eds.). (1988). Engineering Data Compendium: Human Perception and Performance (Vols. 1- 3). Wright-Patterson Air Force Base, OH: Harry G. Armstrong Aerospace Medical Research Laboratory.
8. Booher, H. R. (Ed.). (1990). MANPRINT: An Approach to Systems Integration. New York: Van Nostrand Reinhold.
9. Booher, H. R. (Ed.). (2003). Handbook of Human Systems Integration. New York: Wiley.
10. Cardosi, K. M., & Murphy, E. D. (Eds.). (April 1995). Human Factors in the Design and Evaluation of ATC Systems Washington, DC: USDOT/FAA.
11. Federal Aviation Administration. (1995). The National Plan for Civil Aviation Human Factors. Washington, DC: Federal Aviation Administration.
12. Meister, D. (1985). Behavioral Analysis and Measurement Methods. New York: John Wiley.
13. National Research Council (1997). Flight to the Future: Human Factors in Air Traffic Control. Washington, DC: National Academy Press.
14. National Research Council (199T). The Future of Air Traffic Control: Human Operators and Automation. Washington, DC: National Academy Press.
15. Salvendy, G. (Ed.). (1997). Handbook of Human Factors and Ergonomics (2nd ed.). New York: Wiley-Interscience.
16. Sanders, M. S., & McCormick, E. J. (1993). Human Factors in Engineering and Design (7th ed.). New York: McGraw-Hill.

17. Wickens, C. D. (1992). Engineering Psychology and Human Performance (2nd ed.). New York: Harper Collins.

18. Wiener, E. L., & Nagel, D. C. (Eds.) (1988). Human Factors in Aviation. New York: Academic Press.

4.8.4 Electromagnetic Environmental Effects

E^3 Engineering is the technical discipline dealing with the safe and efficient operation of electronic devices regarding radiated and conducted electromagnetic emissions. This includes both a given system's ability to deal with such emissions from its operational environment and how the device itself affects that environment.

E^3 activities seek to minimize the limitations of a system due to electromagnetic factors, as well as document limitations and vulnerabilities that remain after a system's deployment.

4.8.4.1 What Is Electromagnetic Environmental Effects Engineering?

E^3 Engineering is a set of Specialty Engineering analyses that relate to electronic systems. Such systems range from electric household appliances to integrated circuits.

The Federal Communications Commission (FCC), responsible for government regulations related to E^3, gives special attention to what it refers to as "digital devices." The FCC defines a digital device as:

> *Any unintentional radiator (device or system) that generates and uses timing pulses at a rate in excess of 9000 pulses (cycles) per second and uses digital techniques . . . .*

In other words, electronic devices using high-speed switching waveforms are digital devices. These devices usually generate significant EMI and shall be designed to conform to government regulations on electromagnetic emissions.

However, E^3 considerations go far beyond government regulations. Manufacturers and developers employ E^3 analyses to ensure proper function of all electronic systems within an operational environment and the compatibility of these with nonelectronic elements of that environment. The analyses also identify potential problems that could arise from changes in the environment.

There are many types of E^3 that may affect the electromagnetic compatibility of a system. Each type is a specialty area unto itself. From a broad perspective, the operational requirement is to properly address the EM environment over the system lifecycle. The following sections discuss the individual elements of E^3. (Note: E^3-related definitions appear in American National Standards Institute (ANSI) C63.14.)

4.8.4.1.1 The Electromagnetic Environment

The Electromagnetic Environment (EME) consists of the systems and other elements (such as humans and nature) that exist within the area where a given system is (or may be) operated. Identifying and describing the EME is a major part of E^3. This involves describing EMI present within the environment and vulnerabilities to systems and other elements of the environment.

In some instances, developers may wish to define the *survivable* EME for a system; that is, the most extreme conditions (EMI present) within which the system may operate safely and without degradation of its function. But whenever possible, it is important to

provide a complete description of the normal EME within which the system, subsystem, or equipment may be required to perform.

4.8.4.1.2 Electromagnetic Compatibility

A key area of E^3 is Electromagnetic Compatibility (EMC). This is the ability of a system to function within its EME and itself and not be a source of troublesome EMI. EMC analyses involve evaluating the EME, all EMI present within that environment, and the new system's own EMI emissions. This data is then used to determine if either the new system or the elements of the operational environment are adversely affected by each other.

FAA-G-2100G, paragraph 3.3.2 Electromagnetic Compatibility, may be invoked as a requirement for acquisitions. It references all appropriate FCC rules and FAA-referenced Military Standards.

EMC considerations are critically important and may be seen as design objectives beyond those required for the basic functional performance of an electronic system. This means that while a system may function properly in the laboratory, problems may occur when it is deployed within a different EME.

There are two general types of emissions to consider in evaluating EMI: conducted emissions and radiated emissions. Conducted emissions are electric currents transferred through physical coupling, such as noise fed back into a device's alternating current (Alternating Current (AC) power system. Radiated emissions are electromagnetic (EM) waves emitted intentionally or unintentionally that may be unintentionally received by other systems. Wires transmit and receive EM signals like intentional antennas. Switching waveforms in circuits generate a wide band of EM emissions.

4.8.4.1.3 Electromagnetic Susceptibility

EM Susceptibility (EMS) specifically deals with a system’s weaknesses or lack of resiliency to certain EM conditions.

A system may likely be exposed to different operational EMEs during its lifetime. A system that suffers degradation within certain potential EMEs is said to be *vulnerable*. A vulnerability analysis is usually required to determine the operational impacts of laboratory-observed susceptibilities.

A *susceptibility* is a particular condition that causes a system to be degraded. For example, conducted susceptibility refers to a system's inability to withstand an infusion of noise into its power lines. Devices that run on standard AC power shall not be susceptible to sudden brief spikes or losses of power if that the power system is affected by lightning or other surges.

4.8.4.1.4 Hazards of Electromagnetic Radiation

Hazards of EM Radiation (RADHAZ) are areas of E^3 that deal with specific types of dangers related to radiated EM waves. Hazard of EM Radiation to Fuels (HERF) is a RADHAZ area dealing with fuels that may be present within an EME. An EM field of sufficient intensity may create sparks that may ignite volatile combustibles, such as fuel. (i.e., EM radiation may induce a current in a conductive material, and sparks are formed in the air gap between two conductors.) It is difficult to locate all potential antennas and spark gaps within an EME, so it is necessary to keep the power densities of EM fields within safety margins when fuels are present.

Hazard of EM to Personnel (HERP) is another important area of RADHAZ; it deals with the dangers of radiation to humans within the EME. Microwave absorption by a human causes heating of the body. At high power levels, such as from radar towers, this may be hazardous. And EM waves in the x-ray range and higher (in terms of frequency) may cause ionization, even at low power levels. RADHAZ precautions help ensure safety for the nonelectronic elements of an EME.

4.8.4.1.5 Electromagnetic Pulse

An EM Pulse (EMP) is an intense burst of EMI caused by a nuclear explosion. This pulse may damage sensitive electronic systems or cause them to temporarily malfunction.

4.8.4.1.6 Electrostatic Discharge

An Electrostatic Discharge (ESD) is an unintentional transfer of static electricity from one object to another. Static voltage transferred from a human to a device (e.g., voltage generated by walking across a carpet) may be as high as 25 kilovolts. The brief currents created may damage or cause malfunction of integrated circuits and other electronics.

4.8.4.1.7 Lightning

The phenomenon of lightning gets special attention within E^3 because of its tremendous power levels and multiple effects. Lightning effects are categorized as *direct* (physical effects) and *indirect* (induced electrical transients and interaction of the EM fields associated with lightning).

4.8.4.1.8 Precipitation Static

Precipitation Static (P-Static) is the buildup of static electricity resulting from an object's exposure to moving air, fluid, or tiny solid particles (e.g., snow or ice). It may cause significant ESD and is a particularly important consideration regarding systems aboard aircraft and spacecraft.

4.8.4.2 Why Perform E^3 Activities?

The following sections discuss the key reasons for incorporating E^3 activities into the SE process.

4.8.4.2.1 Government Regulations

The FCC develops and enforces government regulations relating to E^3. Before a new electronic device is to be sold in the United States, it shall meet the FCC's standards. These standards are detailed in Rules and Regulations, contained in Title 47 (Part 15) of the Code of Federal Regulations.

FCC requirements focus on a system's generated EMI, rather than its EMS. Limits are imposed on the conducted and radiated emissions of digital devices. Radiated emissions are regulated strictly in terms of the electric field. Most NAS-related electronic/RF devices fall under FCC Class A (commercial, industrial, or business). Regulations are less stringent for Class A than for Class B (household) devices.

Government regulations change frequently, so it is important to obtain the most current requirements. Information is available from the FCC Web site www.fcc.gov. The FCC may request a sample device of a new system to test.

4.8.4.2.2 System Performance and Cost of Redesign

While manufacturers and developers strive to meet government regulations, , they may impose additional E^3 requirements on a new system to enhance product performance and customer satisfaction. Government E^3 requirements by no means guarantee a new system's compatibility with its intended operational environment. Thus, it is up to manufacturers and developers to consider the EME for a new system, the impacts of the system's own EMI on that environment, and the system's EMS in order to avoid potential problems that FCC regulations are unable to predict or prevent.

Developers and manufacturers who consider potential E^3 problems from the start may avoid costly redesign later. The earlier in a system's lifecycle that a problem is identified, the less the cost of correcting it is likely to be. For instance, if a problem with EMC is discovered after a new system has been deployed, the system may have to undergo extensive redevelopment. However, if this problem had been determined during the design and planning stage, it could have been addressed in the requirements before manufacture had begun, saving both significant time and resources.

4.8.4.2.3 Hazard Prevention

Hazards of EM radiation on fuels and personnel (HERF, HERP) are important considerations. These issues may be included as part of Safety Risk Management activities.

4.8.4.2.4 International Considerations

EMI is increasing throughout the world. Systems that may be used outside of the United States, such as avionics, shall be able to deal with types and intensities of EMI present in other countries that may be different from conditions in the United States. It is recommended that such systems be designed with special attention given to minimizing vulnerability to EM radiation.

Also, it is recommended that consideration be given to the possibility of intentional jamming, which creates significant EMI.

4.8.4.2.5 Sources of Information on Electromagnetic Environmental Effects

- FCC www.fcc.gov
- ANSI/IEEE standards.ieee.org
- OMB Circular A-11
- Joint Spectrum Center www.jsc.mil/jsce3/e3prg.asp (military)
- FAA fast.faa.gov

4.8.4.3 Analyses of Electromagnetic Environmental Effects

While Section 4.8.0.3 describes the Specialty Engineering process in general terms, this section specifically discusses the various E^3- related analyses. Not all E^3 analyses discussed, however, are important for a given system. It is recommended that it be determined during planning, which analyses are worth the time and resources and which are not.

It is recommended that E^3 analyses be performed on COTS systems as well as new systems to ensure compatibility with the EME within which these systems or subsystems may be used. The amount of detail involved with E^3 analyses increases with each subsequent phase of the SE lifecycle. Measurement procedures for evaluating a product's emissions during low-level technical analyses shall be clearly spelled out. It shall be understood how the results are to be interpreted. The EME may undergo appreciable changes at any point during a system's lifecycle. Thus, E^3 analyses shall be reconducted to ensure continued EMC of *each* system within the EME.

4.8.4.3.1 Description of the Operational Electromagnetic Environment

Before any EMC analyses are conducted, it is necessary to describe the EME within which the system in question may perform. This means detailing all sources of EMI in the operational environment. EME contributors are gauged by the power levels and frequencies of their emissions and their locations (with respect to the new system).

In some cases, it may also be advisable to denote inherent susceptibilities associated with other systems within the EME.

An existing OSED document may be useful as a starting point for an EME description. The OSED contains information about the operational environment and the systems/subsystems associated with the system under analysis. However, the OSED may not describe all EME contributors.

Optionally, a description may be drawn up of the maximum survivable EME conditions in which the system shall be able to function without degradation. This is useful in cases in which a specific operational EME may not be identified (e.g., the system may have numerous and appreciably different operational EMEs to which it is expected to be exposed).

4.8.4.3.2 Electromagnetic Compatibility Analyses

EMC analyses identify compatibility issues relating to radiated and/or conducted emissions. This involves evaluating how the EME and the system affect each other in terms of EMI.

It is useful to calculate the system's *electrical dimensions* before an EMC analysis is conducted. This is done to determine whether or not simple mathematical methods (e.g., Kirkchoff's Laws) are sufficiently accurate for an EMC analysis. If the system is *electrically large*, then simple mathematics are insufficient, and Maxwell's Equations shall be employed. These are a set of differential equations that describe an electric field as three-dimensional parameters (x, y, z) and time (t).

4.8.4.3.2.1 Federal Communications Commission Regulations

It is convenient to address FCC compliance issues for EM emissions during EMC analyses, since both deal with the system's EMI. While actual testing to verify that FCC requirements are met may not occur until a system is built, incorporating these regulations into requirements from the beginning of system development helps to mitigate compliance problems later.

4.8.4.3.3 Analyses of Hazards of Electromagnetic Radiation

RADHAZ analyses are conducted only when they have relevance for a particular system and its environment. For example, if there are no fuels present within the operational EME, an HERF analysis is unnecessary. It is recommended that the types of RADHAZ analyses (if any) to be performed be determined from the EME description.

4.8.4.3.4 Electromagnetic Susceptibility Analyses

As with RADHAZ, specific susceptibility analyses are conducted only when they have relevance. Each analysis requires time and resources, so it is impractical to invest in an analysis that has no significance for the system and its EME. Susceptibility analyses include:

- Conducted Susceptibility (AC power lines)
- ESD Susceptibility
- Susceptibility to Lightning
- P-Static Susceptibility
- EMP Survivability

4.8.4.4 Outputs and Products of Electromagnetic Environmental Effects

It is important to employ E^3 analyses and predictions during all phases of an electronic system's lifecycle. Figure 4.8-1 illustrates the fundamental Specialty Engineering process and its outputs. The following sections link the outputs of E^3 activities to the overall System Engineering process. However, it is important to note that all E^3 analyses, like other Specialty Engineering analyses, shall be documented in a DAR.

4.8.4.4.1 Requirements

Most E^3 activities result in requirements that feed the Requirements Management process. This includes the Mission Need Statement, Statement of Work, specifications, and all performance-based requirements.

4.8.4.4.2 Concerns and Issues

It is recommended that E^3 activities—in addition to identifying necessary requirements—also identify potential problems that may surface later in a system's lifecycle. It is also good practice to document identified system susceptibilities that are not significant enough to require correction. These issues are included with concerns and issues, which feed the Risk Management process (Section 4.10).

4.8.4.4.3 Verification Criteria

It is critical to provide verification criteria to ensure that stated E^3 performance requirements are met. It is also important to provide detailed information describing how E^3 testing is performed and how test results are to be interpreted. This feeds the Validation and Verification process (Section 4.12).

4.8.4.4.4 Solutions to Problems of Electromagnetic Environmental Effects

EMC and EMS problems may be corrected through a number of means, including shielding, emission suppression components, and/or modification of the operational environment. However, some problems may not be directly correctable, potentially forcing extensive and costly redesign of the product. This is why it is beneficial to consider E^3 issues early in a system's development.

4.8.5 Quality Engineering — Reserved

4.8.6 Information Security Engineering

Information Security Engineering (ISE) is a Specialty Engineering discipline within Systems Engineering. It is recommended that Systems/security engineers and program managers use the following reference documents for further information regarding planning and conducting ISE:

- FAA Policy Order 1370.82 describes roles and responsibilities related to certification and accreditation (C&A) of IT products and systems within the FAA
- FAA Information Systems Security (ISS) Handbook outlines how security engineering activities, including producing C&A products, shall be conducted, including specific work products
- FAA AMS provides acquisition policy and guidance about when, how, and in what sequence security engineering activities and work products are to be done during the system lifecycle

The FAA directives and guidance incorporate necessary federal and industry policy and standards. The following ISE section describes why security engineering is important, and it describes what steps and processes shall be followed within the FAA to integrate system security into the overall system engineering process for an FAA system.

4.8.6.1 Perform Information Security Engineering

Federal legislation, such as the Clinger-Cohen Act of 1996, and the Federal Information Security Management Act (FISMA) of 2002, establish a clear legal basis for establishing information security risk management practices for federal IT resources. To implement the legislative mandate within the Executive Branch, the Office of Management and Budget (OMB) Circular A-130, Management of Federal Information Resources, establishes policy for managing federal information resources.

OMB includes procedural and analytic guidelines for implementing specific aspects of these policies as appendices. The Circular A-130 Appendix III, Security of Federal Automated Information Resources, establishes a minimum set of controls to be included in Federal automated information security programs; assigns Federal agency responsibilities for the security of automated information; and requires that an agency official authorize use of the information technology system.

The FAA Order 1370.82 and the ISS Handbook have implemented the Security Certification and Authorization Package (SCAP), which documents the security requirements and the validation and verification of those requirements as the basis for security authorization by the proper FAA official. The SCAP implements key aspects of FISMA and OMB A-130.

Chapter 10 of DOT Order 1350.2, Departmental Information Resources Management Manual, implements OMB guidance for DOT, while the FAA implements departmental direction in FAA Order 1370.82 and applicable portions of the AMS.

Several factors drive the FAA focus to develop and implement rigorous ISS (see Figure 4.8-12):

- The AMS and FAA practice call for using or adapting commercially available IT products to satisfy mission needs of the agency. Referred to as COTS, these products may contain vulnerabilities that, unless properly engineered and managed, may produce significant risks to the services, capabilities, and functions a system is expected to perform in meeting FAA mission needs.

- The pervasiveness of networked information and the increased interconnectivity of FAA systems significantly broaden the FAA's exposure to malicious activities from a variety of sources. Expanded services and capabilities brought about by networking and automation enable improved performance and efficiency; yet may dramatically expand vulnerabilities to systems' confidentiality, integrity, and availability unless security is properly addressed.

- Global terrorism and our post 9/11 world drive the need for more active, capable and responsive defense of the United States. The FAA is modernizing its capabilities to ensure that the aviation transportation system is adequately protected from risks to the safety and security of the flying public. Proper ISE ensures that information exchange has appropriate security controls, features, and services. Security controls support continuity of operations for IT systems under a range of conditions that increasingly involve homeland security defense and disaster response as inherent to FAA services and capabilities.

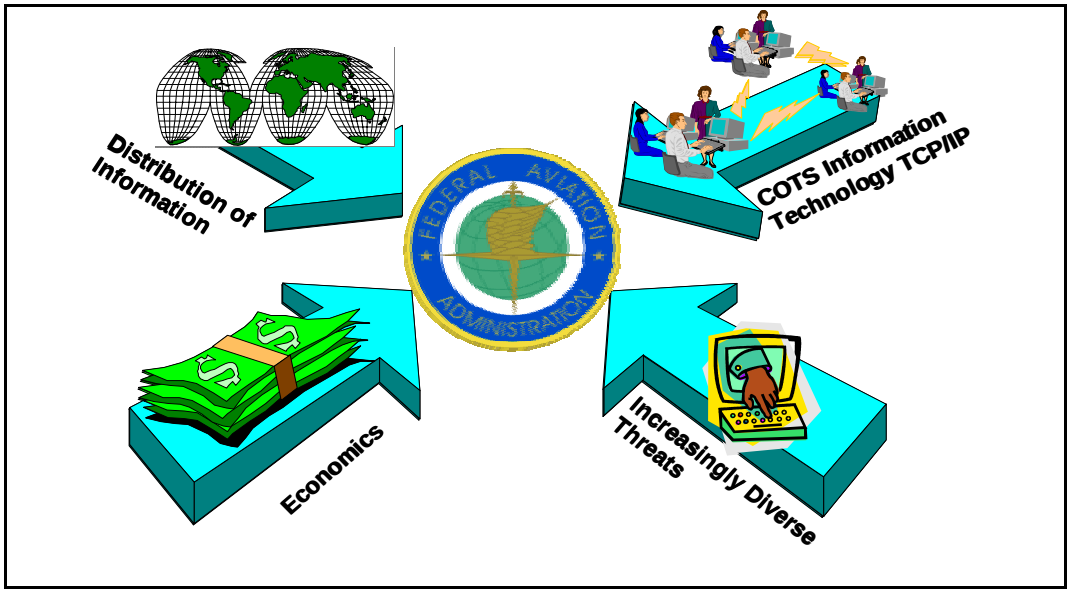


Figure 4.8-12. Force of Change Driving Security

The above factors drive the FAA toward more thorough and disciplined implementation of ISE throughout the system lifecycle.

Including security early in development and acquisition of FAA systems usually results in lower costs and more effective security features when compared to adding security features after the systems have entered service. The SEM presents a security-engineering framework that supports all phases of the AMS, from early planning to contract closeout and/or system disposal. The next section outlines the general principles for ISE.

4.8.6.2 Information Security Engineering Principles

Similar to systems safety engineering, the concept of risk management is central to conducting effective and complete ISE. Security risk management includes assessment, mitigation, monitoring, and control of security risks throughout the life of every FAA information technology system. From the ISE perspective, combining the likelihood of a particular threat exploiting or triggering a particular system vulnerability produces a security risk (FAA ISS Handbook). Proper ISE seeks an acceptable level of security risk, also referred to as "risk," at an acceptable cost. An acceptable risk is one determined to represent an acceptable condition of potential

loss, damage, or disruption for the FAA mission. Adequate security controls are like insurance—the system sponsor or developer spends enough resources to mitigate the risk of loss, damage, or disruption to an acceptable level. However, to be cost-effective, it is recommended that the sponsor or developer not spend more than the risk of loss, damage, or disruption.

In conducting ISE for a system, consider the following important points (see also Figure 4.8-13):

- Security shall always consider the operational environment of the system and the system's contribution to the FAA mission and services. Security shall include consideration of continuity of operations and disaster response by the system in its operational environment.
- ISE shall consider the personnel and physical security features and services, including management and administrative controls, procedures, and processes.
- It is recommended that ISE use existing SE and AMS products and processes as a cost-effective means of building and improving ISE practices.
- Security engineers shall collaborate with the Integrated Requirements Team (IRT) and system stakeholders. Collaboration with the IRT, including system safety engineers, may avoid unnecessary and duplicative security requirement statements and costly, specialized controls for security services that may be effectively handled by other system features, such as procedures, physical controls, or interfacing systems/services.

Chapter 3 of the FAA ISS Handbook describes how to determine ISS risks using the Security Risk Management Process in Figure 4.8-14. The figure illustrates a closed-loop process for managing risk at any phase or point in the system lifecycle. It is recommended that this process be applied very early in the system development so that security requirements are defined upfront. There is further information in this section about applying this process during phases of the AMS to produce ISE products. Also, the ISE supports the overall Risk Management process of (Section 4.10).

It is recommended that each system developer and system owner apply the ISE risk-management process as a primary tool for performing and contributing to other SE activities, analyses, plans, and products. Figure 4.8-15 illustrates how ISE supports, and is supported by, other SE practices.

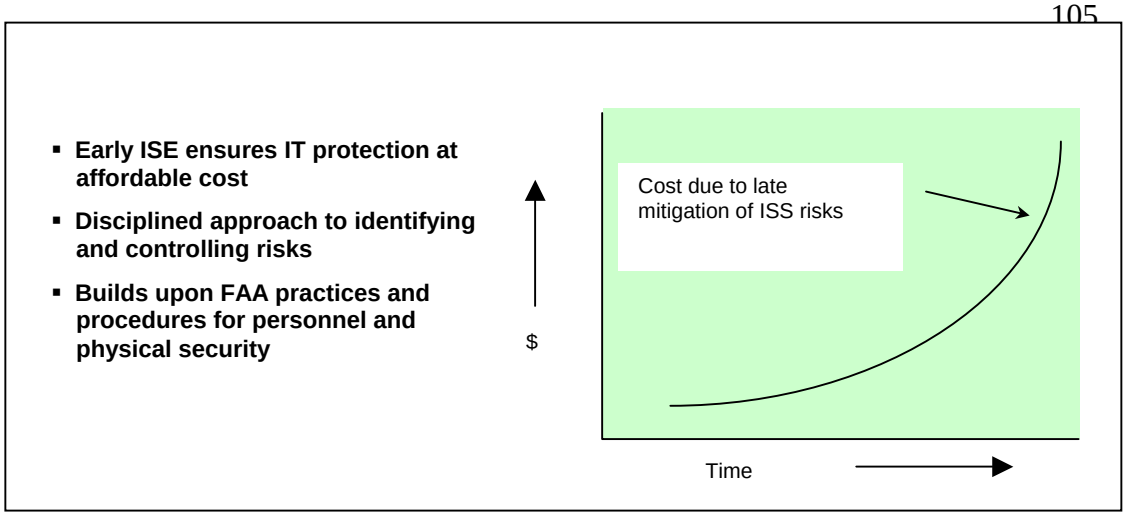


Figure 4.8-13. Benefits of Information Security Engineering

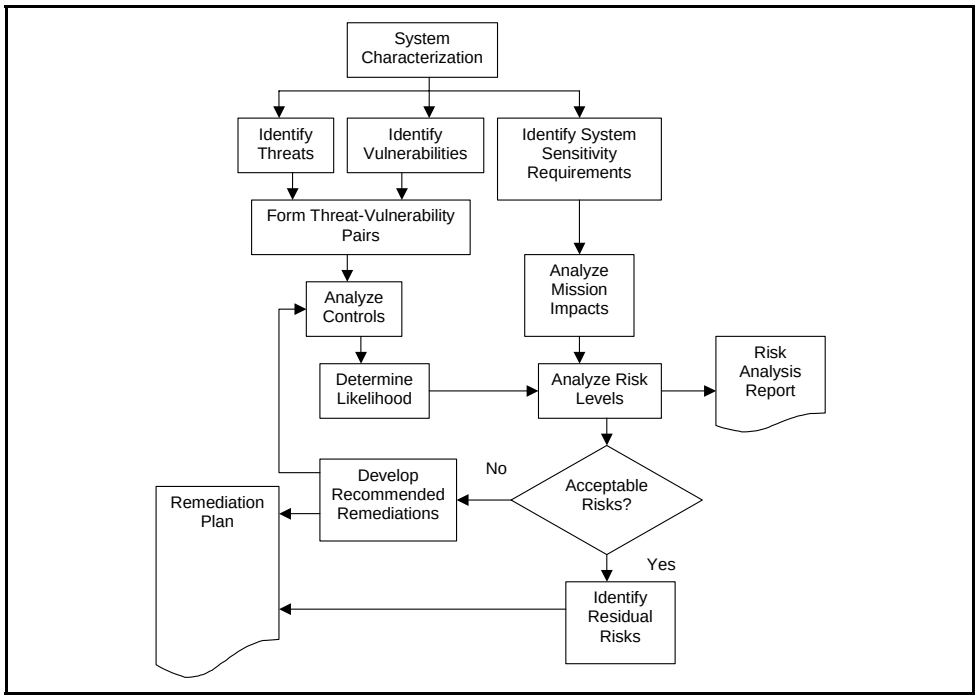


Figure 4.8-14. System Security Risk Management Process

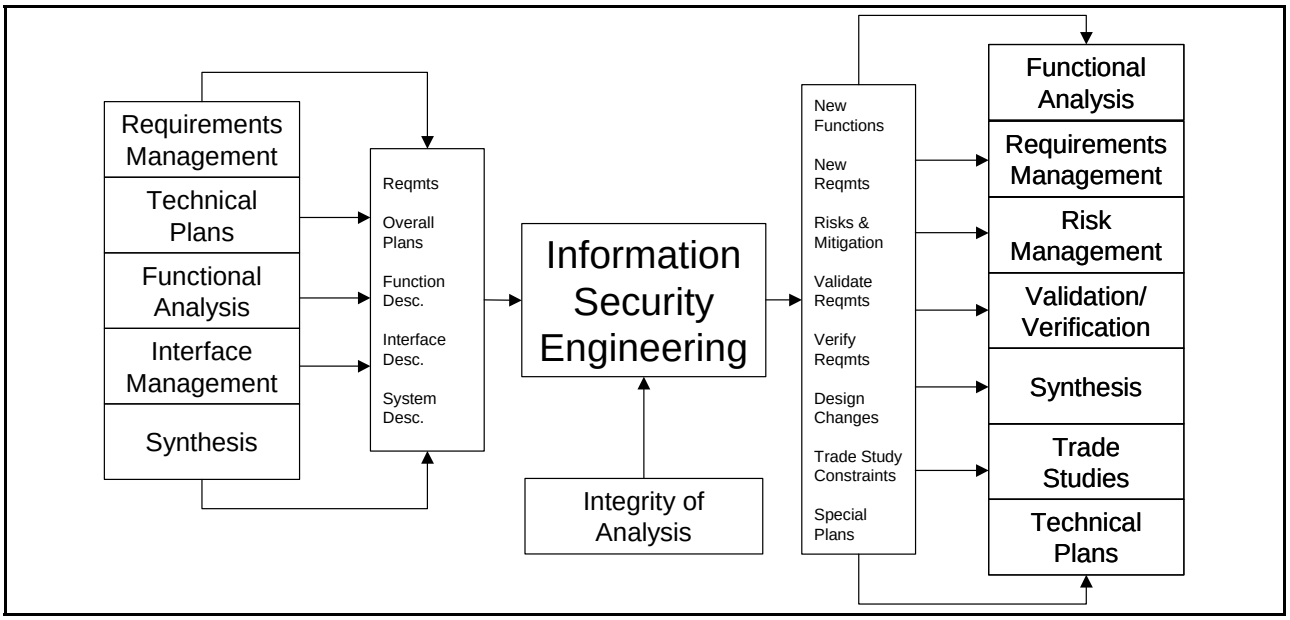
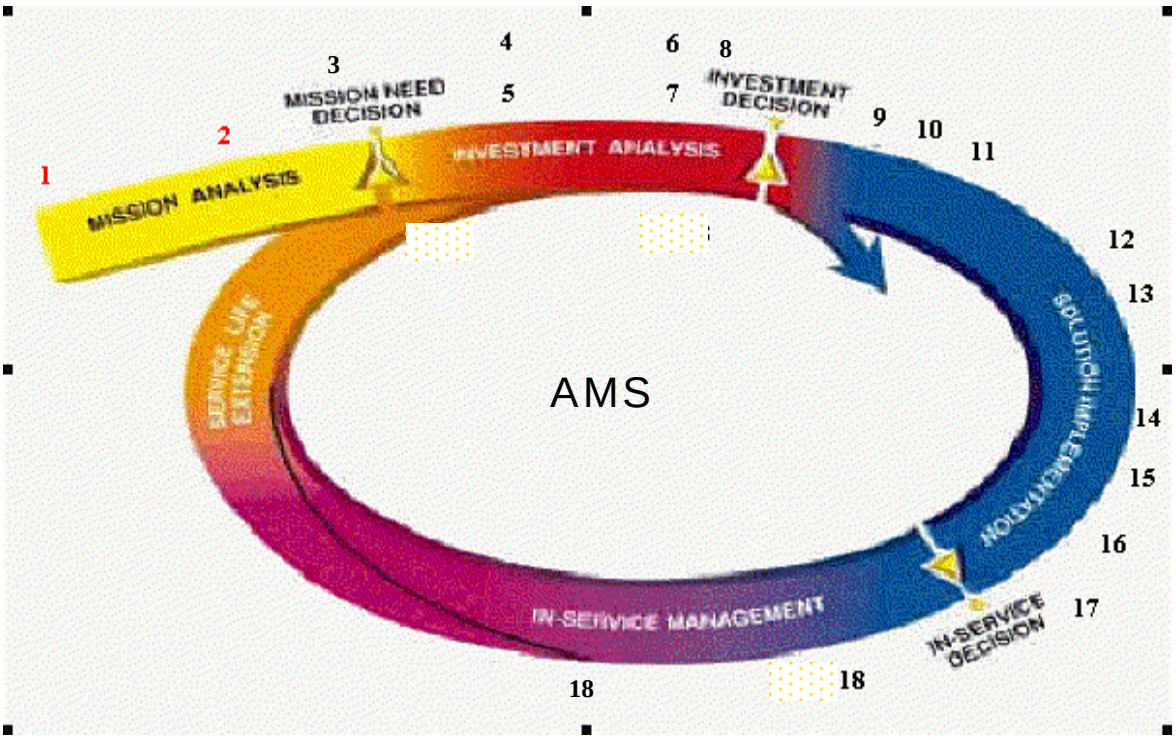


Figure 4.8-15. ISE Relationship to Other System Engineering Processes

Early application of ISE principles may reduce lifecycle costs and improve overall SE. ISE uses existing capabilities of many COTS products, but relies on early application of ISE processes, tools, and security risk management practices. Also, ISE leads to identifying high-risk security elements earlier in the system lifecycle. When high-risk elements are found and mitigated early, it is simpler and less expensive to make corrections. The outputs of the ISE process feed other SE processes, improving the overall SE of the system.

4.8.6.3 Information Security Engineering Process Tasks

The AMS Lifecycle integrates a continuum of ISE processes and products. Figure 4.8-16 shows what security analyses and products are performed relative to the AMS phases and decision milestones. The representation is notional. Each program or Product Team may need to tailor its activities to meet its program milestones. The security analyses and activities are sequenced to support the phased decisions of the AMS. It is recommended that each program or Product Team use its respective SEMP and security planning to tailor its security risk management program. National Institute of Standards (NIST) Special Publication (SP) 800-18, Guide for Developing Security Plans for Information Technology Systems, provides the basis for security planning referenced in the FAA ISS Handbook.



Legend
ISE Risk Management Process aligned with AMS

1. Basic Security Policy
2. MNS Threat Stipulation and Begin Detailed Security Engineering Activities
3. CONOPS and Preliminary Security Requirements or Protection Profile
4. Preliminary Vulnerability Assessment
5. Preliminary Risk Assessment
6. Updated Vulnerability Assessment
7. Updated Risk Assessment and Risk Mitigation
8. Updated CONOPS and Security Requirements or Protection Profile
9. Security Requirements Integrated with System Requirements
10. Integrated Security Architecture and Design
11. Final ISSP
12. Security Test Planning and Procedures
13. User's Guide, Training and Contingency Plans
14. Integrated Security Testing with SAT

15. Integrated Security with OT&E
16. Final Security C&A Documents
17. Security Authorization/Accreditation
18. Tech Refresh and Upgrade Planning

Numbered items correspond to AMS Lifecycle diagram numbers, above

Figure 4.8-16. Security Risk Management Relative to the AMS

The following paragraphs outline in greater detail. The AMS and the ISS Handbook contain further guidance.

- **Mission Analysis Phase**

  Conduct Preliminary Risk Assessment and generate high-level System/Mission Requirements, resulting in a succinct, qualitative description of the basic security needs of the system and a set of high-level ISS requirements that are derived from the Mission Needs Statement, concept of operations, and the OSED. Assess criticality of data and systems to FAA mission and service.

- **Investment Analysis Phase**

  – Confidentiality, Integrity, and Availability Requirements Analysis — identify the protection requirements through an analysis of laws and regulations that define baseline security and consider functional and other security requirements. Apply and refine the criticality assessment from Mission Analysis phase.

  – Security Risk Assessment Update — update the preliminary risk assessment based on the results of the confidentiality, integrity, and availability requirements. Use Trade Studies (Section 4.6) to assess cost-effective security controls that may form the basis for desirable system security requirements. Tradeoff analyses may be warranted to assess alternative control measures, including procedural, physical, and personnel measures.

  – Analysis of the Level of Assurance Required — address how much confidence is needed and that the NAS security is to work in an integrated fashion, correctly and effectively. Assurance may be gained through many techniques, including, among others, conformance testing and validation suites, or evaluations by another vendor.

  – Coordinate Stakeholder, Certifier, and Authorization Review — for this phase of development, ensure a technically qualified person certifies that the security controls on the system, application, or networks meet the NAS ISS requirements.

  – Specification and SOW — based upon the Investment Analysis Phase, provide ISS constraints and requirements to Requirements Management (Section 4.3) as input for final requirements, specifications, and SOW development.

  – Evaluation Proposals — support Trade Studies (Section 4.6), Synthesis (Section 4.5) and Validation (Section 4.12.1) in assessing the minimum ISS requirements for solicitation information requests SIR and evaluating alternative solutions that are proposed.

  – Performance Measurement and Monitoring — Using results from ISS requirements, trade studies, synthesis, and Integrated Technical Planning (Section 4.2), identify effective measures for ISS performance, status, and assurance. Measures may be useful for the applicable phase of acquisition and system development.

- **Solution Implementation Phase**
  - Security Risk Assessment Update — update the assessment based upon the expected ISS functional and assurance controls from the chosen solution. Support Validation (Section 4.12.1) and Synthesis (Section 4.5) to assess controls and assurance as being cost effective and meeting the ISS requirements. Use Requirements Management (Section 4.3) to mitigate security risk to acceptable levels.
  - Information Security Certification and Authorization — use the results of ISE activities, including related system engineering elements like Integrated Technical Planning (Section 4.2) that includes CONOPS, Synthesis (Section 4.5), Validation and Verification (Section 4.12), and Lifecycle Engineering (Section 4.13) to collect and document ISE for C&A. The ISS Handbook provides templates for collecting and presenting C&A documentation.
- **In-Service Decision and In-Service Management Phase**
  - Stakeholder, Certifier and Authorization Review — ensure a technically qualified person certifies and authorizes that the security controls on the system, application, or networks meet the NAS ISS requirements.
  - Performance Measurement and Monitoring — update ISS measures, metrics, and monitoring. Ensure that monitoring ISS performance and assurance for the respective NAS System has not degraded. Assess changes in the environment and system for previously unforeseen risks from new threats and vulnerabilities. Plan and take corrective action as necessary.
- **Service-Life Extension and/or Closeout**
  - Update the Security Plan — ensure security plans evolve with the system. Conduct periodic C&A, consistent with guidance of FAA ISS Order 1370.82.
  - Update ISS requirements — update risk assessment based upon performance measurement and monitoring of In-Service Management. Identify updated and/or new ISS requirements for Service-Life Extension.
  - Archive Information — retain information as necessary keeping in mind legal requirements and future technology changes that render the retrieval method obsolete.
  - Sanitize Media — ensure data is deleted, erased, and written over as necessary.
  - Dispose of Hardware and Software — dispose of the hardware and software as directed by ISS Policy.

The ISE processes and products may also be represented as a series of steps. To satisfy the objectives of each step, consistent with Section 4.8.0.3, it is recommended that the General Specialty Engineering Process Tasks be used. Figure 4.8-17 indicates the ISE steps and shows the relationship of the General Specialty Engineering Tasks to the ISE process. Each program, IPT, or Product Team developing or acquiring IT systems shall institute a Security Risk Management Process that includes risk assessment, risk mitigation, evaluation and assessment, as recommended by NIST SP 800-30, Risk Management Guide for IT Systems. The ISE process steps (Figure 4.8-17) are mapped to the AMS lifecycle by Table 4.8-13. The legend in Figure 4.8-17 indicates the Specialty Engineering Tasks that apply to each ISE process step/activity, as the risk management process is applied throughout the lifecycle.

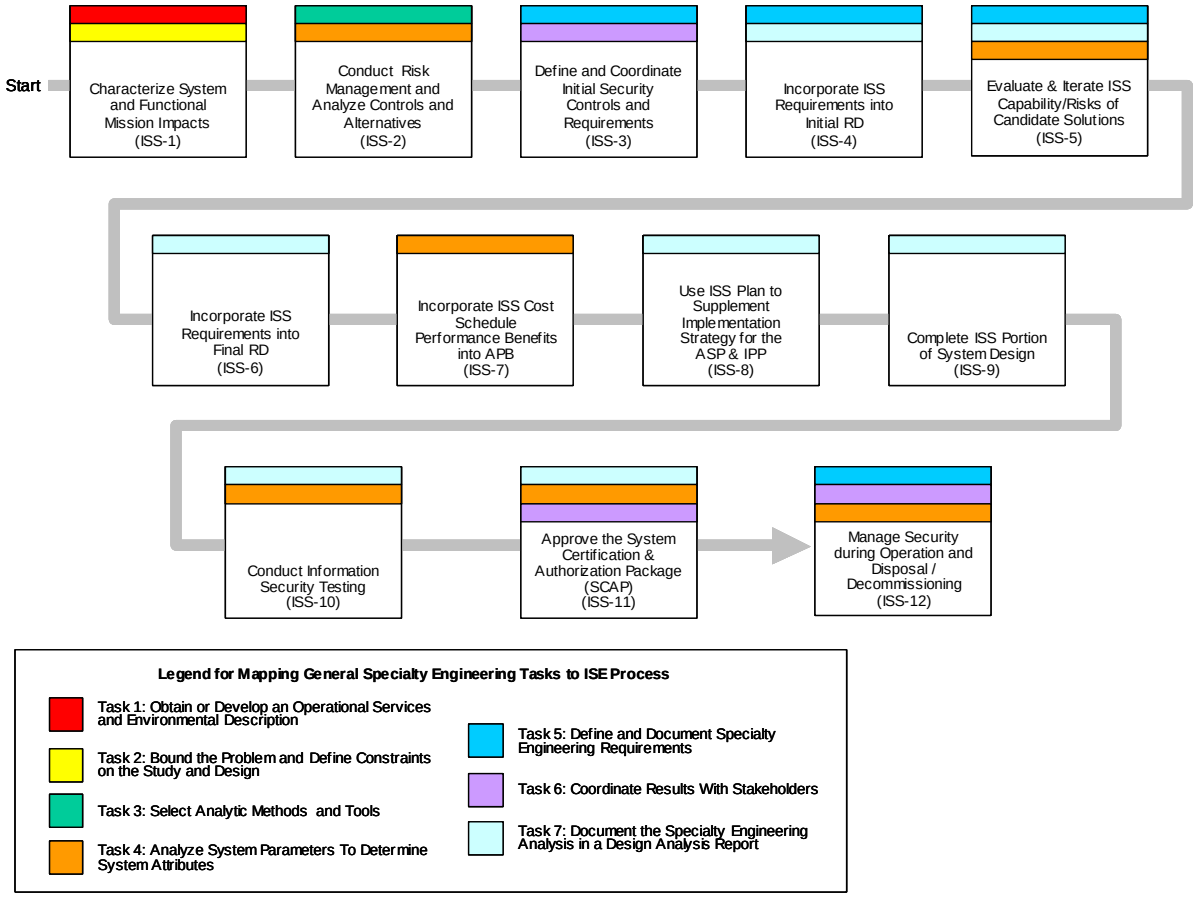


Figure 4.8-17. ISE Process with General Specialty Engineering Tasks Applied

Figure 4.8-14, System Security Risk Management Process, contains all the steps of NIST SP 800-30. Risk management is an iterative process that shall be embedded into each major phase of systems development, and involves the steps outlined in Figure 4.8-14.

- System Characterization
- Threat Assessment
- Vulnerability Assessment
- Analysis of Controls
- Likelihood Determination
- Assessment of Mission Impact
- Analyze Risk Levels
- Risk Mitigation, or Recommended Controls
- Identification and Documentation of Residual Risk

Additionally, the program, IPT, or Product Team Security Risk Management Process shall provide outputs and products as described within the ISS Handbook and summarized in the following section. Each program, IPT, or Product Team shall plan and provide for support of the products defined in Table 4.8.6-3, as a part of system lifecycle acquisition and support.

4.8.6.4 Information Security Engineering Outputs and Products

The ISE process generates the activities and products described in the next sections.

4.8.6.4.1 Program Planning

It is recommended that the program, Product Team, and system sponsor/owner have a System Security Plan (SSP), which is to evolve during the system's lifecycle. The ISS Handbook provides a template for developing the SSP. It is recommended that the SSP evolve with the system development through update and revision based on risk management activities that address growing understanding of how risk requirements for the system may be satisfied. Early in development, the SSP addresses threats and needs of the system with an operational security assessment that reflects the output of the OESD. The risk management process (Figure 4.8-14) shall be applied through each phase of development. To further guide planning, Table 4.8-13 relates the AMS security risk management activities to the ISE Process. Analysis products outlined in Paragraph 4.8.6.4.2 below are used to update the SSP.

Table 4.8-13. Mapping AMS Security Risk Management Activities to ISE Process

AMS Security Risk Management Activities	ISE PROCESS STEPS
1. Basic Security Policy	ISS-1: Characterize System and Functional Mission Impacts
2. MNS Threat Stipulation and Begin Detailed Security Engineering Activities	ISS-2: Conduct Risk Management and Analyze Controls and Alternatives
3. CONOPS and Preliminary Security Requirements or Protection Profile	ISS-3: Define and Coordinate Initial Security Controls and Requirements
4. Preliminary Vulnerability Assessment	ISS-2: Conduct Risk Management and Analyze Controls and Alternatives
5. Preliminary Risk Assessment	ISS-2: Conduct Risk Management and Analyze Controls and Alternatives
6. Updated Vulnerability Assessment	ISS-2: Conduct Risk Management and Analyze Controls and Alternatives
7. Updated Risk Assessment	ISS-2: Conduct Risk Management and Analyze

AMS Security Risk Management Activities	ISE PROCESS STEPS
	Controls and Alternatives
8. Updated CONOPS and Security Requirements or Protection Profile	ISS-4: Incorporate ISS Requirements into Initial RD ISS-5: Evaluate and Iterate ISS Capability/Risks of Candidate Solutions ISS-6: Incorporate ISS Requirements into Final RD
9. Security Requirements Integrated with System Requirements	ISS-8: Use ISS Plan to Supplement Implementation Strategy for the ASP & IPP
10. Integrated Security Architecture and Design	ISS-8: Use ISS Plan to Supplement Implementation Strategy for the ASP & IPP
11. Final ISSP	ISS-8: Use ISS Plan to Supplement Implementation Strategy for the ASP & IPP ISS-9: Complete ISS Portion of System Design
12. Security Test Planning and Procedures	ISS-10: Conduct Information Security Testing
13. User's Guide, Training and Contingency Plans	ISS-10: Conduct Information Security Testing
14. Integrated Security Testing with SAT	ISS-10: Conduct Information Security Testing
15. Integrated Security with OT&E	ISS-10: Conduct Information Security Testing
16. Final Security C&A Documents	ISS-11: Approve the SCAP
17. Security Authorization/Accreditation	ISS-11: SCAP
18. Tech Refresh and Upgrade Planning	ISS-12: Manage Security during Operation and Disposal / Decommissioning

4.8.6.4.2 Analysis Products

The ISS Handbook highlights how ISE work products are used to validate and verify the security requirements of a given system. The work products are generated according to the individual SSP for each FAA service/domain/system. The ISS Handbook provides templates to guide collection of analysis into products used for security accreditation of the service/domain/system by the responsible FAA approving authority, consistent with FAA ISS Policy Order 1370.82.

Table 4.8-14, ISE Risk Assessment Matrix, provides a means of analyzing individual risks and determining the need for mitigation or risk-reduction measures. The matrix reflects the level of risk associated with the **likelihood** of a given threat-source exercising a given vulnerability and the **impact** of that threat source successfully exercising that vulnerability. Risks to IT systems arise from events, such as the following:

- Unauthorized (malicious or accidental) disclosure, modification, or destruction of information
- Unintentional errors and omissions
- IT disruptions due to natural or man-made disasters
- Failure to exercise due care and diligence in implementing and operating the IT system

To use the matrix, apply the determined **Likelihood** value generated during the System Security Risk Management Process (Figure 4.8-14) for each threat source and apply the system's overall **Impact** rating obtained similarly. Locate the **Likelihood** value in the vertical column and locate the **Impact** rating in the horizontal column. The **Risk Level** is where the two values intersect.

Table 4.8-14. ISE Risk Assessment Matrix

Likelihood	1 Minimal	2 Minor	3 Major	4 Serious	5 Catastrophic
5 Near Certainty					HIGH
4			MEDIUM		HIGH
3	LOW		MEDIUM		
2	LOW				
1 Extremely					

Impact

Table 4.8-15 lists the products of ISE and references detailed directions on how to develop these products.

Table 4.8-15. Products of Information Security Engineering

Information Security Process Products	How To Reference	How To Apply to the ISE Process
Risk Assessment Report (Includes Threat and Vulnerability Assessments)	FAA ISS Handbook: Chapter 3, Section 3.3 – Risk Assessment Process FAA ISS Handbook: Appendix A-2 – Risk Assessment Report	ISS-2: Conduct Risk Management and Analyze Controls and Alternatives
Risk Mitigation/Remediation Plan	FAA ISS Handbook: Chapter 3, Section 3.4 – Risk Mitigation/Remediation Plan FAA ISS Handbook: Appendix A-3 – Risk Mitigation/Remediation Plan	ISS-2: Conduct Risk Management and Analyze Controls and Alternatives
Information Systems Security Plan	FAA ISS Handbook: Chapter 4, Section 4.1 – Compile an ISS Plan FAA ISS Handbook: Appendix A-4 & A-5 – ISS Plans for General Systems and Major Applications	ISS-8: Use ISS Plan to Supplement Implementation Strategy for the ASP & IPP
Contingency/Disaster Recovery Plan	FAA ISS Handbook: Chapter 4, Section 4.2 – Develop a Contingency/Disaster Recovery Plan FAA ISS Handbook: Appendix A-6 – Contingency and Disaster Recovery Plan	ISS-10: Conduct Information Security Testing
Security Test Plan and Test Results Report	FAA ISS Handbook: Chapter 5 – Remediation Phase FAA ISS Handbook: Appendix A-7 – Security Test Plan and Test Results Report	ISS-10: Conduct Information Security Testing
Executive Summary	FAA ISS Handbook: Chapter 6, Section 6.1.1 – Develop Executive Summary FAA ISS Handbook: Appendix A-8 – Executive Summary	ISS-11: Approve the SCAP
C&A Certificate	FAA ISS Handbook: Chapter 6, Section 6.1.2 – Certification and Authorization Approval Process FAA ISS Handbook: Appendix A-9 – System Certification and Authorization Certificate	ISS-11: Approve the SCAP

4.8.6.4.3 Security Certification and Authorization Package

As outlined (in Paragraph 4.8.6.1 above), FAA Policy Order 1370.82 requires that information technology systems be accredited through an ISS C&A process. To complete the C&A process, the system developer or system sponsor/operator shall submit a SCAP. The SCAP documents the results of validation and verification of security requirements and includes an assessment for the FAA Designated Approving Authority of the level of residual security risk. The principle documents in the SCAP are the Risk Assessment and Mitigation Report, the ISS Plan, Contingency/Disaster Recovery Plan, System Test Plan & Test Results, and the Executive Summary. However, additional ISS documents may need to be created depending on the nature of the system.

The FAA ISS Handbook offers detailed information about the C&A Process and how to go about submitting a SCAP for review. The SCAP is a necessity and an integral step when doing ISE. This is emphasized in ISS-11 of the ISE Process.

4.8.7 Hazardous Materials Management/Environmental Engineering

Hazardous Material Management/Environmental Engineering (HMM/EE) is the subset of Specialty Engineering concerned with the impacts of both the program on the environment and the environment on the program. Federal, state, and local environmental agencies have established mandates that regulate program impacts on the environment. These mandates include requirements to manage hazardous materials and to safeguard natural resources including ambient air, water, and land-based resources. FAA orders and directives (e.g., FAA Order 1050.10, Prevention, Control, and Abatement of Environmental Pollution at FAA Facilities) relate federal environmental regulations to FAA activities and also provide additional environmental requirements specific to NAS operations. Conversely, environmental impacts on programs vary, depending on site-specific environmental conditions that may affect FAA operational requirements. The following sections describe the purpose and general process of HMM/EE within SE.

4.8.7.1 What Is Hazardous Material Management/Environmental Engineering?

HMM/EE is the mechanism applied within the SE process to ensure a program's ongoing compliance with applicable environmental laws. HMM/EE is also the SE process designed to provide early, predeployment planning and coordination to minimize the negative impacts that site-specific environmental conditions may have on a program's operability. Compliance with various environmental regulations is required throughout a program's lifecycle, requiring early and continuous application of HMM/EE principles.

Key considerations are pollution prevention, safety and health (including system safety), cultural and natural resource conservation, public participation, and energy and water conservation It is recommended that additional issues concerning the applicability of state and local agency requirements to federal agencies be referred to the legal office for an evaluation of supremacy clause and sovereign immunity implications. For example, the National Environmental Policy Act requires preparation of an environmental assessment for all proposed federal actions that are not categorically excluded.

Additionally, the Resource Conservation and Recovery Act delineates standards for managing and disposing of hazardous wastes that result from various processes during program operation, and at the end of the program's lifecycle. Through HMM/EE, the breadth of environmental requirements are continuously monitored, and considered, to ensure that FAA's programs take the steps to maintain compliance.

HMM/EE processes also highlight the impacts that environmental conditions and site-specific characteristics may have on a program. FAA specifications developed for various types of equipment delineate operating conditions that shall be considered during the program's developmental stages. For example, the general FAA specification for electronic equipment, FAA-G-2100, details the design standards that shall be followed to ensure equipment functionality in environmental conditions of both seismic zones and temperature extremes. HMM/EE verifies that similar standards are considered and adhered to in the SE process to ensure the reliability of systems fielded under unique environmental settings.

4.8.7.2 Why Perform Hazardous Material Management/Environmental Engineering?

HMM/EE is performed to:

- Support reliable, safe, and sustained NAS operations
- Ensure that compliance with FAA, federal, state, and local environmental requirements
- Ensure environmental considerations are included in the acquisition management process
- Track the status of environmental issues with new and existing systems
- Minimize cost and schedule risks through early detection of environmental issues

Through various regulations, such as FAA Order 1050.17, Airway Facilities Environmental and Safety Compliance Program, the FAA has mandated and delineated requirements to comply with applicable environmental regulations. The FAST ensures that these regulations are considered in the acquisition process in AMS Section 2.9.8, Environmental, Occupational Safety and Health, and Energy Considerations:

> *FAA acquisitions are subject to federal environmental, occupational safety and health, and energy management statutes, regulations, executive orders, and Presidential memoranda. Key considerations are pollution prevention, safety and health (including system safety), cultural and natural resource conservation, public participation, and energy and water conservation. Additional issues concerning the applicability of state and local agency requirements to federal agencies should be referred to the legal office for an evaluation of supremacy clause and sovereign immunity implications.*

The following illustrate some of the requirements:

- The National Environmental Policy Act "requires preparation of an environmental assessment or an environmental impact statement for all proposed federal actions that are not categorically excluded. Depending on the results, an environmental assessment can lead to an environmental impact statement or a finding of no significant impact. Following the prescribed review periods, the FAA may make a decision on the federal action."
- Various other environmental laws (e.g., the Federal Facilities Compliance Act) "impose environmental requirements, and sanctions for noncompliance, including civil penalties."
- The Occupational Safety and Health Administration (OSHA) "requires a safe and healthful workplace for all employees, and compliance with OSHA standards."

> *OSHA (29 CFR §1910.28) and GSA (Federal Property Management Regulations) require the FAA to establish and maintain an Occupant Emergency Plan for all FAA facilities. In the event an acquisition program impacts egress routes or fire safety of a facility, the plan must be updated by the program office or the Product Team performing the project.*

- The National Energy Conservation Policy Act "requires energy and water conservation measures for federal buildings, facilities or space."

> *Environmental, safety and health, and energy conservation considerations apply from the beginning of the acquisition lifecycle through product disposal. The Acquisition Program Baseline shall incorporate estimates for the full cost of complying and allow sufficient time for doing so. FAST contains procedural guidance for required actions*

When applied early, HMM/EE identifies applicable environmental requirements to include in development and acquisition of new systems, thereby providing significant savings through risk minimization, cost avoidance, and enhancement of system efficiency. Additionally, consideration of environmental impacts on systems while they are in the developmental stages ensures their functionality in various field conditions.

HMM/EE conducted as part of in-service program management analyzes the impact that engineering changes in the field may have on environmental concerns. As obsolete equipment is removed, HMM/EE ensures that replacement equipment complies with applicable environmental regulations. In particular, decommissioning and removal of obsolete equipment require HMM/EE considerations to ensure that final disposition/disposal is conducted in accordance with applicable environmental requirements. HMM/EE also evaluates the impact that regulatory changes may have on fielded systems.

Programs that fail to fully incorporate HMM/EE principles may have significant impacts on NAS operations. Noncompliant programs may:

- Be removed from service through regulatory enforcement actions
- Require costly post-fielding/retrofit modifications
- Incur fines

Additionally, costs associated with new equipment fielding, and obsolete equipment disposition and disposal may lead to significant budgeting issues if they are not considered during the program development phase.

4.8.7.3 Hazardous Material Management/Environmental Engineering Process Tasks

HMM/EE follows the process tasks outlined in General Specialty Engineering Process Tasks (Paragraph 4.8.0.3).

4.8.7.4 Hazardous Material Management/Environmental Engineering Outputs and Products

Throughout the various phases of the system acquisition process, HMM/EE is used in developing and reviewing key documents. Early implementation of HMM/EE principles is essential to minimize the impact that environmental requirements may have on system costs and operations. During the preliminary activities, such as development of mission needs, requirements, and investment analysis, HMM/EE is used to make initial assumptions and estimates on how environmental considerations may come into play throughout the various lifecycle stages.

During the solution implementation phase of the acquisition process, HMM/EE is used to shape portions of the SOW and system specifications documents as they relate to environmental

considerations. For example, SOWs may be developed to support FAA efforts to meet National Environmental Policy Act demands that federal agencies minimize use of toxic substances in its operations.

During the in-service management phase of the system lifecycle, HMM/EE is used to address issues that may arise unexpectedly in the field. In particular, older pieces of equipment that may not have been developed with HMM/EE in mind may require corrective measures to meet environmental regulations. Additionally, the set of ever-changing environmental regulations may impact the way systems are operated. Finally, as old systems are decommissioned, HMM/EE is necessary to ensure that all disposal actions consider applicable environmental laws.

4.8.7.4.1 Program Integration

As part of the SE process, HMM/EE provides expertise for developing various documents required for program integration. Throughout the various lifecycle phases, HMM/EE ensures that all applicable regulations and environmental conditions are properly addressed so that their impacts are accounted for appropriately. For example, HMM/EE would support development of the IRD, keeping in mind environmental regulations that require federal agencies to verify that their activities do not negatively impact certain ecosystems. Similarly, HMM/EE's role in developing IPPs, SOWs, Disposition/Disposal Plans, and other such documents generate comments and input concerning the compliance requirements that may impact the progress of program implementation, and FAA's compliance status and future liabilities.

Included in the HMM/EE aspects of program integration is a functional analysis of the OSED (see Section 4.4 (Functional Analysis)). This portion of the functional analysis ensures that the environmental conditions that the various systems face are fully considered and that plans are appropriately developed to address identified conditions.

Figure 4.8-18. depicts HMM/EE Inputs and Outputs.

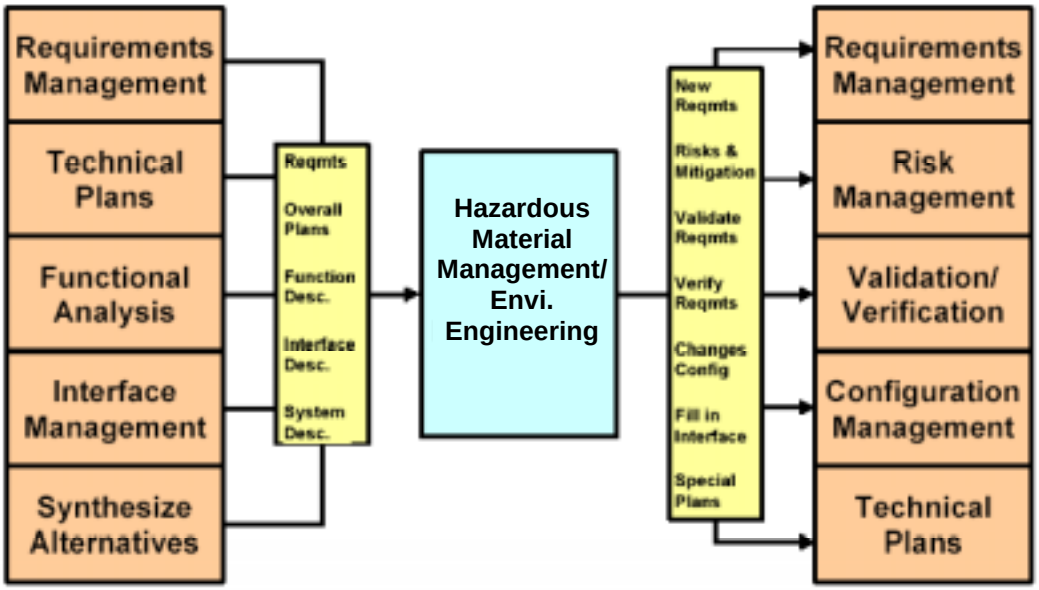


Figure 4.8-18. HMM/EE's Relationship to Other System Engineering Processes

4.8.7.4.2 Program Planning

FAA Order 1050.17 Airway Facilities Environmental Compliance Program implements the overall program for environmental compliance at FAA facilities. Each Region in the FAA has an Environmental Compliance Plan (ECP). The ECP is designed to identify and address compliance requirements in 19 environmental areas for all facilities, and therefore all systems within a region.

In addition to FAA Order 1050.17, FAA Order 4200.2, Utilization and Disposal of Excess and Surplus Personal Property, and AMS Section 2.8, Removing an Obsolete Solution, provide the requirements and framework for developing and implementing system-specific disposal plans for obsolete systems. These disposal plans are part of the Integrated Program Plan appendices; see Paragraph 4.2.2.1, Introduction to the Integrated Program Plan.

4.8.7.4.3 Products

Additionally, it is recommended that, through the HMM/EE process, a program have the capability to produce an inventory of the hazardous materials fielded equipment may contain. This information has many purposes, including, but not limited to:

- Ensuring protection of the environment and surrounding communities
- Ensuring regulatory compliance during the program's operational life
- Supporting the safety of personnel working with equipment
- Supporting disposition/disposal efforts when obsolete equipment is removed from service

4.8.7.5 References

1. FAA Order 1050.17 Airway Facilities Environmental Compliance Program
2. FAA Order 4200.2 Utilization and Disposal of Excess and Surplus Personal Property
3. AMS Section 2.8 Removing an Obsolete Solution
4. Order 1050.10, Prevention, Control, and Abatement of Environmental Pollution at FAA Facilities

4.9 Integrity of Analyses

4.9.1 Introduction to Integrity to Analyses

Analysis is defined as a logical examination or study of a system to determine the nature, relationships, and interaction of its parts and environment. Analysis emphasizes baseline system performance and/or compares development, production, or usage alternatives. Analysis is performed throughout the entire product lifecycle to support program decisions, encompassing technical performance and system acquisition considerations. Specific analyses are used throughout the System Engineering (SE) process. Analyses conducted to support a program may only add value if the results are credible, useful, and sufficient.

Analysis, as described here, encompasses a broad range of perspectives. The nature of the system dictates that analysis may be performed relative to the entire system (or its subsets), the system's interaction with other systems, and/or the environment in which the system operates. Analysis may focus on the operational, functional, or physical aspects of the system and its interfaces. Analyses may range from the simple to the complex, quantitative to qualitative, top-down to bottom-up, and basic formulas to sophisticated simulations. Some specific scenarios that require analyses include:

- Exploring system concepts regarding viability and technology maturity
- Determining operational system requirements and measures of system merit
- Determining key system performance relationships to cost and other acquisition parameters
- Evaluating key system quality factors, including reliability, readiness, and maintainability
- Evaluating potential changes to improve performance, reduce cost, etc.
- Assessing risks and potential risk mitigation options
- Synthesizing allocated requirements into an acceptable physical design
- Evaluating specific physical designs (components and interfaces)
- Determining system characteristics before building or integrating the system
- Verifying system, subsystem, and component performance at various stages
- Monitoring production quality
- Diagnosing observed or perceived system deficiencies
- Evaluating produced and fielded system performance
- Evaluating processes used to support and achieve results

To ensure credible, useful, and sufficient data/results for program management's decision-making process, the integrity and fidelity of various analyses performed on a program shall be understood and validated. This validation takes several forms**:** through the attributes of the tool suite (Paragraph 4.9.3.2), the proficiency and skills of the analyst (Paragraph 4.9.3.3), and the validity of the input data (Paragraph 4.9.3.4). The actual analyses performed are described in the other sections of this manual. The Integrity of Analysis process supports the other SE processes and is intended to provide a disciplined framework for conducting any required

analysis, whether technical, programmatic, or administrative in nature. An Analysis Management Plan (AMP) that outlines the details of the various analysis methods and tools is either generated or incorporated into the Integrated Program Plan (IPP). It is recommended that this planning effort reflect the available inputs and program constraints regarding technical capabilities, schedule requirements, and cost requirements.

A wide range of tools may support analysis, including a spacecraft facility, wind tunnel, manned aircraft simulator, iron bird, computational model, physical model, computer-aided design model, spreadsheet, photograph, or paper and pencil. The analysis methods used, including tools, shall provide the required level of fidelity in representing the system or subsystem and any associated interfaces. The selected analysis method may be quantitative or qualitative, or both. The common feature of all tools is that the tools are approximations of the system being analyzed. The level of fidelity achieved is one of the primary features that often sets one tool apart from another tool.

Integrity of Analyses is defined as a disciplined process applied throughout a program to ensure that analyses provide the required levels of fidelity, accuracy, and confirmed results in a timely manner. Competent users who iteratively apply a validated set of tools to a clearly defined data set ensure integrity. The Integrity of Analyses process (Figure 4.9-1) identifies the following tasks that shall be performed to ensure integrity:

- For each analysis, identify objectives, level of detail, and degree of validation required
- Select and/or develop the tools to meet the identified needs
- Ensure availability of analysts proficient in using the selected tools
- Ensure availability of proper and correct input data for each analysis conducted
- Perform analysis (reference task; see the SE element performing the actual analysis)
- Verify that analysis results are correct, useful, and sufficient

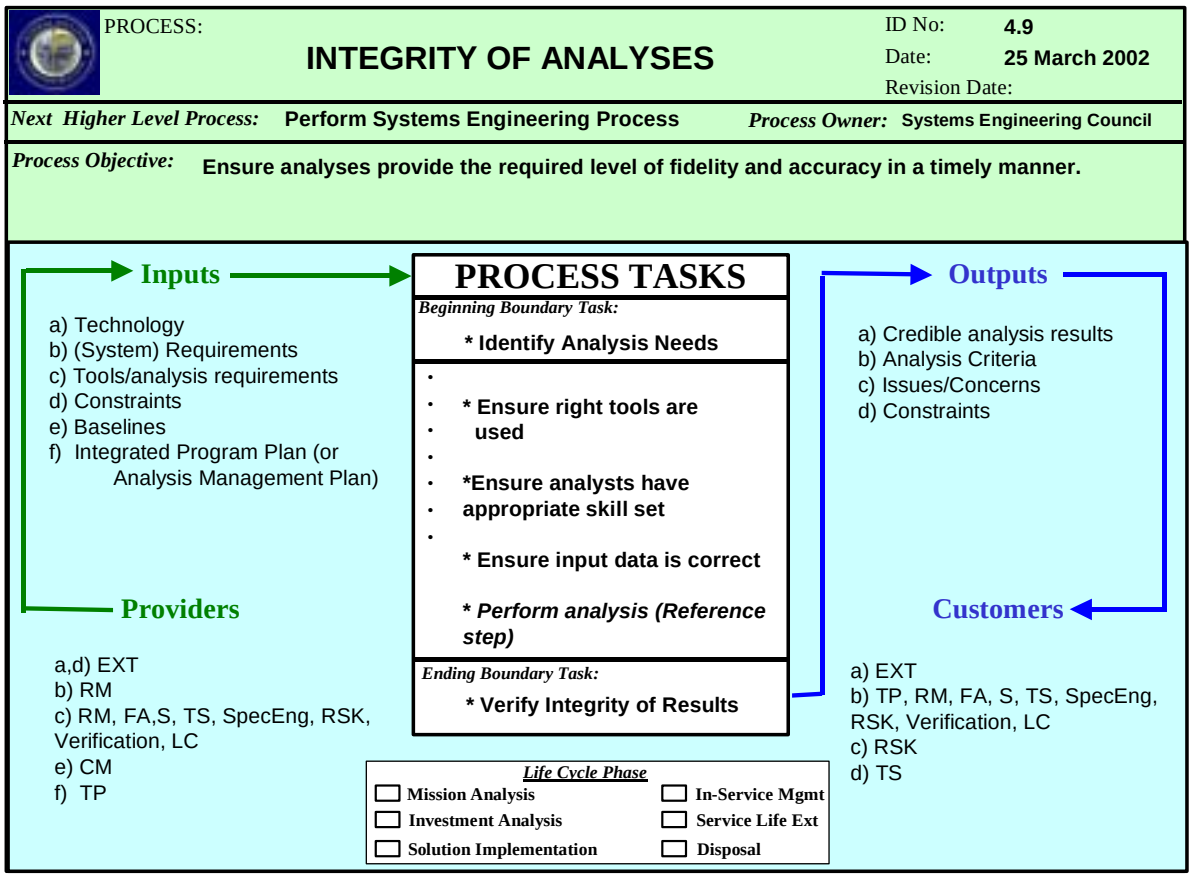


Figure 4.9-1 Integrity of Analyses Process-Based Management Chart

4.9.1.1 Purpose

The Integrity of Analyses process provides systematic guidance that leads to analysis results, including the following:

- **Credible.** Results are valid and their implementation is feasible.
- **Useful.** Results align to their intended use in the program decisionmaking process.
- **Appropriate**. Quantity and quality are sufficient to properly aid decisionmaking without performing excessive analysis.
- **Verifiable**. Results are accompanied by a methodology, rationale, and traceability that produce an appropriate confidence level in the results.

Executing the process tasks identified in Figure 4.9-1 results in selecting the required analysis methods, performing the analysis, and verifying the results.

The initial selection of the method, tools, or model to be used in an analysis focuses on finding a practical tool that provides the most visibility into the problem with the least complexity. The process is implicitly iterative and is used across the program throughout its lifecycle. Because the process is iterative, there is an ongoing need to use the best approach to select the right method, tool, or model, considering the preferences of the stakeholders and other teams' previous experience with different tools. In addition, the limitations of budgets, technology, and schedule shall be evaluated. The bottom line is to have analyses in place that guard against mistakes and embed a consistent level of confidence in the integrity of the analysis. The analysis, in turn, contributes significantly to the success of the decisionmaking processes of program management, teams, stakeholders, and contract managers. This result is achieved by addressing the methods of analysis to be used, attributes of the toolset, quality of the workmanship, and validity of the input data. The following paragraphs define the tasks that need to be completed to achieve analysis with integrity. Figure 4.9-2 illustrates the process tasks as well as the interactions between the Integrity of Analyses process with other SE elements.

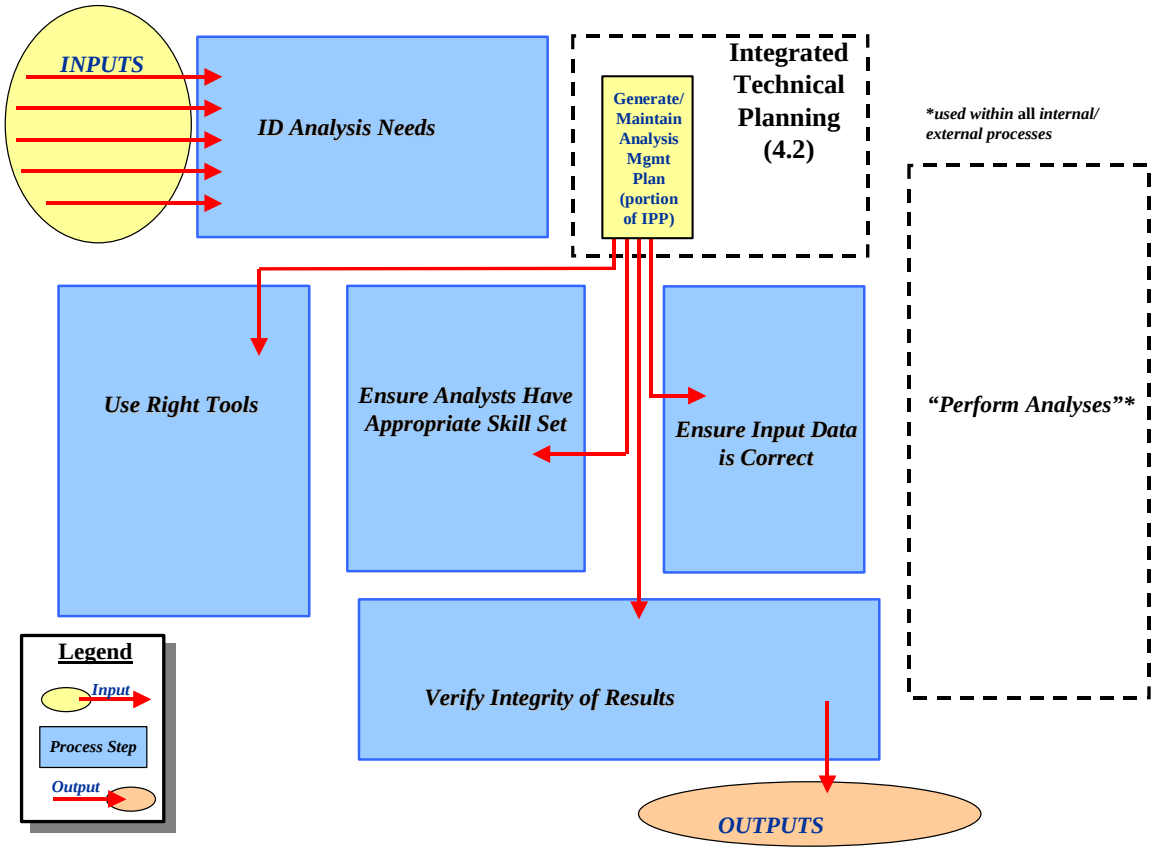


Figure 4.9-2. Integrity of Analyses Process

4.9.2 Inputs to Integrity of Analyses

Technology. Technology insertion determines the methods and tools employed for various analyses. The degree of technology insertion is driven by schedule and economic factors.

(System) Requirements. These requirements are defined to the extent that the results of a given analysis support a programmatic decision, whether driven by technical, cost, or schedule.

The requirements are generated from customer, internal, or supplier sources and may be expressed textually or as models.

Tools/Analysis Requirements. The various process elements discussed in Integrated Technical Planning (Section 4.2) that perform analyses provide the requirements for tools and analysis for the project, which are constrained by program technical, schedule, and cost requirements and plans imposed by project management. These requirements are typically reflected in the planning information developed under Integrated Technical Planning.

Constraints. The analysis needs are frequently a balance between the desires and costs of analytic excellence (usually championed by the analysts) and the program's cost/risk/benefit constraints, which are usually reflected in the program's budgets, schedules, and goals.

Baselines. This data set defines the aspect of the system being modeled or analyzed, and is under configuration control to the extent that all elements of the program are using the same baseline.

IPP. As part of the IPP or as a stand-alone plan, the AMP contains the planning effort for the right tools, data, and analyst skill set. The AMP is developed and maintained under the Integrated Technical Planning process (Section 4.2).

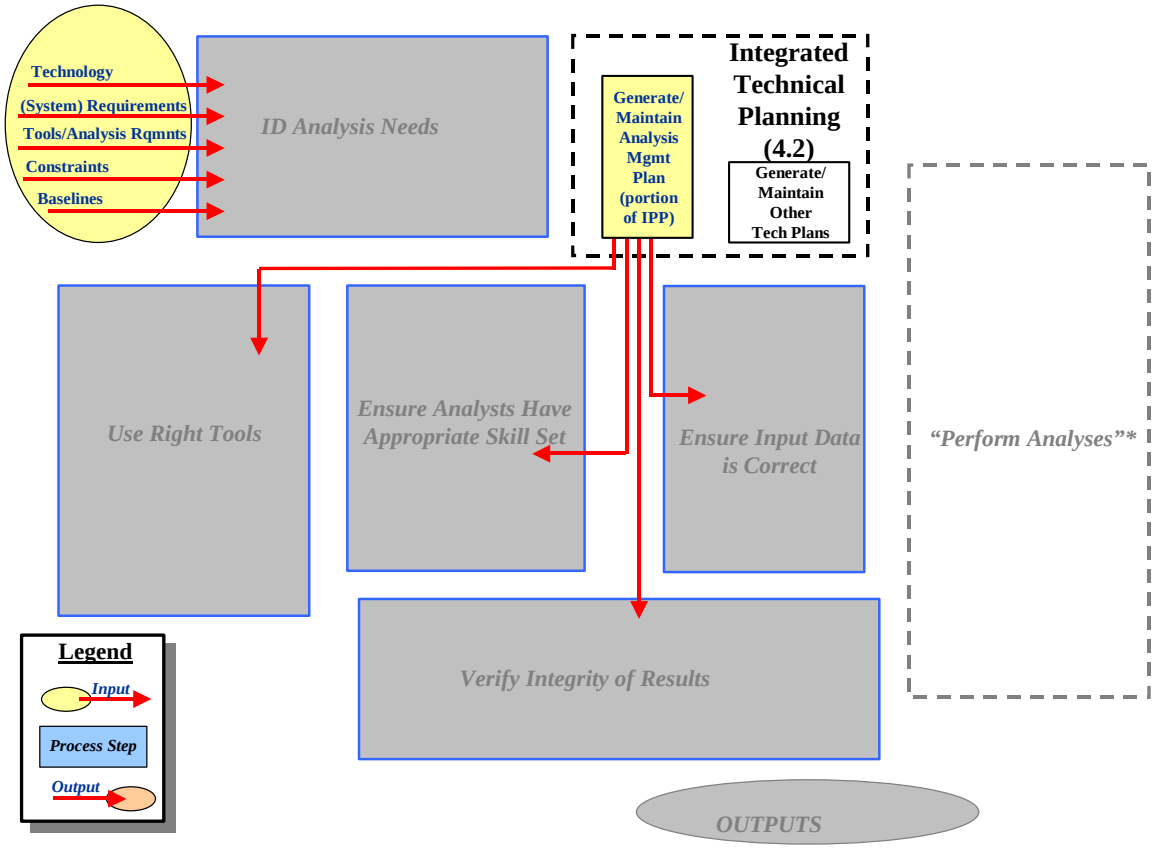


Figure 4.9-3. Integrity of Analyses Process Inputs

4.9.3 Integrity of Analyses Process Tasks

4.9.3.1 Task 1: Identify Analysis Needs

As indicated by the definition in the introduction of this section, analysis is used to investigate system structure or behavior. The analysis results form a decision aid that emphasizes certain aspects of system structure or performance in a limited number of architectures or configurations. Analyses are performed for a variety of specific needs relative to the system's lifecycle. For an analysis to be truly effective, the analysis results shall be closely aligned with the expressed needs and the decisions that the analysis is designed to support. It is good engineering practice to identify and plan around these needs. It is recommended that specific analysis needs be identified in the following areas:

- **Understand the various perspective(s)** to aid in decisionmaking (e.g., system users, acquirers, builders, testers, and suppliers). Analysis results shall address stakeholder requirements and be capable of undergoing translation to address different stakeholder perspectives.

- **Codify objectives, requirements, and constraints** for the analysis itself and for managing the analysis. This includes using appropriate case definition and acceptable analysis products, as well as criteria that ensure suitability and effectiveness of the analysis when the analysis is complete. It is recommended that a concerted effort be made to identify which requirements are firm or soft and what conditions enable change.

- **Obtain sufficient system and environmental definition** to conduct the analysis cases. This includes defining analysis boundaries, necessary assumptions, rationale, frequency and depth of analysis, interactions required with other analyses, and capabilities of the toolset.

- **Identify control and decision points** to manage analysis methods and tools effectively. Established exit criteria for each phase of analysis are useful.

- **Understand data flow and organization needs** associated with the analysis.

The Integrity of Analysis process tasks appear in Figure 4.9-4. Once the needs are understood clearly and addressed, the foundation is laid for managing the analysis set to obtain the needed results, which then serve as the basis to generate the AMP, as described in Integrated Technical Planning (Section 4.2).

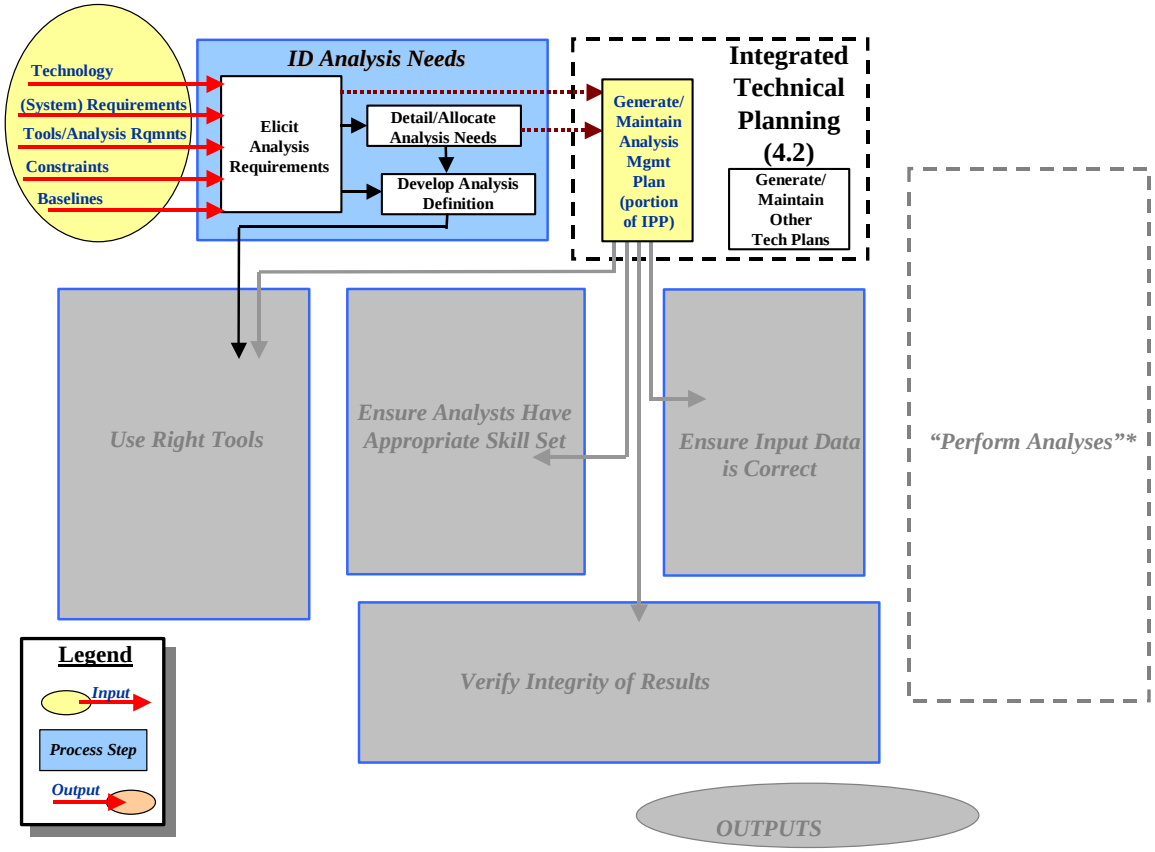


Figure 4.9-4. Identify Analysis Needs

Early analysis planning is key to program success. The quality of the analysis effort across the program is augmented by developing the program's AMP, a living document that manages and controls program analysis activities. The plan typically begins with a clear statement of project management goals, philosophies, and policies, followed by data to support planning for the analyses to be performed. The analysis needs are frequently a balance between the desires and costs of analytic excellence (usually championed by the analysts) and the cost/risk/benefit constraints of the program's budgets, schedules, and goals.

The AMP identifies required levels of analysis and the data to perform an analysis, defines procedures for ensuring analyst competency, contains details on the subset of analysis methods and tools that may be used for a validated analysis, and defines the criteria to ensure integrity of the analysis results. The AMP provides specific tailoring required by the project. The plan provides specific tailoring required by the project and is updated when a new tool is validated on the program or when a currently validated tool is updated to reflect a change in the product design and is subsequently revalidated. Because new methods and tools may be needed for product variants, and because multiple versions of a product may exist concurrently, the AMP may contain reference to multiple validated versions of the same tool.

4.9.3.2 Task 2: Ensure the Right Tools Are Used

Developing meaningful system performance and cost estimates, establishing the associated system performance and design requirements, and defining acceptable tolerances may be

accomplished only if analyses and performance models/databases are well defined and controlled and demonstrate validity. In addition, it is essential that analysis tool/model changes, updates, and predicted performance variances are properly identified and tracked over time. Independent but related tools/models and simulations also be validated by comparison with a single reference baseline to ensure consistency of results.

An excellent and frequently stated guideline for choosing a tool/model is to select one that provides the most visibility into the problem but has the least complexity. It is recommended that practical tools/models include only features that are necessary for exploring the interactions between the study, object system, and its environment. There are many inhibitors to applying this guideline. Familiarity with a tool or a model often biases use of the tool. Lack of familiarity, inadequate training, or a "not invented here" syndrome may cause analysts to avoid a tool. The customer may expressly require use of a particular simulation tool or model. Management may demand that a single model be used throughout the program's life. A sound SE approach to select the right tool may overcome a number of these inhibitors. To ensure the proper selection of a tool, it is recommended that the requirements of the analysis be considered, including:

- Analysis objectives
- Required level of fidelity and accuracy
- Cost controls
- Schedule constraints
- Need for additional resources

Analysis needs are allocated to tool components. Allocation includes assessing the level of fidelity required for each study function. For example, one study may require high fidelity if thrust, fuel flow, and range are being assessed, but lower fidelity in target selection. Tools that satisfy the functions and allocated study requirements for the model may be selected from

existing tools, modifications to existing tools, or by the creation of new tools (Identify Candidate Tools task). Each tool shall be examined to verify its ability to meet the analysis needs of the project before it is selected for use. Existing tools may not provide the functionality needed for the analysis. Under these circumstances, the project is faced with modifying an available commercial-off-the-shelf product, developing a proprietary tool for that application, or reconsidering the analysis scope. This evaluation shall be performed periodically to ensure the tools continue to satisfy current project requirements. In addition, analysis shall be performed to assess the availability of new technology in tools, as it becomes available, and determine when it is prudent to switch to the newer technology, factoring in the costs of migration in terms of people, time, and money. The considerations for selecting the right tool(s) appear in Figure 4.9-5 and discussed in detail below.

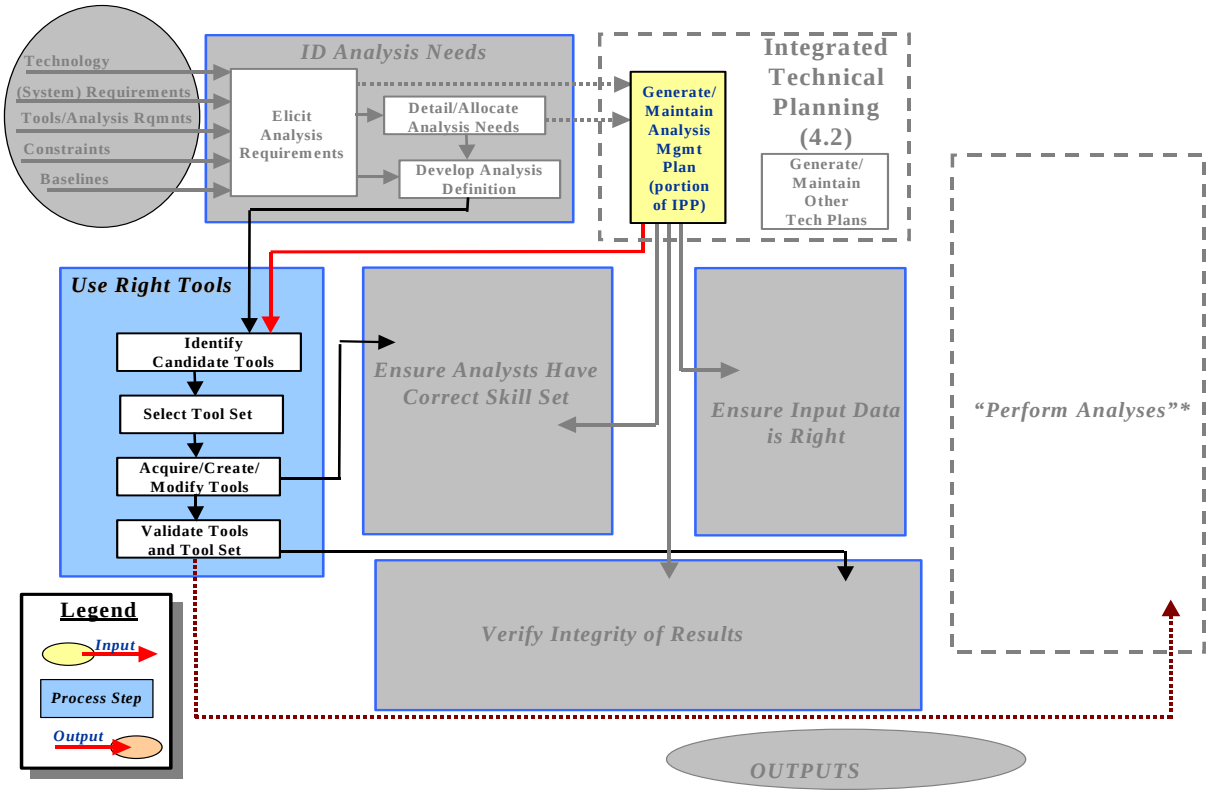


Figure 4.9-5. Use the Right Tools

4.9.3.2.1 Tool Fidelity

One of the more confusing aspects of proper model selection is fidelity. High fidelity and high visibility into cause and effect are usually contradictory goals for a tool. As fidelity increases, basic top-level interactions and characteristics become obscured, which is particularly true of tools that incorporate random choices. Even in totally deterministic tools, the decision logic may become so complex that the visibility is lost. Occasionally, high fidelity may block goal achievement. High-fidelity tools often provide more than is realized and analysts remain blissfully unaware of the true causes of model results.

For practical reasons, such as cost and schedule, the best choice is to use the least fidelity possible, but a model that still includes the desired effects. One shall constantly look for interactions between system components and the environment that require modeling at a higher fidelity. If the system under study includes a human decision process, then one of the best places to determine such interactions is by talking to people who operate the real system to determine what things they attempt to use to their advantage or what they attempt to avoid. A common belief is that all man-in-the-loop models are high fidelity and very complicated, which is not necessarily the case. In one example recently used by a military contractor, aircraft, ships, and missiles are point masses with movements constrained by very simple tables or equations. Sensor capabilities are modeled by simple equations that are one step above cookie-cutters. Interactions with the environment, such as earth curvature and atmospheric attenuation on infrared sensors, are modeled equally simply. This example surfaced because of a deliberate attempt during requirements allocation on a specific project to emphasize human decision

making rather than hardware modeling. It is a good example of breaking the traditional mold with an inexpensive alternative that fully satisfies study needs.

At the other extreme, lack of fidelity may also distort answers. Operations analysts have used a series of air-to-air combat models to answer questions about issues such as the value of increased thrust in fighter aircraft. The early versions of these models used cookie-cutter launch envelopes for the missiles with no provisions for infrared (IR) signature and missile-seeker effects. Head-on engagements with IR-guided missiles resulted in mutual kills. As a result, increased maximum thrust for close-in maneuvering combat on current generation aircraft like the F/A-18 or F-16 showed little improvement in expected kills and losses (two of the standard measures of effectiveness for combat aircraft). When moderately realistic IR features were introduced into the model, pilots were given the opportunity to reduce thrust in head-on situations and evaluate the results. Suddenly, the aircraft were spending about half of the engagement maneuvering in idle power to reduce the IR signature and increase survivability. Because there was much less time required to fly at maximum thrust to keep up aircraft energy (speed and altitude), the value of increased thrust over the shorter duration began to have a significant impact on the aircraft's effectiveness and survivability.

4.9.3.2.2 Use of Validated Tools

Validation dictates that **any** error incurred in the examination or study is within a tolerance band that ensures that results satisfy the expressed need to the agreed confidence level. **A validated analysis method or tool is defined as one that has been proven to provide credible results at the associated level of fidelity.** Validation may be performed using top-down or bottom-up techniques. Bottom-up validation is performed by comparing the methods and tool outputs, with varying sets of test case inputs, to the results of (1) another more complex validated model using the same test cases or (2) actual real world performance (i.e., telemetry gathered in an actual flight). Bottom-up validation via real-world performance is usually difficult because it is nearly impossible to determine the model inputs required to simulate the real-world system. Top-down validation ensures credibility by verifying the top-down structure and performance of individual components. The best choice for validation is top-down because the issues are better understood and there are fewer hidden assumptions.

For example, a software model that was previously validated to simulate a missile flight path without Global Positioning System (GPS) could be revalidated following the addition of a GPS receiver model in two ways:

1. **Bottom-Up Validation**. The overall results of the entire model (with the new software for GPS added) are compared to either another model or real world data.

2. **Top-Down Validation.** Only the new software component added to simulate the GPS receiver (i.e., by comparison to actual hardware) and its interface with the other previously validated software are validated.

Regardless of whether validation is top-down or bottoms-up, the algorithms and inputs used in the analysis tool shall be demonstrably correct and traceable back to their origin. It is a program management decision, and to what extent to use validated methods/tools. Examples of methods/tools that are candidates for formal validation include preflight modeling of unmanned aircraft/space vehicles, formal functional qualification testing, and Risk Management (Section 4.10). However, a significant amount of valuable analysis may be performed with unvalidated tools. Use of an unvalidated methodology/tool simply introduces the additional risk that the

results may have reduced credibility. Often, this risk is acceptable when weighed against the inconvenience, increased cost, or inability to meet schedule associated with forcing the analyst to use a validated method/tool. In most cases, a new or modified tool initially is used without validation and a decision is made later regarding whether to perform validation based on expected future use of the tool.

4.9.3.2.3 Tool Validation Process

Authorized analysis methods and tools are used over a broad spectrum of applications. Analysis tool validation is specific to the analyzed system(s) and performance for which the toolset is demonstrated. Both applicability and use are defined for every case validation. Situations may occur in which analysis data is required to support the program before full toolset validation. To address these situations, provisional and limited validations have been identified. Both types of validations exist to satisfy program needs for analysis data in advance of full validation; however, neither invalidates the need for full validation.

a. **Full Tool Validation**. Tools are validated when they have met all accreditation requirements, have been recommended for validation by the responsible organization, and been reviewed by the Configuration Control Board (CCB) responsible for the baseline involved (Configuration Management (Section 4.11) provides more information on this topic).

b. **Provisional Tool Validation**. Provisional validation may be granted when model performance has been essentially demonstrated, but compliance with all validation requirements has not been achieved.

c. **Limited Tool Validation**. Tool validation may be limited to indicate that performance demonstration for full validation is incomplete, though all data indicate that model performance is correct and consistent for a limited analysis. Documentation requirements may be tailored for limited validation.

The analysis toolset validation process supports and is key to the analysis oversight responsibilities of each implementing program. Validation is based on demonstrating model performance, analyzing toolset configuration management/controls, and documenting the analysis methodology. As part of the approval process, the program manager designates approval authority for formal validation, which may be accomplished by forming an Analysis Review Board, or through the Program CCB, as discussed in Configuration Management (Section 4.11). If an Analysis Review Board is established, its membership may consist of program management, a member of SE, and a member of each project team using the analysis tools. The Program Board (Analysis or CCB) reviews applicability and use for which the analysis tool suite is to be validated. The term CCB is used for this board throughout the rest of this section.

Once the analysis method/toolset has been authorized for use, the implementing program determines whether the toolset requires validation for its usage and the degree of validation. The degree of validation required varies with the lifecycle stage and other factors. Methods of validation include verifying the ability of the tool to provide answers for known test cases or to cross-check the results with other tools or methods for agreement.

The tool validation portion of the AMP specifies what is to be tested, how it is to be tested, and what comparisons are to be made to reference check cases and other data in validating the analysis methods and tools. Reference check cases allow the responsible organization a comparative way to demonstrate that a toolset may be validated. It is recommended that comparison of analysis data to reference check case data be included as the first step in any validation plan. To complete validation, the responsible organization may propose any cost effective combination of the following methodologies listed in order of decreasing priority:

- Comparison of data with the real system
- Comparison to other analysis applications whose validation basis is actual test comparison
- Comparison of data with other validated toolsets
- Technical audit of toolset performance
- Demonstration of toolset capability

It is recommended that a sensitivity analysis be performed to characterize the behavior as each input is individually varied. The purpose for which the toolset is being validated is the primary concern in determining the mix of methodologies selected for validation.

Demonstrated performance refers to the ability of an analysis to produce results that compare favorably with results obtained from the system being modeled over common areas of performance. The responsible organization proposes its performance demonstration as part of the AMP. The overall demonstration shall be controlled by a matrix that has analysis capabilities/characteristics on one-axis and test scenarios (demonstrations) on the other axis. This matrix identifies how each analysis capability/characteristic is to be demonstrated for the purpose of certification. Once all performance demonstrations have been completed and action items assigned to the responsible organization(s) are closed, the CCB reviews the toolset validation package for completeness and assesses the need for further review before approving the validation package. In addition, a validation test matrix, which provides the CCB with a guide to validation requirements and completion status, is developed by the responsible organization. This test matrix is provided as part of the validation plan and is used by the CCB at subsequent review meetings to track validation completion status.

4.9.3.2.3.1 Validation Approval Package

The final validation package shall conform to the approved AMP. Approval of the following documentation is required as part of the Analysis toolset validation process:

a. AMP

b. Configuration Control Plan sections related to analysis toolset control

c. Analysis certification report

d. Analysis tool users manual

e. Analysis tool version definition

A member of the responsible organization presents the validation package to the CCB for final approval. Once the package has been approved, the responsible organization is provided with a signed validation certificate.

4.9.3.2.4 Validated Methods and Tool Configuration Management

The responsible organization maintains Configuration Management (Section 4.11) and controls the validated set of tools. All validated methods and tools are under configuration control and are documented in the approved Program Analysis Management and Configuration Management plans. Validated tool Configuration Management shall ensure traceability of all changes to validated tools over time, identification of the specific versions of the toolset used to develop analysis results, and the specific configuration of embedded hardware/software subsystems or components being modeled.

4.9.3.2.4.1 Criteria for Analytical Tool Validation Update

Changes within the analysis toolset that do not introduce changes to modeled systems or their performance domain do not require a validation update as long as regression testing demonstrates identical results. The responsible CCB defines specific validation update requirements for each analysis toolset as part of the review. The following guidelines are used to determine if validation update is required:

- If the analysis tool revision creates significant differences in analysis results, applicability, or use
- If there is significant program visibility and community interest in a functional characteristic which was modified
- If there are significant hardware/component changes to the systems being addressed that impact reference models, databases, or simulations
- If change accumulations account for a significant deviation from the previously validated baseline

If required changes impact more than one tool or model, the responsible CCB may ensure that all affected tools/models are appropriately revised and that changes installed continue to provide comparable analysis results. In every case, the responsible CCB may reassess the applicability to determine if the changes are required.

4.9.3.2.5 Analysis Reference Standards System

Analysis results are not expected to precisely replicate results from the modeled system(s). Additionally, analysis results may not be consistent among themselves. Analyses are compared to a standard reference set of baselines to ensure consistency of results when they are used to substantiate and evaluate specific areas of system performance. Only reference analyses, reference models, and reference databases are employed as performance or design baselines.

4.9.3.2.5.1 Reference Analyses

A set of authorized, validated analyses (certified in the case of simulations) is established as reference analysis methods. Accreditation of reference methods usually includes validation using actual test data. Reference simulations serve as the principal performance baseline(s) for the appropriate CCB action and provide a point of departure for derived analyses that may be used to establish the effect of proposed system design changes or to assess system sensitivities. Reference analysis methods typically include reference models and/or databases and are used to generate reference checkcases.

4.9.3.2.5.2 Reference Models

In cases where overlap exists between elements being modeled by more than one validated tool, the function modeled in one particular validated tool is identified by the CCB as a reference model. Reference models are established to capitalize on primary expertise in specific areas of performance and to provide consistency at the subsystem level. Reference models shall be segregated, validated, and made available to the analysis community.

4.9.3.2.5.3 Reference Databases

Reference databases are established in cases where there is no advantage to modeling a subsystem function. Reference databases are created by a model that is used to generate tables of values that constitute the database. The database then represents the selected subsystem performance through tabulated values. Reference databases are established by the responsible CCB to provide consistency at the subsystem level, take maximum advantage of specific areas of expertise, and simplify analyses.

4.9.3.2.5.4 Reference Checkcases

Reference checkcases are selected, reviewed, and distributed to each CCB and are available to the responsible organizations as the basis for certification comparison. Reference checkcases are generated by reference analysis methods, often are based on actual test events, and include relevant inputs, initial conditions, assumptions, and expected outputs in a form (e.g., hard copy and/or electronic media) usable by each responsible organization.

4.9.3.3 Task 3: Ensure Analysts Have Appropriate Skill Set

The previous paragraphs on using the right tools addressed the level of confidence required for each analysis, as stated in the AMP. Part of that confidence, from a programmatic sense, is derived from the proficiency of the analyst. Quantification of that component of confidence may be difficult or impossible to precisely determine, but qualitatively it shall be addressed. There are three elements involved:

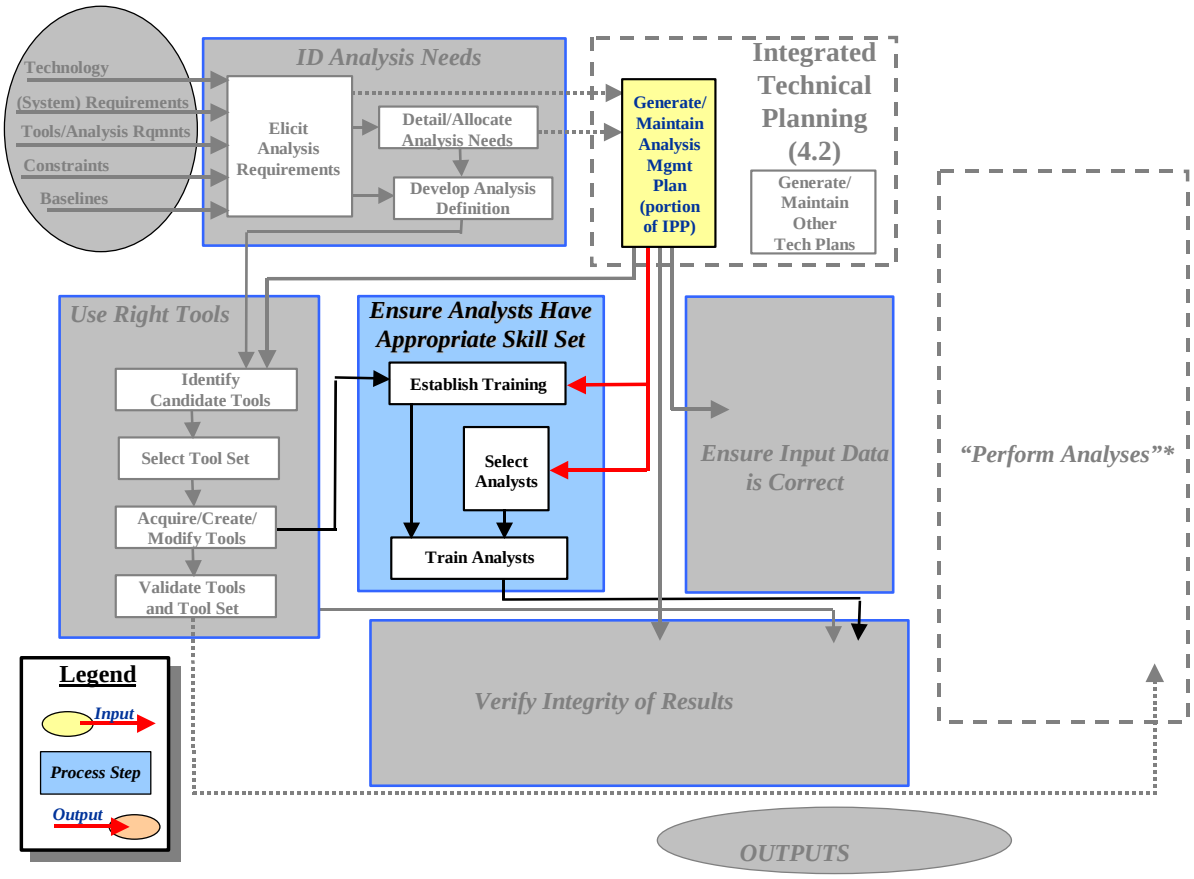


Figure 4.9-6. Ensure Analysts Have Appropriate Skill Set

(1) establish the training required, (2) select the analyst(s), and (3) train the analyst(s) based on a gap analysis between the skill set required to perform the analysis and the skills the analyst already possesses.

The AMP shall describe the approach to be used for each analysis to ensure that the analyst possesses the necessary level of proficiency to perform the analysis. Such approaches include:

- Acceptance of credentials (e.g., validated professional degrees, personnel performance reviews, known track record) or stipulation by supervisors. The currency of such information is important—this aspect is addressed in the "Establish Training" element.

- Training accomplished within a defined previous period (and whether subsequent test or demonstration of performance validated such training). In the sense of on-the-job training, a policy of ongoing revalidation of analysts is useful, if for no other reason than to maintain a current roster of analysts and their credentials.

- Satisfactory performance in a validation trial to be judged against prescribed target results.

An extreme case, in which the program may be at great risk unless a particular analysis has a very high confidence, may lead to the need to: (1) to certify analysts as world-class experts in using a particular version of the tool to be used; (2) ensure that the experts have recent experience in its use in a very similar application; and (3) require a number of identical but independent analyses by different but independent analysts to produce results within a specified tolerance of each other, or against a reference case or test data. An example would be the thermal analyses that were required early in the International Space Station program that were necessitated by a proposed change in orbit inclination coupled with a major change in assembly sequence in orbit.

For the purposes of this manual, programmatic issues as well as purely technical issues are included. Consequently, it is appropriate to discuss the distinction between competence and proficiency. Competence deals with one's ability to achieve excellence in results, no matter how much it takes. Analysts may be distinguished on the basis of the ease, speed, and/or clarity with which their results are produced. No guidelines are offered herein, but it is recommended that the matter be addressed in the AMP.

Another evaluation method is the technique of "peer review." The practice of using a nearby colleague (typically of approximately the same competence) to review the analysis has been shown to be useful. In analytic work, the opportunities for simple neglect or even typographical errors are great, and it is impossible to easily detect personal errors; however, with peer review, these kind of problems are more easily found. An analyst may believe himself/herself capable of a certain job (and credentials may imply that), but peers may discover that his/her sphere of expertise does not include the analysis in question. (The most dangerous situation is often when one does not realize what he/she does not know.) The AMP documents the implementation of program management's policies in this area. This process task appears in Figure 4.9-6.

4.9.3.4 Task 4: Ensure Input Data Is Correct

It is ultimately an analyst's responsibility to determine that the data used in an analysis is appropriate for that analysis. This responsibility then flows upward in a program and organization, and the AMP addresses how that member's responsibility shall be supported. Special attention shall be paid to instances where analyses need to be merged or where one analysis provides input data for use in subsequent analyses. In such cases, it is especially necessary for analysts to use compatible data that agree in quality and type. The considerations involved are shown in Figure 4.9-7.

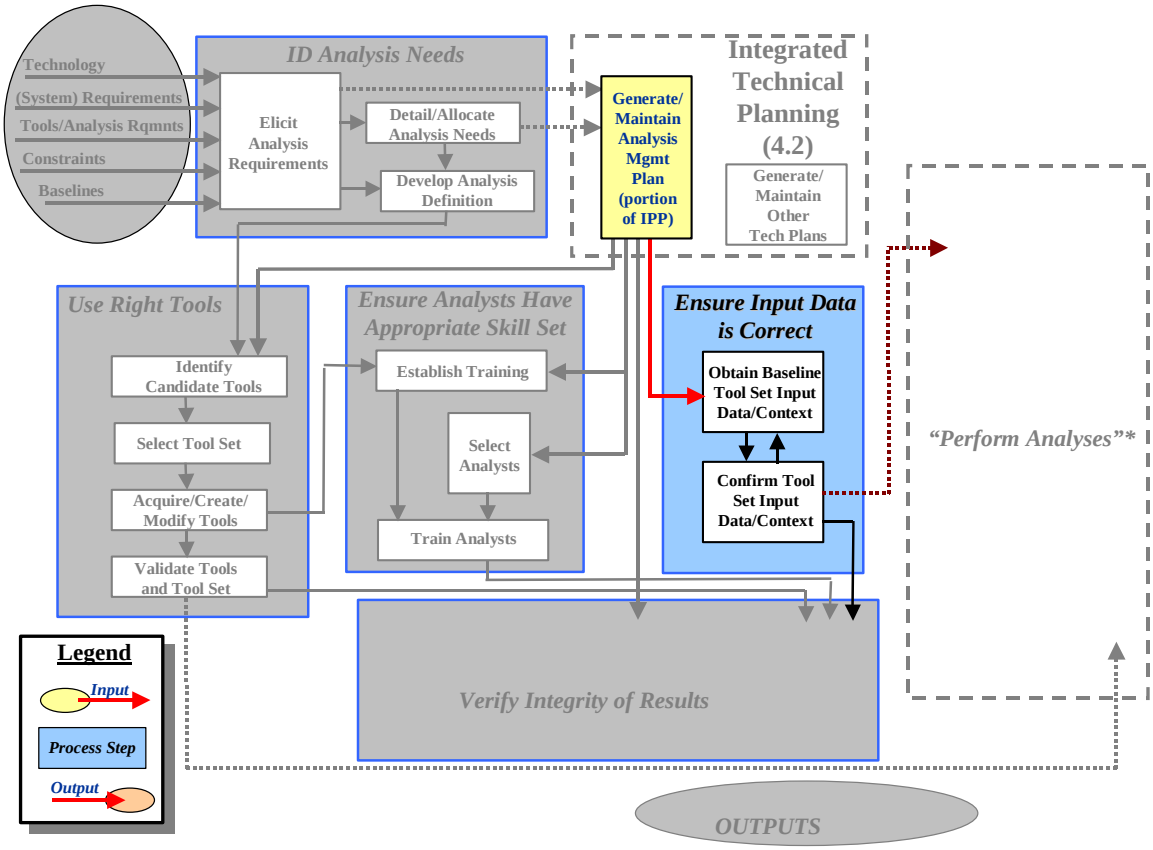


Figure 4.9-7. Ensure Input Data Is Correct

4.9.3.4.1 Data Sources and Control

The AMP specifies acceptable sources for each **kind** of data: general or universal data (such as atmospheric properties); corporate data (possibly proprietary, such as material properties or design limits); and program-specific data (tradeoff factors such as the partial derivative of aircraft range with respect to takeoff weight for a nominal mission). Organizational standards and libraries may exist that may be referenced, and a program may supplement those with program-unique data or define its own. The object is to provide baselined data and configuration control of that baseline by the process defined in the program plan. Using baselined data results in traceable analytic results. The consistency derived from all analysts using the same baselined data produces results may be confidently merged, compared, and/or interpreted. Besides the issue of where the data physically resides and from where it may be retrieved, there is the need to document and control the identification of the data's original source. If it represents measured data, its measurement error, range of uncertainty, or confidence interval shall be recorded.

4.9.3.4.2 Data Quality

One factor that shall be determined for each planned analysis is the **numerical confidence interval** that is acceptable in the results, which, in turn leads to a requirement for precision, accuracy, and granularity of the input data, as well as its treatment within the algorithms. Note

that granularity includes the effect of decisions regarding the number of significant digits to be used. (There is no difference between declaring Pi to be 3.14 and defining it as the ratio of a circle's circumference to its diameter if both are measured to 3 significant digits.) Where the scope, required level of precision, or coarseness of an analysis calls for it, the AMP shall specify how baselined data may be approximated or granulized.

4.9.3.4.3 Documentation of Data within Analyses

An analysis is ultimately credible if it is able to be independently repeated. When repeatability is considered, it is clear that part of that ability is knowing exactly what data was used to create the first result; therefore, that data shall be carefully documented. The source, pedigree of validation, and extent of accuracy, precision, and granularity shall be documented, and the reader shall have the confidence that **all** the data were considered, even constants and parameters that are frequently forgotten, especially if they may have been **"**hard-coded**"** within a relation or equation.

4.9.3.5 Task 5: Perform Analysis

The actual analyses performed are described in the other sections of this manual. The Integrity of Analysis process supports the other SE processes and is intended to provide a disciplined framework for conducting any required analysis, whether technical, programmatic, or administrative in nature. The interaction between the Integrity of Analysis process and the actual performance of analyses appears in Figure 4.9-8

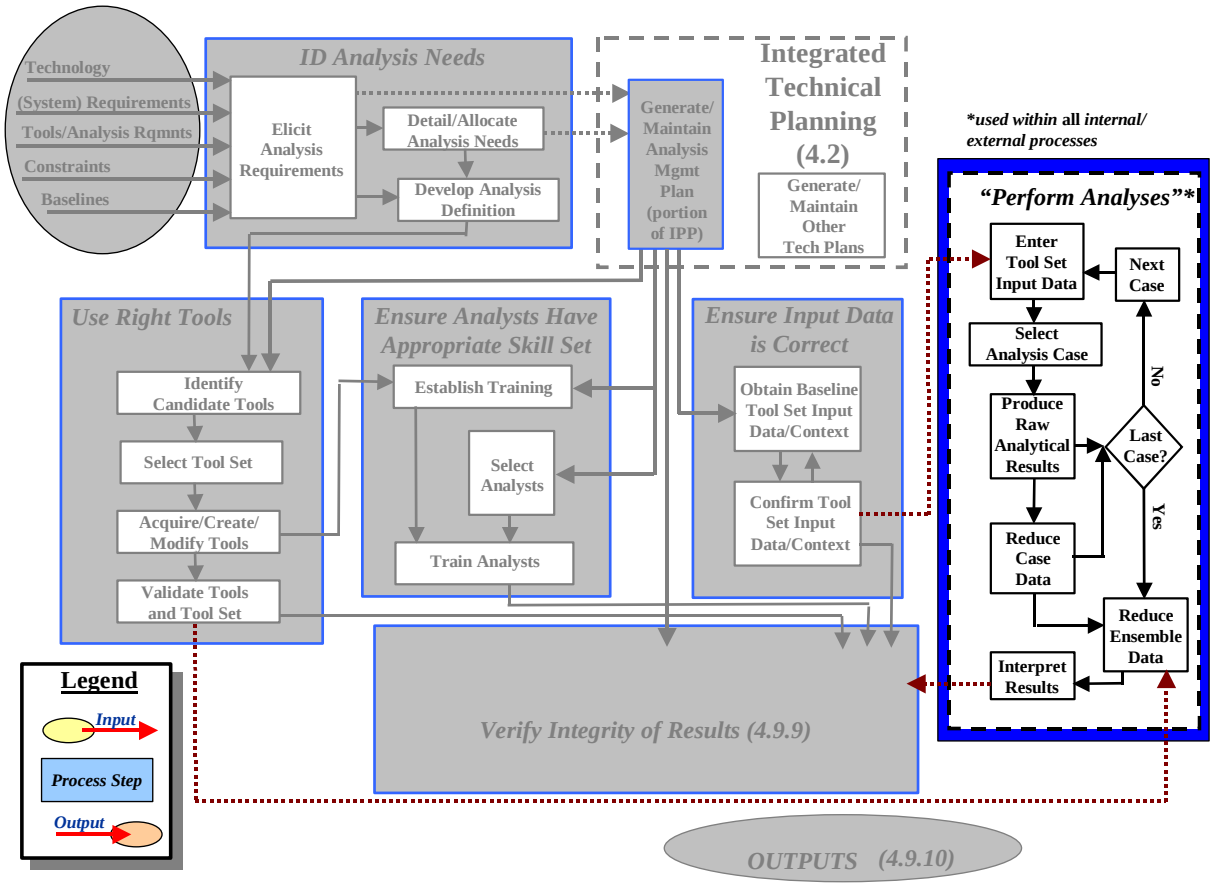


Figure 4.9-8. Perform Analyses Reference

4.9.3.6 Task 6: Verify Integrity of Results

In general, an analysis is useless unless it may be independently repeated; therefore, the inputs and all underlying assumptions shall be documented. It is recommended that criteria be established in the AMP for each type of analysis to ensure that the results are accurate, correct, and sufficient. The criteria are enforced by developing, validating, and using analysis templates. Comparing results from two or more truly independent analyses may be performed to achieve confidence in the results when the accuracy and/or validity of the analysis tools and methods have not been proven. The greater the independence of the individual analyses, the greater the confidence in the validity of the result.

Sufficiency of the analysis shall also be addressed: Did the analysis consider the entire envelope of interest? Were the selected portions of the envelope adequate to draw a proper conclusion? Did the analysis account for all significant effects? In rare cases, it may be necessary to perform an analysis to determine precisely which effects need to be considered to substantiate the results of an analysis.

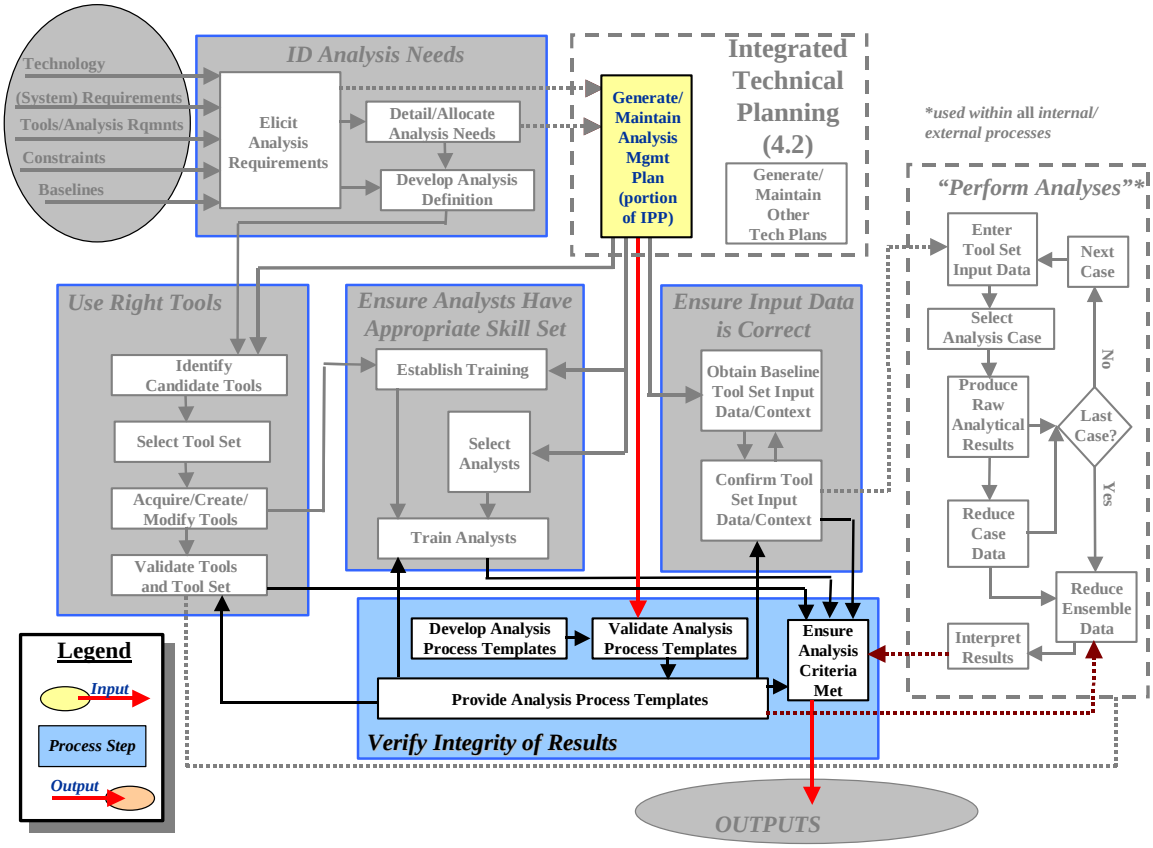


Figure 4.9-9. Verify Integrity of Results

- Even though a modeling technique or simulation tool has been proven to be completely accurate, errors may still be present in an analysis. Errors in an analysis may be caused by omitting terms that have a significant effect on the result, using the wrong input data (e.g., wrong atmospheric model), and misinterpreting/misunderstanding input data (e.g., wrong units, wrong reference coordinate system). Independent analysis may catch these errors only if there is no collaboration between the analysts. The criticality of the results of the analysis should determine the degree of verification justified.

- Another type of innocent error is caused by an analyst's misunderstanding of the problem statement (i.e., requirements). In this case, a completely valid answer may be presented to the wrong question.

- An analysis may be nothing more than an opinion poll. Evaluating the characteristics of the population considered only ensures this accuracy of this type of analysis.

- Ultimately, the results are verified by users per the original plan. If the results are insufficient, then a root cause analysis is performed where appropriate. The outcome of this analysis may result in the original analysis being reconducted by modifying:
  - Methods
  - Tools

- Inputs
- Users

4.9.4 Outputs of Integrity of Analyses

The two major outputs of this process are analysis criteria captured in the AMP and credible analysis results (Figure 4.9-10). In addition, any residual issues/concerns generated by this process are furnished to the Risk Management process (Section 4.10) for resolution. Any constraints driven by tool selection, skill requirements, or other programmatic considerations documented in the AMP are furnished to the Trade Studies process (Section 4.6) to assist in defining the appropriate trade space.

4.9.4.1 Analysis Criteria

The AMP is used to specify the analysis philosophy to be imposed. It is recommended that every analysis be understood as being bounded or constrained by all the pressures implied above. It is important to capture these issues in the AMP so that aspects such as the following are treated in the plan

The degree of validation required for each tool and type of analysis shall be specified. Tools as simple as an Excel spreadsheet or as complex as man-in-the loop simulations may be used to support programmatic decisions. A method shall be developed to verify that the correct equations are used for the analysis and that they have been properly implemented in the spreadsheet. Whatever the tool, the plan specifies the procedure for acquiring/developing, maintaining, and validating that tool. Typically, a program has a configuration control function (its own, or some core organization's) from which validated tool lists may be drawn and referenced.

- Methods shall be specified to ensure that analysts are proficient in using the tools and executing the analyses. This consists of providing proper documentation, training, and review procedures.

- Methods and analysis criteria shall be specified to ensure that data of the proper quality and range, from documented sources with valid pedigrees, are under configuration control and, thus, traceable when referenced by the analysis documentation.

- The required level of documentation for each type of analysis shall be specified, usually in the form of templates. Formal analysis shall provide sufficient documentation to permit reconstruction of the results from the input data. Quick analysis used to rule out a possible system design may not require the level of documentation or substantiation as analyses that are required to support the final system configuration.

- The review policy for each type of analysis shall be specified.

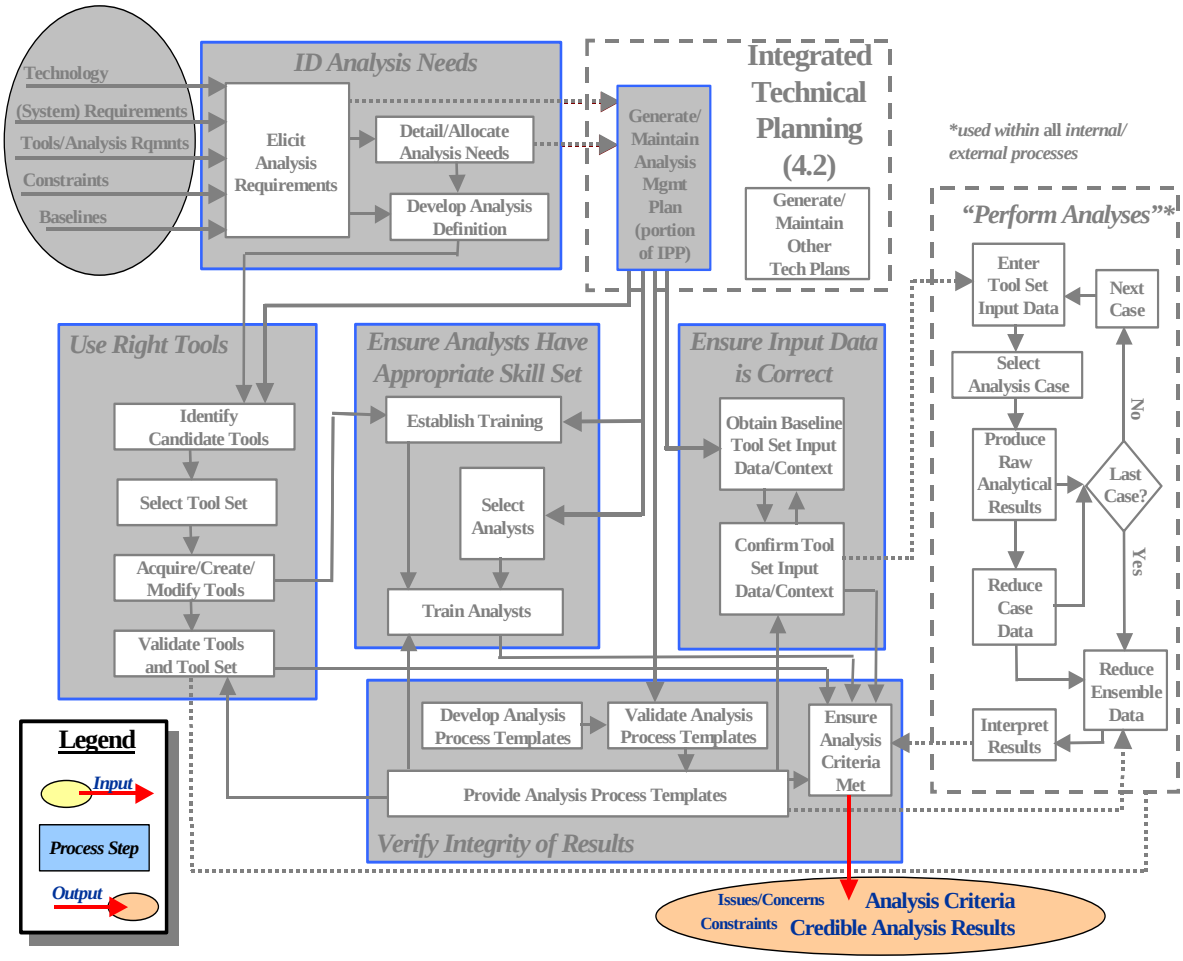


Figure 4.9-10. Integrity of Analyses Outputs

4.9.4.2 Credible Analysis Results

Simulated results are not expected to precisely replicate results from the simulated systems. Additionally, analysis results may not be consistent among themselves. Models shall be compared to standard reference baselines to ensure consistency of results when employed to substantiate and evaluate specific areas of system performance. Only reference simulations, reference models, and reference databases may be employed as performance or design baselines. Analysis results are meaningless without description of the analysis method and the assumptions that generated those results. If the tool version used to generate the results is not validated, the differences between the validated version and the version used, as well as the validation plans for the new version, are also to be presented.

4.9.5 Integrity of Analyses Process Metrics

There are four general measurement categories that are applicable to Integrity of Analyses, and they are shown in Table 4.9.1, along with candidate measures for analysis management. It is recommended that each effort tailor these measures and add other project-specific measures that are applicable to ensure that they contribute the necessary information to the decision-making processes.

Table 4.9-1. Integrity of Analyses Measurement Categories

Schedule and Progress	Resources and Cost	Product Quality	Process Performance
Percent of analysis tasks completed on schedule	Existing validated model is ratio of analysis to total hours **(Total** = analysis hours + verification hours.)	Percent of analysis "passing" verification step (first pass)	Average number of days to complete analysis (per same tool and complexity).

Example of common issue areas, measurement categories, and sample measures.

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4.10 Programmatic Risk Management (*Satisfies iCMM process area 13 criteria*)

4.10.1 Introduction

The Perform Programmatic Risk Management process (Figure 4.1-10) provides an organized, systematic decision-making process to effectively deal with uncertainty in accomplishing program objectives. **Risk is defined as a future event or situation with a realistic (non-zero nor 100 percent) likelihood/probability of occurring and an unfavorable consequence/impact to the successful accomplishment of the well-defined program goals if it occurs. Risk Management is an organized, systematic decision-support process that identifies risks, assesses or analyzes risks, and effectively mitigates or eliminates risks to achieve project objectives.** A risk creates *risk exposure* for a project based on the combined effect of its likelihood and consequence. It is recommended that the process be applied at all levels, from small projects to large programs, and be applied continuously throughout the program's lifecycle looking at all aspects of the program (see Figure 4.10-2). The risks shall also be capable of being "rolled up" from a project or several projects to a program. Risk roll-up involves a review of the consequences/impacts from a higher (program) level. The risks to meeting the objectives or benefits of these projects or programs are typically known as programmatic risks, though the source of these risks may be external to the program itself. This process complies with the requirements of the integrated Capability Maturity Model (iCMM) (Process Area 13). It also satisfies Electronic Industries Alliance (EIA) 632 requirement 24 and EIA 731 Focus Areas 2.5-2 through 2.5-8.

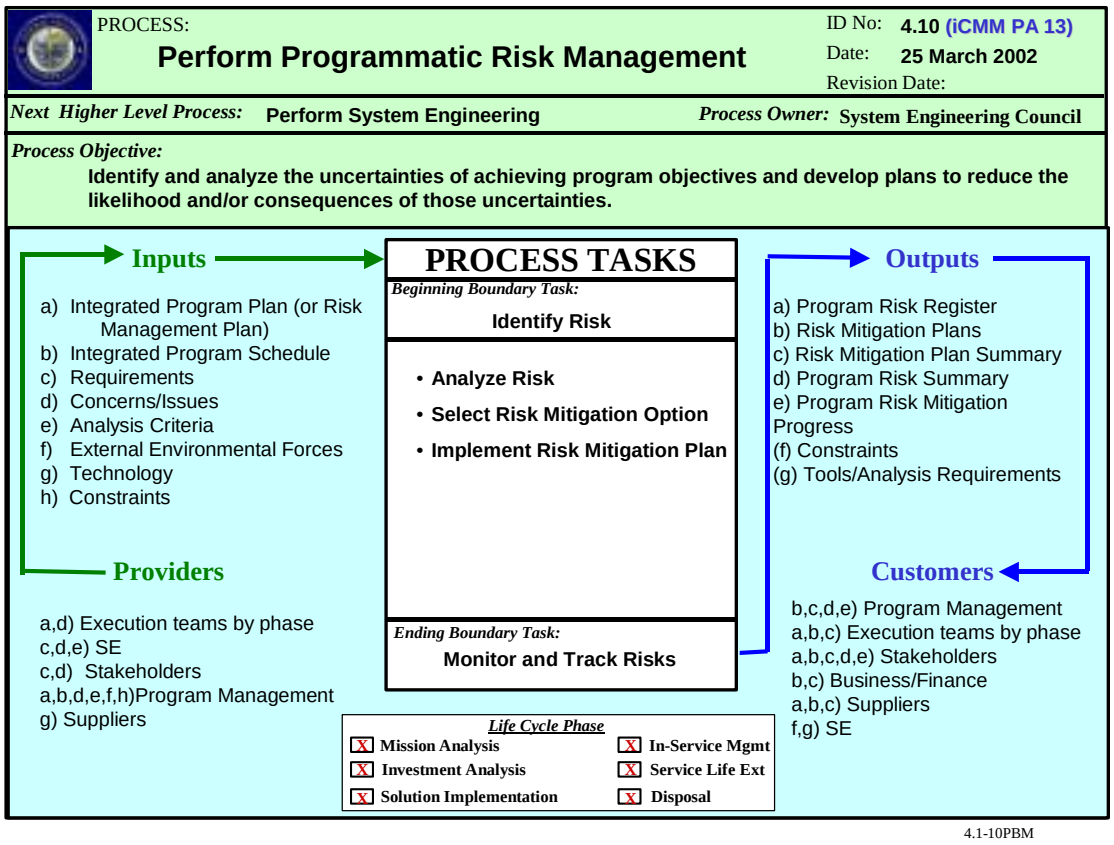

Figure 4.10-1 Risk Management Process-Based Management Chart

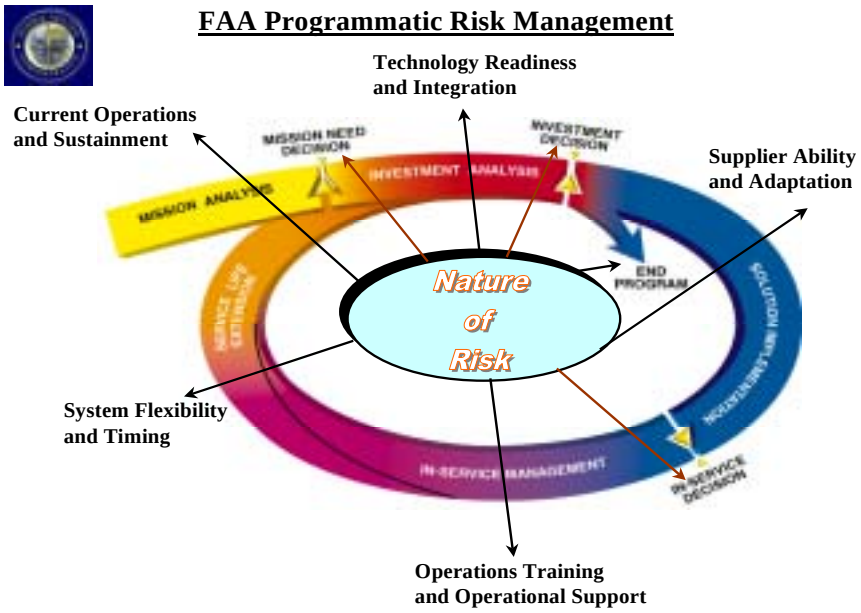

Figure 4.10-2

4.10.1.1 Function of Programmatic Risk Management

Programmatic risk management is a basic system engineering element of successful program management (Figure 4.10-3). When properly executed, Risk Management engages all disciplines and execution teams and is present in all program stages/phases. The functions (Figure 4.10-4) of the process are to:

- Identify each risk to the program
- Analyze and assess the negative consequences/impact and the likelihood/probability of the risk actually occurring and determine the risk realization date
- Develop specific approaches and plans to mitigate the risk
- Implement the risk-mitigation plan
- Monitor and track risk-mitigation effectiveness

Based on results from these functions, program management may then determine:

- The amount of schedule and budget reserves to be allocated and to what, based on identified risks
- How to measure overall program performance with respect to each risk
- How much and what type of help is to be needed from other sources
- When to look at the process to see if the mitigation effort is working
- When to add mitigation efforts, costs, and milestones to integrated program schedule and budget

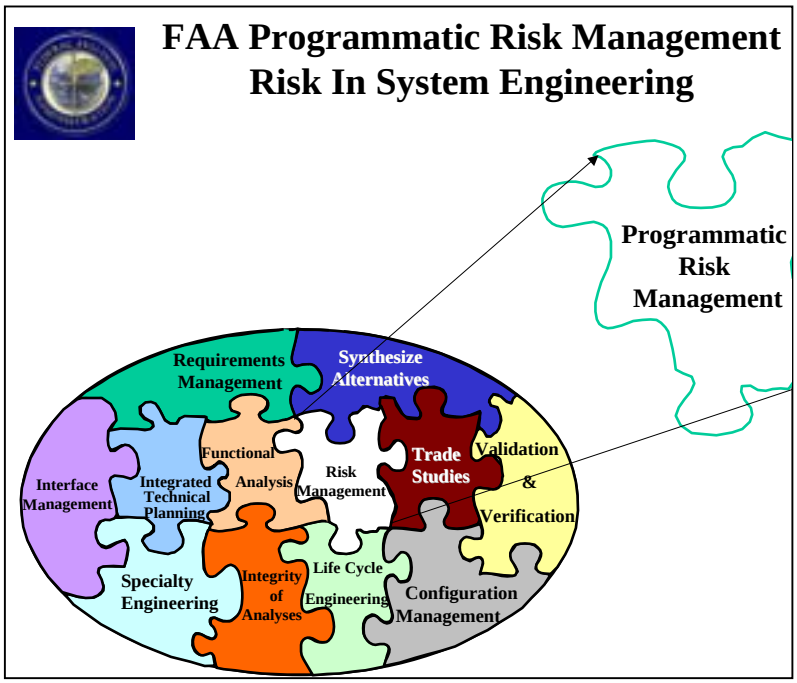

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Figure 4.10-3

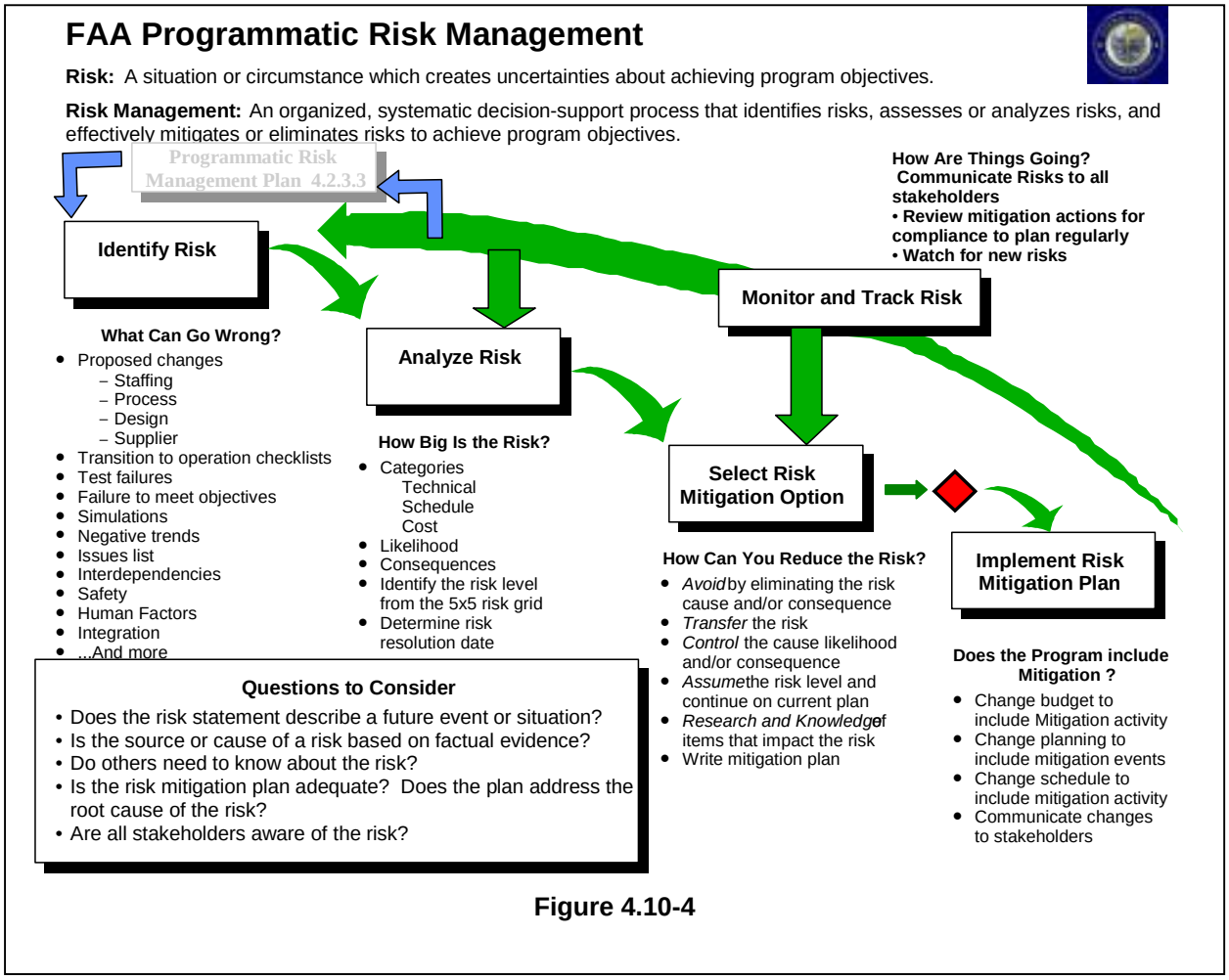


Figure 4.10-4

4.10.1.2 Objectives of Programmatic Risk Management

The fundamental objective of the Programmatic Risk Management process is to identify and analyze uncertainties of achieving program objectives and develop plans to reduce the likelihood and/or consequences of those uncertainties.

This process is applied to ensure that a program meets technical, schedule, and cost commitments; delivers a product that satisfies all stakeholders' lifecycle needs; and provides the expected benefit. Four lower-level objectives are established as part of meeting the overall objective:

- Timely identification of risks (identifying a potential problem with sufficient leadtime so the team may implement appropriate alternate plans)

- Consistent assessment of the level of risk across a program (providing a structured decision-making framework for prioritizing resource application)

- Communication of risk-mitigation actions across the program/project (ensuring that all elements of the program/project are aligned in resolving risks)

- Review of risk-mitigation action performance

4.10.2 Process Description *(Satisfies iCMM PA-14, BP13.04 criteria)*

Every participant in a program/project shares the responsibility of assessing and mitigating risks. The process is a part of the overall program/project management and system engineering process. This process shall be aligned with the individual products (hardware, services, and software) that result from consistent functional analysis and requirements allocations, the Integrated Program Plan (IPP), the integrated program schedule, the associated funding, and the identified goals and benefits. The program is assessed as to risks associated with impacts on program benefits, interdependent programs, or environments. For each product, risks are evaluated against the acquisition baseline technical requirements, schedule, and cost leading to the successful satisfaction of the program objectives. Risks are identified, assessed, and appropriate risk-mitigation actions are established that comply with the program/project risk management plan within the IPP (see Paragraph 4.2.2.2 in Integrated Technical Planning (Section 4.2)). This plan is developed and tailored (when the technical nature of the program demands tailoring) to satisfy the specific program/project needs (see Section 3.5.7). ***(Satisfies iCMM BP 13.01 criteria)***

Results from each assessment are a starting point for the risk-mitigation plan to support program management decisions (technical, schedule, and cost). The products of this process are also shared with stakeholders to achieve alignment/acceptance of the resource decisions. All risks are examined at each program/project/event/item/peer review as defined in the risk management plan. Updates reflect changes in risk resulting from planned mitigation activities or other unplanned events. Risk progress is actively tracked. For each risk, a "risk realization date" is established, marking the point in time when either the risk no longer exists or when the program shall be modified to accommodate the negative consequences. The question to be asked and answered is: "What happens on this date?" Risk is "rolled up" when it is taken from a lower-level project to a higher-level program.

An essential element of the Programmatic Risk Management process from an organizational point of view is the non-advocate concept. The purpose of a non-advocate is to provide an impartial, objective assessment of the project team's results, especially with respect to the assignment of risk levels. The input of a non-advocate is essential on those projects where two or more of the project specialists disagree on the risk levels. A non-advocate would typically be, but not be limited to, a program management person (above or at the same level of the program/project manager), a stakeholder representative, and/or a person from another project or program. The responsibility of a non-advocate is to examine and assess all aspects of the program/project risk management process before each review. For small projects, one or two non-advocates may be acceptable. A non-advocate provides an assessment to program/project managers for consideration and action.

4.10.2.1 Overview

The top-level process for Programmatic Risk Management is shown in Figure 4.10-1. The process includes steps that result in the identification of potential risks, analysis and assessment of risk, development of risk-mitigation plans, implementation of the Risk-Mitigation Plan, and monitoring of risk status. The process is iterative and is used across the program throughout the program's lifecycle, with the nature of the risks changing to coincide with the lifecycle stage. Specific knowledge domains implement variants of this process to fit their specific needs and environment. However, all domains effectively perform Risk Management as shown in Figure 4.10-4.

4.10.2.2 Inputs

The inputs required to initiate Programmatic Risk Management include both program/project- and product-related data as shown in Table 4.10-1. Many of these inputs are developed and refined through the continuous, iterative use of other system engineering processes. Each item in the table is to be evaluated for resultant program risk.

Table 4.10-1. Inputs to Risk Management

Input	Reference
Requirements Documents	4.3.3
Integrated Program Plan	4.2.1
System Engineering Management Plan (SEMP)	4.2.3.2
Risk Management Plan	4.2.2.2
Analysis Criteria	4.9.5.5
NAS Architecture	4.5.5
Trade Study Report	4.6.1.4
Design Analysis Report	4.8.4.3
Controlled Data and Reports	4.11.8
Contract	
Product Configuration Data	4.11.3
Acquisition Program Baseline (APB)	FAST
Acquisition Reviews	
Specialty Engineering Reports	4.8
Interfaces	
Test Plans and Reports	
Manufacturing/Production Information	
Resources/Budgets	

Input	Reference
External Uncertainties	
Technology	
Acquisition Strategy Paper	
Mission Need Statement	
Concept of Operations	
AMS Documents	
Technical Analysis	
Contractor Outputs	
Statement of Work	
Verification Results	4.12
Training Results	
Maintenance Results	
Lessons Learned	FAST
Operational Results	
Safety Assessments	
Security Assessments	
Human Factors Assessments	
Integrated Program Schedule	
Program Review Results	
System Safety Program Plan	4.8

4.10.3 Risk Management Process Tasks

The Programmatic Risk Management process is summarized in Figure 4.1-10. The major process steps shown in Figure 4.10-4 are described in the remainder of this section.

4.10.3.1 Task 1: Identify Risk *(Satisfies iCMM BP 13.02 criteria*)

Risk identification is a systematic effort to uncover possible events or conditions that, if they occur, may hinder achievement of program objectives. The process begins concurrently with program or project planning and continues throughout the life of the program. While risk events or conditions may have many different root causes (e.g., equipment interoperability requirements, maintainability and supportability requirements, installation deadlines, contractual arrangements), the identification process isolates those events or conditions that may affect program technical performance, cost performance, or the program schedule. At the conclusion of the identification phase of risk management, it is recommended that a program manager have a list of (uncertain) events and conditions that may affect program cost, schedule, or technical performance. Risk identification shall be performed during each stage of the program, or whenever significant changes occur in plans or program status. Circumstances requiring risk assessments include:

- Programmatic changes
- Unfavorable trends in Technical Performance Measures, predicted system performance, schedules, and financial status
- Design/Program/Peer reviews
- Change proposals (including proposed changes in requirements)
- Occurrence of a major unforeseen event
- Newly identified risks
- Special assessments at the direction of Agency Management
- Changes or risks in interdependent programs
- Environment changes

As shown in Figure 4.10-5, participants in risk identification include all stakeholders, users, suppliers, and appropriate members of execution teams. Teams consider all likely risk sources in identifying potential risks to the program/project. Risk identification is based on the current program/project goals supported by the associated technical, schedule, and cost requirements and plans.

A programmatic risk has two aspects: (1) the likelihood/probability that an event will occur and (2) an unfavorable consequence/impact if it occurs. It is recommended that the likelihood of a risk occurring not be so low as to be negligible (i.e., probability essentially equal to zero) nor be equal to 1, which typically indicates that it has, in fact, already been realized. A risk shall also have a negative consequence/impact if realized. Positive consequences are not considered in the FAA risk identification and analysis process; these are considered opportunities. Note that if

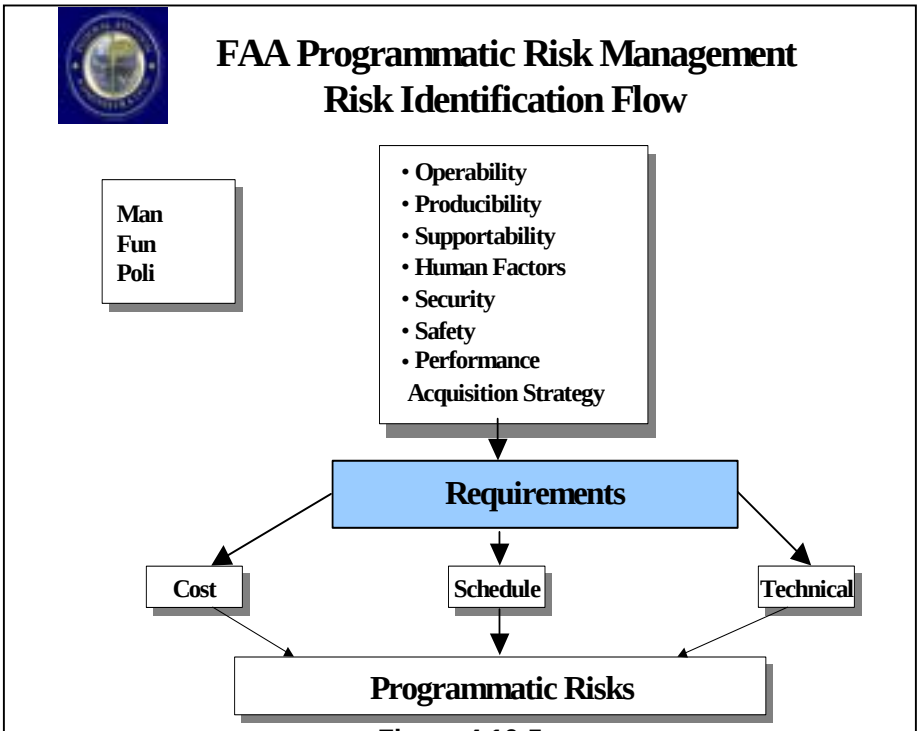


Figure 4.10-5

there is no uncertainty (i.e., the situation or circumstance is certain to occur or has already occurred), there is no risk even though the item has an unfavorable consequence. It is recommended that this situation be handled as a management issue, for which a corrective action plan shall be generated and implemented. This essentially requires rebaselining the program or possibly cancellation of the program if the negative consequences are too severe.

Each risk shall have a "risk realization date." This is a date when either the risk no longer exists or when the program shall be modified to accommodate the negative consequences. This date shall be documented when the risk is identified. The question to be asked and answered is: "What happens on this date?" The negative consequence of the outcome of the event that occurs on a given date is the basis for the risk.

4.10.3.1.1 Potential Sources of Risk

Risks originate from three basic areas—technical (or performance), schedule, and cost. A risk identification flow is shown in Figure 4.10-5. Technical risk is based on the likelihood that the program as planned will be unable to deliver a product to satisfy the technical requirements. As such, well-documented, defined and quantified technical requirements are necessary to define a technical risk. Most of the risks listed in Table 4.10-2 are technical risks. Schedule risk results from the likelihood that the program actions may not be accomplished in the planned program timing. A detailed program schedule identifying each accomplishment and the critical path is necessary to develop schedule risks. Cost risk results from the likelihood that the program may not accomplish planned tasks within the planned budget. A detailed budget, in which the cost of each accomplishment is specified and any management reserve is known, is needed to determine a cost risk. Potential loss of funding is not a programmatic risk in this risk process. Within the FAA risk process, ***cost*** is the ultimate expenditure required for a resource and the end product produced by that resource. ***Budget*** is the forecast of all costs planned for a given project/program, and ***funding*** is the supply of money provided to accomplish a given project/program. The risk source is based on the **root cause** of the risk and, as such, only a

single source will cause a risk. The source is technical, schedule, or cost in nature and not a combination or all of these. This is not to be confused with the symptoms, which may manifest themselves as some combination of performance (technical), benefit, cost, and/or schedule impact.

A program's acquisition strategy generates risks in its own right. Development programs are different in nature from those using commercial-off-the-shelf (COTS) solutions. Risks that need to be considered in a COTS-based acquisition appear in Figure 4-10.6.

For each risk area, it is recommended that many sources be considered. For technical risk, likely sources include technology maturity, complexity, dependency, stakeholder uncertainty, requirements uncertainty, and testing/verification failure. Sources of schedule risks may include incomplete identification of tasks, time-based schedule (as opposed to event-based schedule), critical-path scheduling anomalies, competitive optimism, unrealistic requirements, and material availability shortfalls. Cost risks may stem from an uncertain number of production units, supplier optimism, additional complexity, change in economic conditions, competitive environment, supplier viability, and lack of applicable historical data.

Table 4.10-2 provides the potential sources of risk that shall be considered in the process of program risk assessment.

Table 4.10-2. Potential Sources of Risk

Potential Sources of Risk	
• Safety • Security • Maintainability • Reliability • Supportability • Human Factors • Availability • Decommissioning • Reducibility • Commonality • Training • Operations	• Test • Verification • System Integration • Staffing • Tools • System Performance • Technology • Planning • Transition • Environments • Interdependencies (both FAA and non-FAA) • Acquisition Strategy

COTS Considerations

Number	COTS Risk Factor (Characteristic)
01	COTS products can exhibit rapid and asynchronous changes.
02	COTS product obsolescence can affect systems in different ways.
03	COTS products are typically documented with proprietary data.
04	Low initial costs of COTS products can be offset by higher lifecycle costs.
05	Functionally equivalent COTS products/systems can have multiple configurations
06	Different COTS product vendors have different quality practices.
07	COTS products form, fit and function are sold "as is".
08	COTS products are developed to commercial standards.
09	COTS products typically have time-limited manufacturer support.
10	COTS product inter-operability can introduce information security susceptibility.

Figure 4.10-6

The knowledge domains of safety and security impose additional criteria or gates as part of their identification process. In the case of safety, the process commences with an analysis, which identifies potential hazards that are the basis for identifying safety related risks. Safety does not identify a risk until a hazardous situation has been identified.

Information security engineering also utilizes a series of gates prior to identifying a risk. Security is concerned about the existence of viable threats, which may exploit a system vulnerability to cause harm. The combination of a viable threat coupled with a vulnerability in the system that is capable of being exploited by the threat is necessary before the security community moves to declare a (security) risk.

4.10.3.1.2 Risk Identification Methods

Risk identification begins at the lowest feasible level and normally includes inputs from all stakeholders and suppliers. Anyone may identify a potential risk. It is recommended that experts review programs to determine that risks related to their domain(s) have been completely identified. It is also recommended that similar programs be reviewed for determined risks as well as actual problems. The objective of this step is to produce as comprehensive a list as possible of potential risks. This may be achieved using any combination of methods, such as group discussions, interviews, trend/failure analysis, risk templates, lessons learned, trade studies, Best Practices, metrics, and acquisition documentation. It is recommended that the

focus be on root causes and not on symptoms of a more basic problem. The problem shall be defined at the lowest level (root cause) so that the mitigation plan actually addresses the problem.

This process includes screening the list of risks for duplication and consolidation as appropriate. Program Management errors are not risks and shall be corrected before the program moves forward. It is recommended that this screening consider program-level ramifications and ensure that program integration risks are adequately covered. A Risk Worksheet (Figure 4.10-7) may be used to document newly identified potential risks.

4.10.3.2 Task 2: Analyze and Assess Impacts of Risk *(Satisfies iCMM BP 13.03 criteria)*

Risk analysis or risk assessment provides program insight into the significance of identified risks. Risk analysis attempts to assess the likelihood of identified risks and the consequence to the program if the risk event or condition occurs. The process also classifies each risk according to the root cause of the risk event (cost, schedule, or technical performance).

Risk analysis assesses each component of an identified risk: (1) the likelihood of the risk occurring, and (2) the consequence to the program if it occurs, as depicted in Figure 4.10-8. The basic tool used for qualitative risk analysis is the risk template, which contains a set of definitions to be used to evaluate the likelihood and consequence of a particular risk. The set of templates that a program uses may change over time as new templates are added or existing templates are changed, combined, or eliminated. The program may choose to use program-unique templates (only if the technical elements of the program demand it), which are based on and traceable to program or stakeholder requirements, provided supporting rationale is given. However, modification of templates limits the ability to “roll-up” risks to a higher program level, and, as such, a mechanism shall be developed to correlate risks developed through modified templates to the risks developed with the standard FAA templates. The program/project is responsible for the choice, coordination, and control of the templates used on the program. These decisions are contained in the Risk Management Plan section of the SEMP (see Paragraph 4.2.3.12 in Integrated Technical Planning (Section 4.2)).

The result of the risk analysis process is an assignment of a measure termed risk exposure to each identified risk. Risk exposure is one quantitative figure of merit that represents the combined effects of likelihood and consequence; it serves as an aid to program management in ranking identified risks from most severe to least severe. At the conclusion of the risk analysis process, it is recommended that program management have visibility into the range of possible outcomes for the program (in terms of achieving objectives) if in fact an identified risk event or condition occurs.

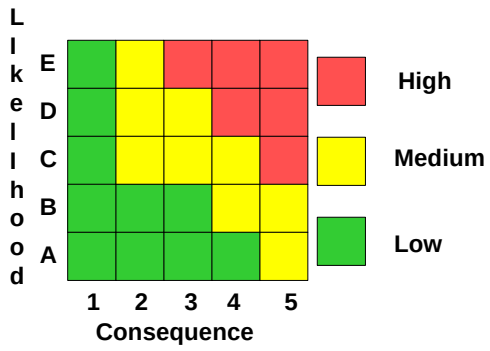
FAA Risk Worksheet

Program/Project Title_____ **Seq. #:** _____

Submitted by: _____ **Date:** _____

Risk:	**Point of Contact**
Source and Root Cause:	

	Risk Assessment			**Rationale**
o **Technical**	o **Schedule**	o **Cost**		
Likelihood	A B C D E			
Consequence	1 2 3 4 5			



Consequence Definition:

Risk Realization Date:

5	**Mitigation Options**	Description	New Risk Level if Implemented
☐	**Avoidance**		H M L
☐	**Transfer**		H M L
☐	**Control**		H M L
☐	**Assumption**		H M L
☐	**Research & Knowledge**		H M L

Figure 4.10-7

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Figure 4.10-7

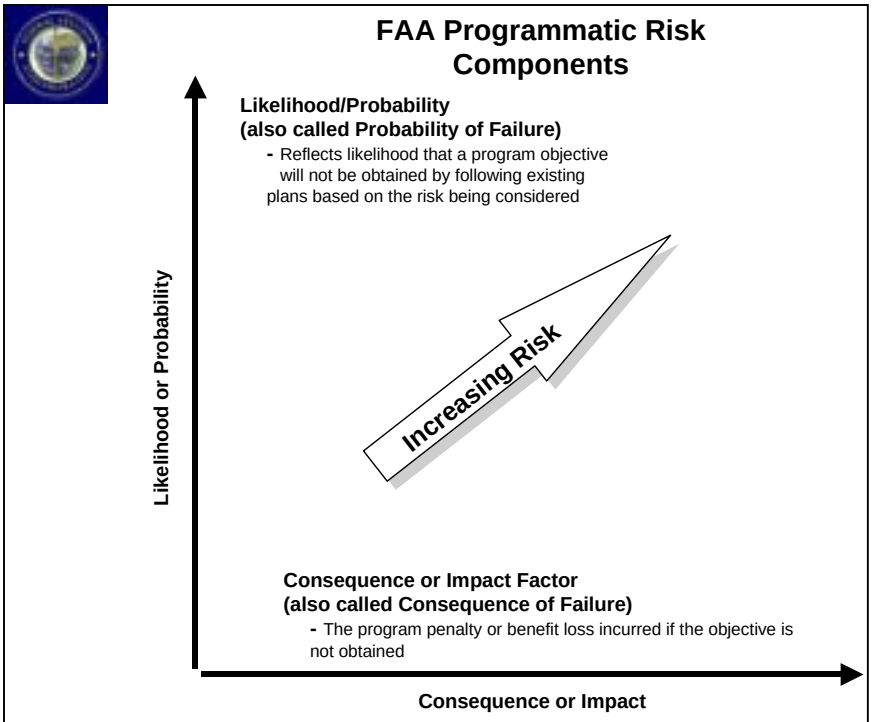

Figure 4.10-8

4.10.3.2.1 Likelihood (Probability) Determination

A likelihood (probability) template is developed that applies to the specific risk/program under analysis. A new template is developed and documented if none of the existing program templates are found to be applicable. This action shall be coordinated within the program/project using the criteria of the Risk Management Plan. Correlation of the new templates to the standard FAA templates in this manual shall be established. Figure 4.10-9 provides the FAA definitions of the risk likelihood levels.

4.10.3.2.2 Consequence Determinations

Another set of templates is used to evaluate consequence/impact to the program if the risk materializes. Consequence templates are shown for three areas of program impact: technical (Figure 4.10-10), schedule (Figure 4.10-11), and cost (Figure 4.10-12). The choice of the consequence template to be used to evaluate a given risk is determined by the nature of the root cause of that risk. If the root cause is technical in nature, it is then recommended that the technical consequences template be used. It shall be remembered that each of these results in a programmatic risk, which threatens the benefits of a program and may also have interdependency impacts. The symptoms of the risk may materialize in any combination of program areas: technical (or performance), schedule, and/or cost. However, treating the symptoms only wastes program resources and NOT directly deal with the source or root cause of the risk.

All NAS programs are developed to provide benefit(s) to the system. Programmatic risk ultimately reflects in impacts to benefit(s). All benefit losses are derived from losses in either technical, schedule, or cost risks. This is a significant part of the risk consequence that shall be defined. The cost/benefit analysis shall be reexamined as a result of cost and/or benefit impacts to provide the information needed to make program decisions. As was the case with

likelihood templates, if none of the existing program consequence templates are found to be applicable to a particular risk, new templates may be developed and documented. Correlation of the new templates to the standard FAA templates in this manual shall be established.

FAA Programmatic Risk Likelihood Definitions

What is the likelihood the risk will happen?

1. Low: Your approach and processes will effectively avoid or mitigate this risk based on standard practices.

   The chance of a negative outcome based on existing plans is not likely. This likelihood level assessment should be based on evidence or previous experience and not on subjective confidence. This assessment level requires the approach and processes to be well understood and documented. Little or no management oversight will be required.

2. Minor: Your approach and processes have usually mitigated this type of risk with minimal oversight in similar cases.

   There is a low likelihood but reasonable probability that a negative outcome is possible. Present plans include adequate margins (technical, schedule, or cost) to handle typical problems. This assessment level requires the approach and processes to be well understood and documented. Limited management oversight will be required.

3. Moderate: Your approach and processes may mitigate this risk, but workarounds will be required.

   A negative outcome is likely, or the current approach and processes are only partially documented. Alternative plans or methods exist to achieve an acceptable outcome even if the risk is realized. Present plans include adequate margins (technical, schedule, or cost) to implement the workarounds or alternatives to overcome typical problems. Significant management oversight will be required.

4. Significant: Your approach and processes cannot mitigate this risk, but a different approach might.

   A negative outcome is highly likely to occur, or the current approach and processes are not documented. While alternative plans or methods are believed to exist to achieve an acceptable outcome, there are not adequate margins (technical, schedule, or cost) to implement the workarounds without impacting the program management reserves in performance, schedule, or cost. Significant management involvement is required.

5. High: Your approach and processes cannot mitigate this type of risk; no known processes or workarounds are available.

   A negative outcome is going to occur with near certainty. No alternative plans or methods have been documented. Alternatively, the risk item has yet to be evaluated adequately to be well understood, so there is a high level of uncertainty about the program success. Urgent management involvement is required.

Figure 4.10-9

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FAA Technical Consequence Definitions

Given the risk becomes real, what would be the magnitude of the impact on system performance?

1. Low: Given that the risk is realized, there would be minimal impact.

   A successful outcome is not dependent on this issue; the technical performance goals will be met. There would be no impact on the success of the program.

2. Minor: Given that the risk is realized, there would be a minor performance shortfall but the same approach could be retained.

   The resulting technical performance would be below the goal but within acceptable limits. There would be no need to change the basic design, process, or approach. There would be no impact on the success of the program.

3. Moderate: Given that the risk is realized, there would be a moderate performance shortfall but workarounds would be available.

   The resulting technical performance would be below the goal. The basic design, process, or approach could be retained with only minor changes, and the overall system performance would still be acceptable as a result of workarounds such as the reallocation of functions or performance goals. There would be only a limited impact on the success of the program.

4. Significant: Given that the risk is realized, the performance would be unacceptable but workarounds would be available.

   The resulting technical performance would be unacceptably below the goal. The design, process, or approach would require a significant change to achieve an acceptable performance level. Additional workarounds such as the reallocation of functions or performance goals could also be required. The success of the program could be jeopardized.

5. High: Given that the risk is realized, the performance would be unacceptable with no known workarounds.

   The resulting technical performance would be unacceptably below the goal. There are no known alternatives or solutions. The success of the program would be in doubt.

Figure 4.10-10

FAA Schedule Consequence Definitions

Given the risk becomes real, what would be the magnitude of the impact on the schedule?

1. Low: Given that the risk is realized, there would be minimal impact.

   The program schedule is not dependent on this issue. There would be no impact on the success of the program.

2. Minor: Given that the risk is realized, additional activities would be required to meet key dates.

   One or more key dates in the program schedule, but not critical path events, would be jeopardized; there are identified schedule workarounds that would be sufficient to mitigate the schedule impact. There would be no impact on the success of the program.

3. Moderate: Given that the risk is realized, there would be a minor schedule slip, and one or more need dates would be missed.

   One or more key need dates in the program schedule, but not critical path events, would be at least one month late; there are identified schedule workarounds that would be sufficient to keep the program critical path from being affected. There would be only a limited impact on the success of the program.

4. Significant: Given that the risk is realized, the program critical path would be affected.

   One or more events on the program critical path would be at least one month late. There are identified schedule workarounds that would be sufficient to meet major program milestones. The success of the program could be jeopardized.

5. High: Given that the risk is realized, a key program milestone cannot be achieved.

   Completion of a key program milestone would be late, and the success of the program would be in doubt. The slip requires a re-baseline of the program.

Figure 4.10-11

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FAA Cost Consequence Definitions

Given the risk becomes real, what would be the magnitude of the impact on cost?

1. Low: Given that the risk is realized, there would be minimal cost impact.

   Program cost is not dependent on this issue. There would be no impact on the success of the program.

2. Minor: Given that the risk is realized, the total costs, operating cost or unit production cost would increase by = 1%.

   The program costs and/or the production unit cost would increase by = 1%. There would be no impact on the success of the program.

3. Moderate: Given that the risk is realized, there would be a minor increase in financial need. The program costs, operating cost or unit production cost could increase above 1% up to = 5%.

   The program costs and/or the production unit cost would increase above 1% to = 5%. There would be only a limited impact on the success of the program.

4. Significant: Given that the risk is realized, the total costs, operating cost or unit production cost would increase by above 5% to = 10%.

   The program costs and/or the production unit cost would increase above 5% to = 10%. The success of the program could be jeopardized.

5. High: Given that the risk is realized, the total costs, operating cost or unit production cost would increase by greater than 10%.

   The program costs and/or the production unit cost would increase by greater than 10%. The success of the program would be in doubt.

Figure 4.10-12

4.10.3.2.3 Risk-Level Determination

The likelihood and consequence are considered to be independent, but tied to the same event, and are mapped into a risk grid to determine the individual risk level (e.g., high (red), medium (yellow), or low (green)) as shown in Figure 4.10-13. This mapping facilitates the prioritization and trend analyses of risks throughout the life of the program. Use of a "color code" for each risk level supports effective communication of program health internally and externally.

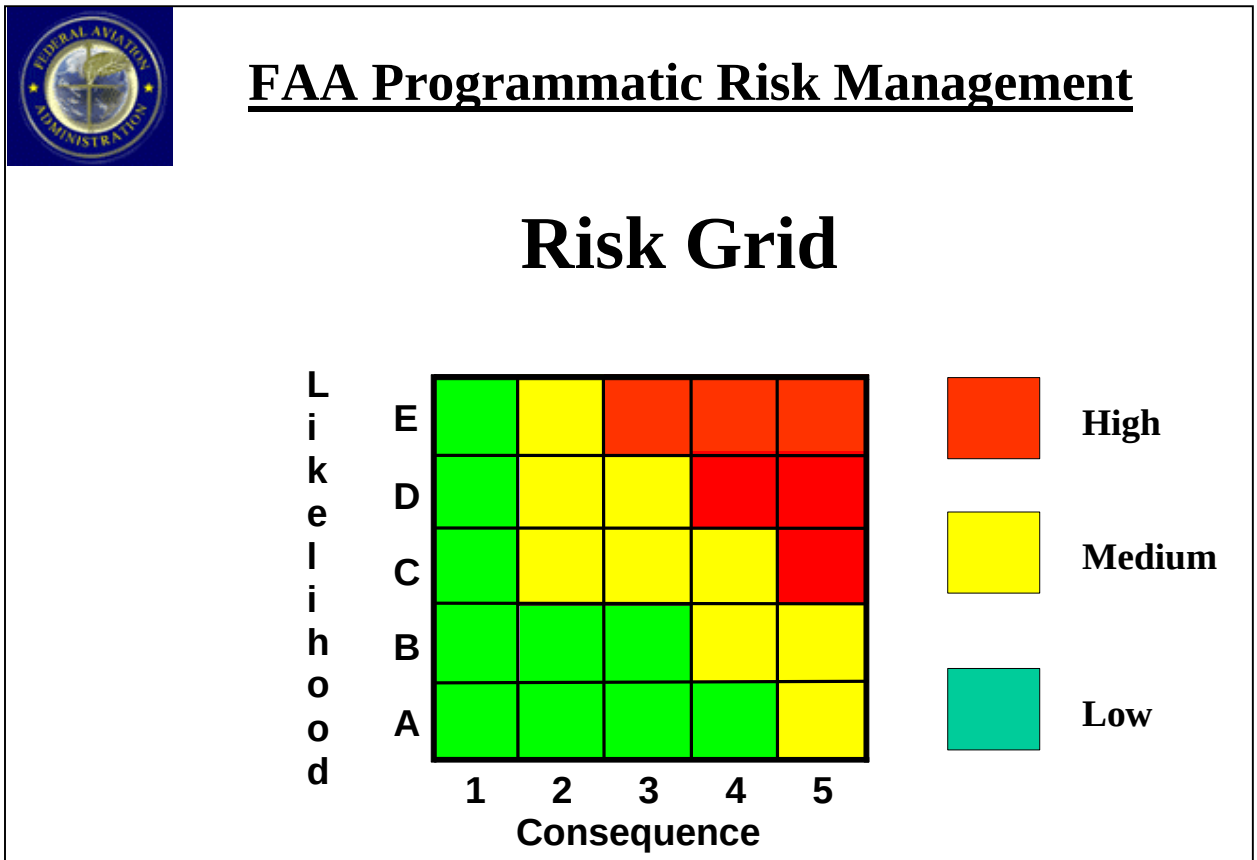

Figure 4.10-13

Risk-level definition high (red) is likely (a high probability) to cause significant disruption of schedule, increase in cost, or degradation of performance. Concerted and continual emphasis and coordination may not be sufficient to overcome major difficulties. Medium (yellow) may cause some disruption of schedule, increase in cost, or degradation of performance. Special emphasis and close coordination is probably sufficient to overcome difficulties. Low (green) has little potential for disruption of schedule, increase in cost, or degradation of performance. Normal emphasis and coordination is probably sufficient to overcome difficulties. The threshold for differentiating between high, medium, and low may change from program to program, but not for risk to risk, and it is recommended that it be determined early in the life of the program.

The color coding on this grid is also used to communicate management's threshold of risk acceptability. For acquisition or development programs, this threshold is usually the line between green and yellow. While development programs are focused on maturing a point

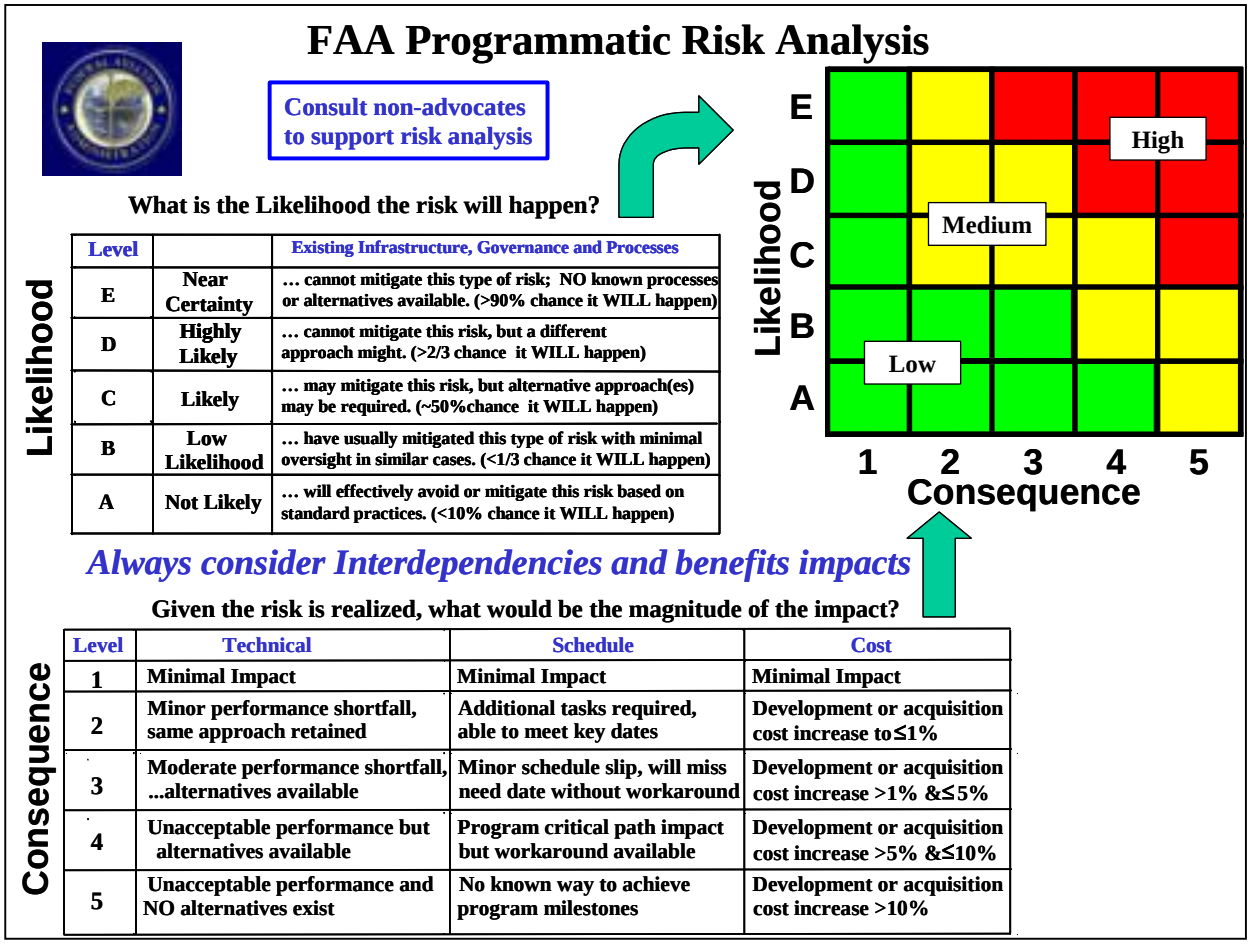

Figure 4.10-14

solution for a requirements set, research is aimed at determining the feasibility of an approach or technology. For research programs, the level of acceptability is typically defined as the threshold between yellow and red because the success criteria of research do not require the same degree of granularity as development. The degree of risk-level acceptance, and the actions required to reduce a risk below that level shall be detailed in the Risk Management Plan. Figure 4.10-14 is a summary of how the consequence and likelihood are consolidated to define the risk level.

Various technical communities employ risk analysis techniques or methodologies specific to their domain. They portray their conclusions and recommendations as grids similar to that shown in Figure 4.10-14; but the scales vary from 3 x 3 to 10 x 10 with many variations in between. It is recommended that the representation that a given specialty community (such as Safety or Information Security) uses to draw conclusions be suited to its particular situation. However, the criteria used and portrayal of a community's conclusions and/or recommendations shall be consistent with the program view of risk. All risks need to be portrayed to management on the same basis (see Section 4.10.3.5) to allow for effective decisions on the application of

risk-reduction resources. However, the basic conclusion(s) reached by the specialty community shall be preserved in any translation into a common program reporting format.

The General Accounting Office (GAO) has defined a process to handle risk in a report issued in 2000 (Reference 16). It contains the same elements shown in the FAA Programmatic Risk model with the exception of the track and control step. Figure 4.10-15 shows the correlation between the two approaches and demonstrates how the GAO recommendations are satisfied with the process described in the FAA SEM.

FAA Programmatic Risk Management

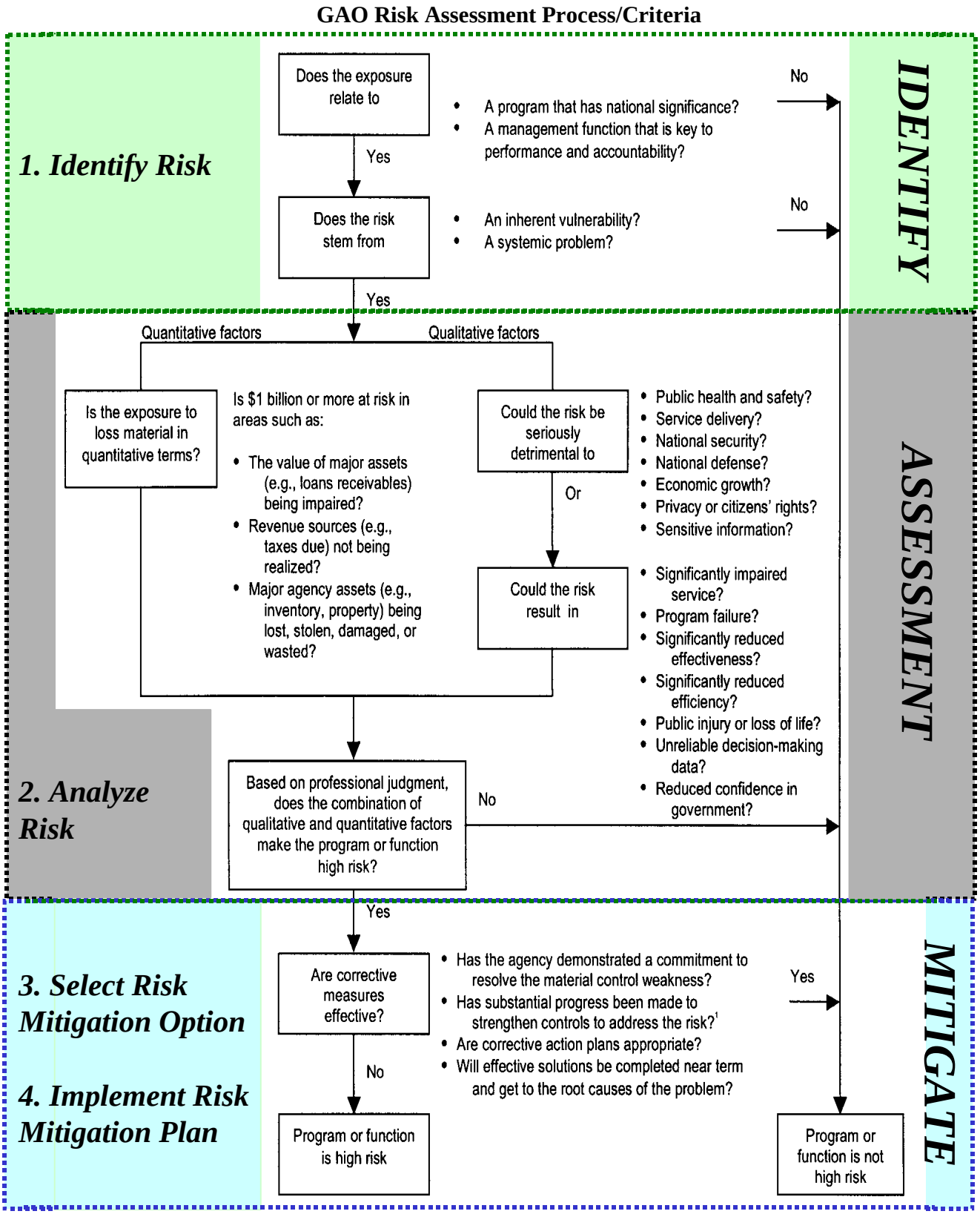

Figure 4.10-15

GAO process requires examination of risk and the development of a mitigation effort. Shown is Figure 5 of GAO/OCG-00-12, Page 9. (August/2000).

4.10.3.3 Task 3: Select Risk-Mitigation Option *(Satisfies iCMM BP 13.05 criteria)*

The objective of risk-mitigation handling is to implement appropriate and cost-effective risk-mitigation plans to mitigate or eliminate the risks. Appropriate risk-mitigation techniques are selected and mitigation actions are developed, documented, and implemented. Risk-mitigation handling (planning, implementation, and tracking) is the core of risk management. Risk-mitigation implementation requires a conscious management decision to approve, fund, schedule, and implement one or more risk-mitigation actions. Risk-mitigation plans and mitigation actions are reviewed frequently at major reviews, program reviews, acquisition reviews, and milestone reviews.

Risk-mitigation actions fall into one, or a combination, of the following strategies:

- Avoidance
- Transfer
- Control
- Assumption
- Research and Knowledge

"Avoidance" is a strategy to avert the potential of occurrence and/or consequence by selecting a different approach or by not participating in the program. This technique may be pursued when multiple designs or programmatic options are available. It is more likely used as the basis for a "Go"/"No-Go" decision at the start of a program. Some examples are selection of state-of-the-practice rather than state-of-the-art technologies and prequalification of suppliers. The avoidance of risk is from the perspective of the overall program/project, which includes the stakeholders, contractors, and execution groups. Thus, an avoidance strategy is one that involves all of the major parties to the program/project and permits a program/project-wide avoidance of the risk.

"Transfer" is a strategy to shift the risk to another area, such as another requirement, an organization, a supplier, or a stakeholder. Examples include reallocating requirements, securing supplier product warranties, and negotiating fixed-price contracts with suppliers. Note that at the program level, the risk remains. The transfer of the risk is accomplished primarily to optimize, in a sense, the overall program risk and to assign ownership to the party most capable of reducing the risk. It is possible that the risk level may change as a result of the risk transfer.

"Control" is a strategy of developing options and alternatives and taking actions that lower or eliminate the risk. Examples include new concepts, more analysis, redundant systems and/or components, and alternate sources of production.

"Assumption" is simply accepting the likelihood/probability and the consequences/impacts associated with a risk's occurrence. Assumption is usually limited to low risks. This is a program/senior management option, not a program option. FAA practice is to develop mitigation plans for all medium and high risks.

“Research and Knowledge” may mitigate risk through expanding research and experience. Since risk arises from uncertainty and inexperience, it may be possible to effectively mitigate

risk simply by enlarging the knowledge pool, leading to reassessment that reduces the likelihood of failure or provides insight into how to lessen the consequences.

At this point, several alternatives for mitigating the risk have been identified and analyzed for selection of the preferred approach. Alternatives include detailed plans for mitigating the risk in several small, sequential steps; alternative steps; or entirely new (nonbaselined) approaches to accomplishing the program. Further, contingency plans are identifiable alternatives, which may be implemented if a mitigation plan fails, and the risky event or conditions occur with more serious consequences than anticipated. The mitigation steps are the major milestones of the mitigation plan. Contingency plans need not be extremely detailed.

For instance, the risks associated with selecting a COTS-based acquisition approach (see Figure 4.10-6) have known risk-mitigation strategies. These strategies need to be included in the trade studies when comparing acquisition approaches. Because COTS has an inherent set of risks that are market-driven, most of the risk-mitigation strategies fall into the “Control” category in order to anticipate and reduce the risks to acceptable levels. More information on COTS risks and mitigation strategies may be found in the FAA COTS Risk Mitigation Guide, which is available at http://www.faa.gov/aua/resources/COTS.

Trade study techniques may be performed to help select the preferred risk-mitigation plan. While the proper criteria and their weights for each analysis are dependent on the risks to be mitigated, it is recommended that the following be included:

- Does the option mitigate the likelihood or consequence of the risk?
- Does the option fit within program scope?
- Is the option easy to implement?
- Are new risks avoided or introduced?
- What is the cost of mitigation?
- What is the schedule for mitigation?

The risk level is the first criterion used to determine the need for a risk-mitigation plan. Program risks that fall into the medium or high categories require risk-mitigation plans. Risks that are assessed as low typically do not require mitigation plans but may have certain aspects that would be prudent to monitor. If this is the case, risk-mitigation plans may be formally or informally implemented for these low-risk issues based on the specific Risk Management Plan for a program.

It is essential that those responsible for plan implementation have a thorough understanding of the risk to be mitigated. This may be accomplished with a good summary statement of the risk. It is recommended that the statement include descriptions of the future event or condition, which confirms trouble for the program; the root cause(s) of the event outcome or conditions; and the specific effects to the program if the event or conditions occur with negative consequences. It is recommended that the risk not be stated in terms of its mitigation plan.

It is recommended that the status also include a summary of risk-mitigation efforts that references more detailed documentation. A Risk Mitigation Plan Summary (Figure 4.10-16) is used to report the analysis and actions on an individual risk.

The risk-mitigation plan documents the specific steps to be implemented, the sequence in which they are to be implemented, and the points in time at which they are to be implemented. Developing a risk-mitigation plan includes assessing the expected outcome following implementation. It is recommended that the same method initially used to assess the risk, such as risk templates, be used to provide a forecast of the risk level after completion of each action of the risk-mitigation plan. The expected impact of each mitigation event on risk level may be projected using a format similar to that of Figure 4.10-17 (a "waterfall chart").

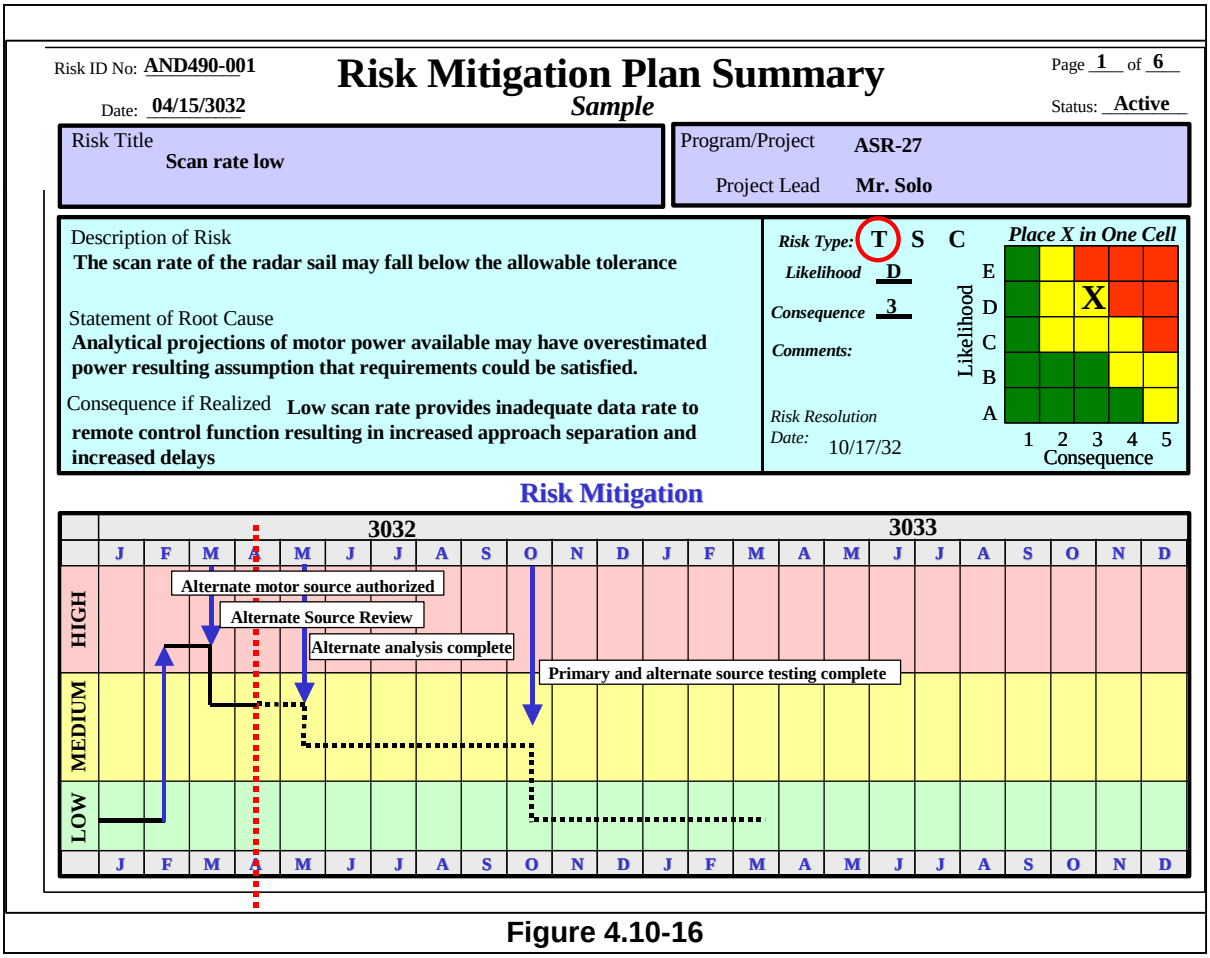

Figure 4.10-16

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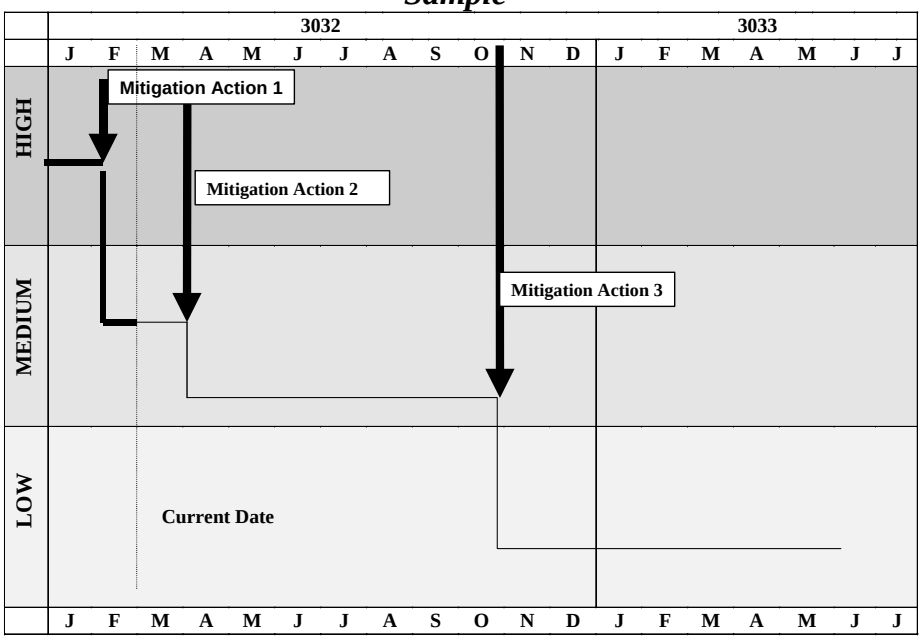

Figure 4.10-17

The risk-mitigation plan becomes the basis for monitoring the success in mitigating each risk. The plan includes, but is not limited to, the following:

- A description of the risk for which the plan applies
- The mitigation approaches, which detail the specific actions that are planned to reduce the risk or eliminate it. It is recommended that these actions be event-based, integrated into a schedule, and have associated with each of them:
  - The decision point or trigger, past or future, that initiates the action or group of actions
  - The resources required to execute the actions (including personnel, capital equipment, facilities, procured equipment)
  - The measures of success to be used for the planned actions or group of actions
  - The fall-back options or contingency plans (if any)
  - The planned completion dates of the actions
- Risk-mitigation metrics
- The Risk Worksheet (Figure 4.10-7)
- The initial Risk Mitigation Plan Summary (Figure 4.10-16)
- Risk Mitigation Waterfall Schedule (Figure 4.10-17)

It is recommended that a risk-mitigation plan be evaluated to determine its effectiveness. This analysis is performed in the same manner as initial analysis for the risk. The set of templates used for analysis of the risk may also be used to determine the mitigation in the risk level following the completion of each major action or group of actions. The regular reassessment of the risk and performance to plan using a fixed set of criteria provides a consistent analysis of the impact to the program.

The Risk Worksheet (Figure 4.10-7) guides the team through the first three tasks in the Risk Management process: Identify, Analyze, and mitigation planning. When a risk-mitigation plan has been prepared, (Program) Management reviews and approves it based on criteria defined in the Risk Management Plan.

4.10.3.4 Task 4: Implement Risk-Mitigation Plan *(Satisfies iCMM BP 13.05 criteria)*

Once risk-mitigation actions are decided, they shall be implemented and carried out effectively so that either risk likelihood or consequence, or both, are reduced to an acceptable level. The implementation of risk-mitigation actions requires that specific tasks be incorporated into the planning, scheduling, budgeting, and cost-accounting systems used on the program. Incorporating risk-mitigation actions directly into the overall program schedule at a point where risk likelihood or consequence may be affected before a risk occurs keeps management and the program team aware of the need to allocate resources (labor, materials, and possibly other

resources) to accomplish risk-mitigation tasks. The Risk Mitigation Plan Summary chart (Figure 4.10-16) is used as a means of reporting progress in mitigating risks. Each major event in the mitigation plan is identified along with how that event mitigates the risk and to what level.

Incorporating the risk-mitigation plans and milestones into these program processes and systems ensures that the risk and its mitigation plans may be monitored and tracked until the risk is eliminated or the risk requires program modification. Risk-mitigation plans may be documented starting with the Risk Worksheet shown in Figure 4.10-7 and a Risk Mitigation Waterfall Schedule shown in Figure 4.10-17. All mitigation activities are shared with and communicated to all stakeholders.

4.10.3.5 Task 5: Monitor and Track Risks *(Satisfies iCMM PA 14 criteria)*

Reassessing currently managed risks is done on a periodic and event basis to reflect current status of the risks as well as to identify and quantify new and emerging risks. New potential risks to the program may be identified at any time. Newly identified risks are analyzed using the same steps described in Section 4.10.3.2.

Steps in the risk-tracking process focus on providing the execution teams, interdependent activities, and program management with program risk trends and status. Actual performance of the planned mitigation actions is compared to the expected performance. The bold line on the Risk Mitigation Plan Summary “waterfall area” (see Figure 4.10-17) indicates progress made to date on the mitigation plan. Detailed cost and schedule tracking is done as part of the program schedule and cost-tracking system.

It is recommended that the Risk Management plan contain the management visibility requirements for the program. These requirements include reporting frequency and content. A sample of a brief summary of all risks for a particular program (or team) with relatively few risks appears in Figures 4.10-18. A standard reporting format shall be used (see Figure 4.10-19) to facilitate integration of risk information across projects and programs. It is recommended that the risk-management plan also indicate the extent of supporting detail, usually in the format of templates (see Figure 4.10-20).

It is recommended that the management visibility effort be focused on monitoring and tracking the effectiveness of the risk-reduction decision. The impact of the risk on program and the relevant ***decision*** are incorporated into the project schedule as risk-mitigation actions. They are inserted into the program's Integrated Program Schedule (Figure 4.10-21). The lowest-level tasks involved.

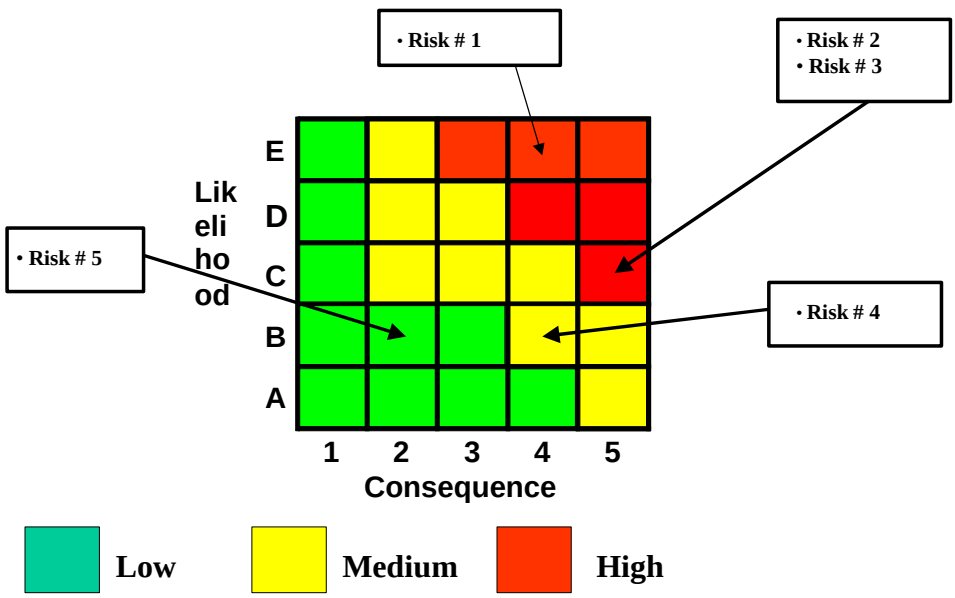

Figure 4.10-18

(Extracted from PMR TEMPLATE)

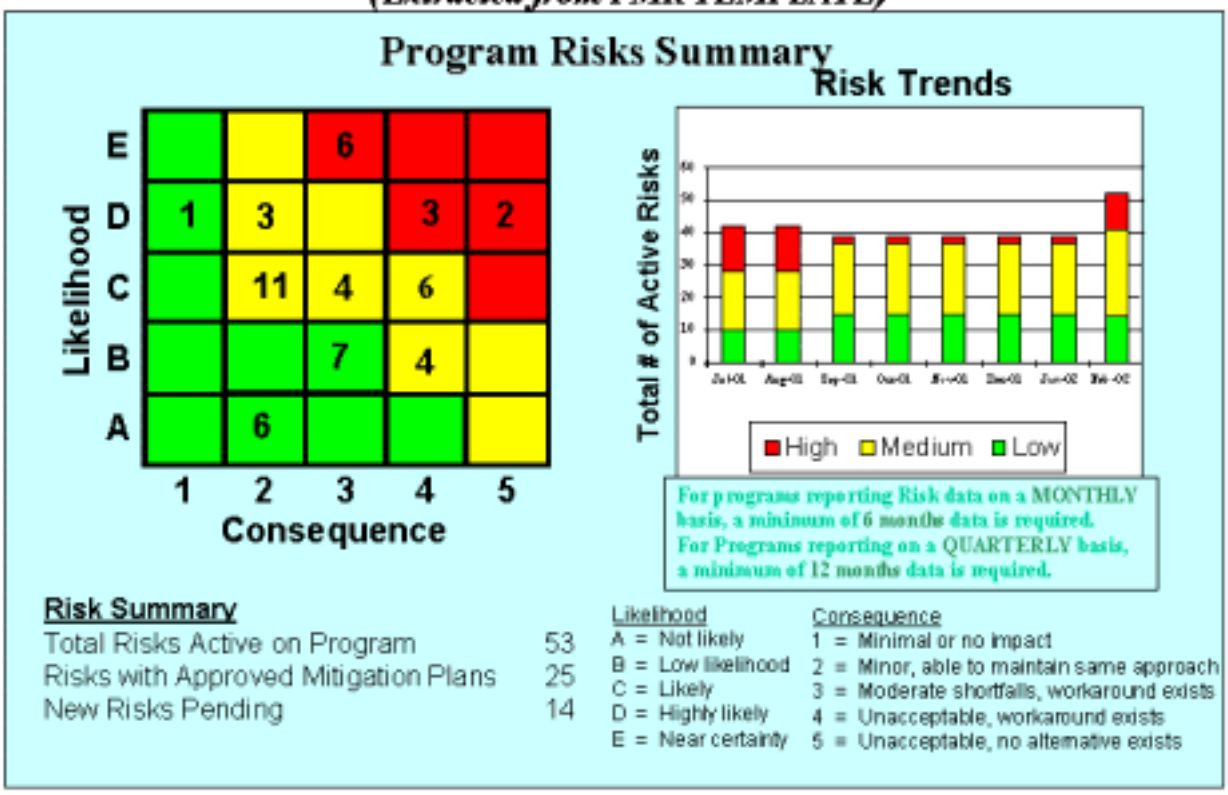

Figure 4.10-19

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(Extracted from PMR TEMPLATES) Program Risks

Risk Level	Risk #	Likelihood	Consequence	Risk Type	Risk Item	Mitigation Status	Risk Mitigation Decision Date
H	46	E	4	S	TSO's and AC's may be delayed pending Standards maturity.	PT will work with industry to secure support	Jan-01
H →	14	D	5	C	Airspace User Coordination - GA Aircraft users do not accept NEXCOM plan - Benefits for GA not sufficient to engender support - Low end GA Avionics costs too expensive	PT reps will meet with reps of the GA community to determine concerns and strategies for resolution of concerns.	Jun-02
H ↑	30	D	5	C	Business case does not demonstrate ROI for airlines to equip.	PT will establish joint working group with industry to develop business case that industry can support.	Jul-02

List risk updates IN PROGRAM PRIORITY ORDER for each New, High Risk item (Red), and Significant Level Changes (High to Low &/or Low to High).

Likelihood
E = Near certainty
D = Highly likely
C = Likely
B = Low likelihood
A = Not likely

Consequence
1 = Minimal or no impact
2 = Minor, able to maintain same approach
3 = Moderate shortfalls, workaround exists
4 = Unacceptable, workaround exists
5 = Unacceptable, no alternative exists

Risk Level:
H - High M - Medium L - Low
→ = same as last report ↑ = up from last report
↓ = down from last report

Risk Type
T = Technical
S = Schedule
C = Cost

Note: There is a difference between a risk and an issue. If something is a certainty, it is no longer a risk and should be described as an issue and reported on the issues/concerns slide

Initially each High risk should be briefed. Subsequently,any new or major change to a risk item should be captured on this slide. See attached proposed "Risk Management" (Attachment #1) for guidance on how to assess and report program risks.

Figure 4.10-20

are flagged with the assessed risk level; higher-level Work Breakdown Structure tasks inherit the maximum risk level present in any subordinate task. Hence, review of the schedule at any level from

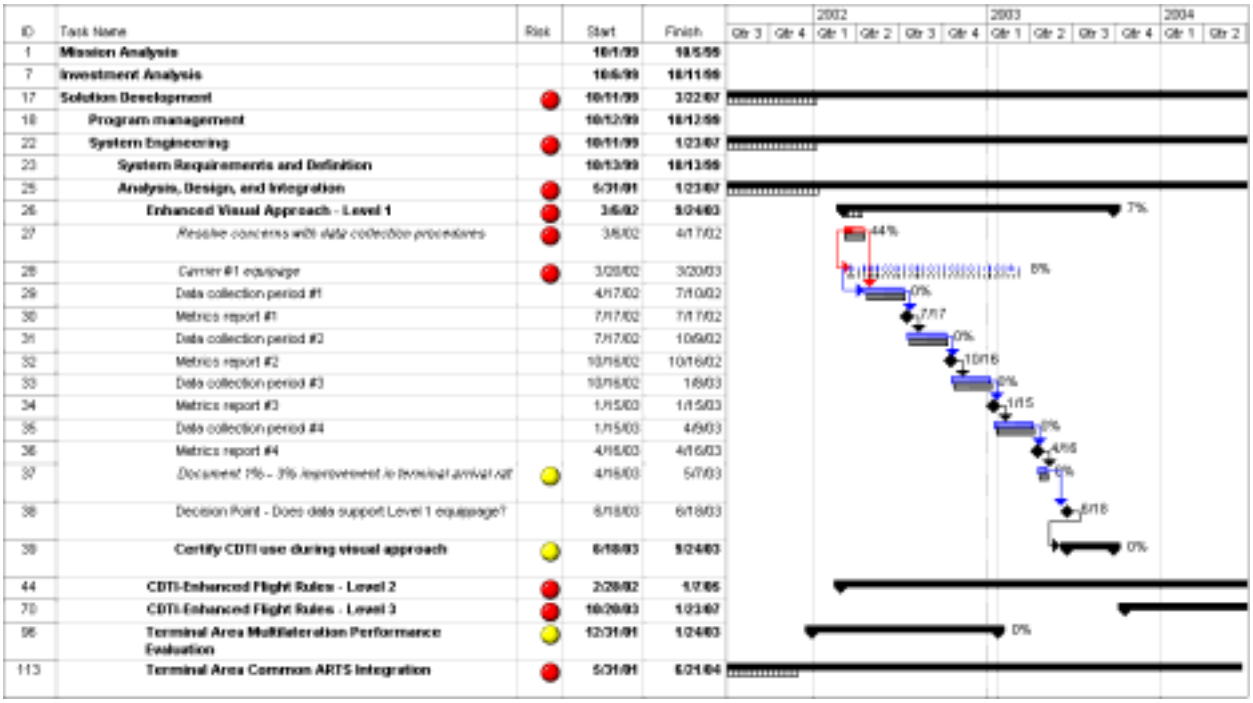
Integrated Program Schedule: summary level (top) and "drill-down" to lowest level tasks (bottom).

Risk information displayed at summary task level in the program Integrated Master Schedule (IMS)

High risk

Medium risk

Low risk



"Drill-down" capability - Risk information displayed for lowest level tasks; summary tasks show highest level of risk for any subordinate task

Figure 4.10-21 – Risk Information Incorporated Into Program

summary tasks (Figure 4.10-21, top) to lowest-level tasks (Figure 4.10-21, bottom) allows program management to maintain appropriate risk visibility, and also allows "drill-down" to increasing levels of detail as the schedule view is expanded.

Effective program management always involves examining cost and schedule during review of the progress of the program. Making risk information visible as part of the IMS ensures that risk

information receives ongoing management attention. Integrating program risk data into the master schedule fosters better, risk-based decisionmaking in at least three ways:

(1) The need for separate risk reviews competing for the program manager's time and energy is eliminated.

(2) Integrating the risk information into the IMS effectively prevents isolation of the risk efforts from the mainstream tasks and program milestones. The risk profile of the program is presented as part of the overall management view of the program. As each decision point is reached, the risk information associated with that event is portrayed, and hence, shall be considered.

(3) The portrayal of program progress illustrated in Figure 4.10-21 alerts management to when a decision needs to be made and what that decision is. This provides visibility across the entire program ***in advance*** of impending decision points so that the necessary relevant information is provided in a timely manner to support an informed decision.

4.10.4 Outputs *(Satisfies iCMM Artifacts criteria)*

The five major outputs of this process are:

- Risk-Mitigation Plans (see Section 4.10.3.3)
- Risk Mitigation Plan Summary (Figure 4.10-17)
- Program Risk Mitigation Progress Chart (Figures 4.10-18)
- Program Risk Summary (Figures 4.10-19 and 4.10-20)
- Program Risk Register (Figure 4.10-22)

It is recommended that the Program Risk Summary, the Risk Mitigation Plan Summary, and the Program Risk Mitigation Progress charts be briefed at all regular program reviews. Management decisions are based on the above information. It is recommended that a complete status of a given risk be briefed when the risk is identified and immediately following the risk realization date.

It is recommended that the Risk-Mitigation Plan be considered an appendix to the IPP and Acquisition Program Baseline. It shall be handled as an integral part of program effort.

4.10.5 Risk Management Tools

The tools needed to implement this process include:

- Approved Risk Management Plan
- FAA Risk Worksheet
- Likelihood and consequence templates tailored for the program

- Risk Mitigation Plan Summary

- A means to communicate results across a program (electronic mail, servers, etc.)

- A means to document the results of the process and manage the outputs (databases, spreadsheets, word processors, etc.)

The risk register (see example in Figure 4.10-22) is a listing of risk information associated with achieving program objectives. If risk registers are created and maintained by each project, a single composite register of all interdependency risk items shall be developed for the program. These registers are to be consistently used to monitor and track overall risk status within team meetings, program management reviews, and major program reviews. Immediately following identification and analysis of a new medium or high risk or when a significant change occurs in a previously identified risk, changes shall be incorporated in the register and other documents and

FAA Program Risk Register

(Example)

DATE 04/15/3032
Page __1___ **of** __1__
Revision

Risk #	Likelihood	Consequence	Risk Level/Change	Risk Item/Consequence	Next Milestone date	Risk Resolution Date	Mitigation Status	Risk Type
1	4	3	M ↓	Sweep rate low/ delays-benefits loss	30320515	30321017	On Track	T
2								
3								

Consequence Key:
1= Minimal impact
2= Minor, able to maintain same approach
3= Moderate shortfalls, workaround exists
4= Unacceptable, workaround exists
5= Unacceptable, no alternative exists

Risk Level:
H - High **M** - Medium **L** - Low
→ = same as last report ↑ = up from last report
↓ = down from last report

Risk Type:
Ⓣ - Technical
Ⓢ - Schedule
Ⓒ - Cost

Figure 4.10-22

the new risk identified to stakeholders. The distribution list is to be established and documented in a program's Risk Management Plan. Computer database systems may be needed to manage these outputs for large programs. Smaller programs may often be able to use desktop computer techniques.

At a minimum, the following information shall be included in the risk register:

4.10.5.1.1.1 Risk Register Identification and Creation/Update Date

This is the name of the program risk item. Include the root cause of the risk in this section.

4.10.5.1.1.1.1 Risk Identification Number

This number is code that identifies a unique sequence.

4.10.5.1.1.1.2 Likelihood

This is a figure-of-merit indicating the relative likelihood/probability that the identified risk will actually occur (Likelihood Template, Figure 4.10-9).

4.10.5.1.1.1.3 Consequence

This is a figure-of-merit indicating the relative severity of consequences/impacts that could result if the identified risk did occur (Consequences Templates, Figures 4.10-10, 4.10-11, and 4.10-12, for examples).

4.10.5.1.1.1.4 Risk Level/Change

This is a single letter indicating the assessed risk of an item as high, medium, or low (H, M, L) or, red, yellow, or green (R, Y, G), respectively. An arrow that indicates the direction that the risk has moved since the last revision to the risk register demonstrates the risk change.

4.10.5.1.1.1.5 Risk Consequence Description

This is a brief, well-stated description of the risk's negative consequences.

4.10.5.1.1.1.6 Next Milestone Date

This date is the projected date at which the risk level converts to lower risk. This is traceable to the Risk Mitigation Plan Summary (See Figure 4.10-16).

4.10.5.1.1.1.7 Risk Realization Date

This is the date of the event that either makes the risk a real part of the program or eliminates the need to track the risk. Early in the program it may be difficult to predict an exact date but a general timeframe needs to be developed. As the program matures, date realization occurs. It is recommended that these dates be reviewed regularly and be on the program master schedule.

4.10.5.1.1.1.8 Mitigation Status

The currently planned mitigation actions are defined.

4.10.5.1.1.1.9 Risk Type

The risk type designates if the risk is a cost risk, a schedule risk, or a technical risk (see Paragraph 4.10.3.1.1).

4.10.5.1.1.10 Risk-Mitigation Plan Status

The teams regularly update and report the status of the risk-mitigation plan for each risk being tracked that requires risk handling. Actions are initiated as required in which mitigation plan activities are not being accomplished. The risk status is also reviewed with program

management on a regular basis. A sample of a brief summary of all risks for a particular program (or team) is shown in a Program Risk Summary (Figures 4.10-18 and 4.10-19) for use depending on program size.

An example of a database tools is "Risk Radar" (a tool free to the government that may be used to generate many of the risk work products (see Section 4.10-7). A version of Risk Radar that incorporates the FAA templates and forms is available for download (http:TBD). This software is available free to all FAA programs (including contractors for use in supporting FAA programs). It requires MS Access 2000 and interfaces with MS Project 2000 for schedule linkage to the overall Program Master schedule.

Analytic tools may be used for probabilistic analysis of schedule uncertainty or technical uncertainty. Critical Path Analysis tools may be used with the Integrated Program Schedule to regularly evaluate schedule risk. In a similar fashion, commercial applications (e.g., @RISK) may be applied to technical parameters (such as weight, latency, power, computer throughput) to establish confidence ranges. Results from these probabilistic analyses may support the overall risk analysis task of establishing a likelihood of occurrence. Further details on the use of probabilistic analysis appear in textbooks and technical papers that cover statistical analysis for risk management.

4.10.6 Risk Management Process Metrics *(Satisfies iCMM PA 18 criteria)*

It is recommended that Risk Management-related metrics be focused on Program and/or Project success criteria. At the Program level these metrics measure program progress to plan. Earned Value Management is an excellent set of measures to portray the extent of schedule and cost risk in a program. The variance to plan for either Schedule Performance Index or Cost Performance Index may be used as a measure of risk on the Program. Technical or performance risk may be measured through by using Technical Performance Measures. The projected and/or actual variance to performance requirements is a measure of technical risk. At a lower level, metrics for the Risk Management process itself may include:

- **Total risks identified over time; total high risks, total medium risks.** The objective is to provide visibility into risk trends over time.

- **Percent of risks (medium and high) with approved mitigation plans.** The objective is to measure the effectiveness of handling the risks requiring action.

- **Percent of overdue mitigation activities.** The objective is to measure the effectiveness of meeting mitigation plan schedules.

- **Aging of active risk records.** The objective is to gain insight into the currency of the risk database.

- **Number of risks past their realization date.** The objective is to provide an indicator of the effectiveness to handle risks in a timely manner.

4.10.7 References

1. AFMC, "Acquisition Risk Management Guide," USAF Pamphlet 63-101.

2. ANSI/EIA-632-1998, pp. 11, 13, 14, 17, 30, 33-4, 45, 49, 52, 67, 75, 77, 81, 96, 109, Requirement 24.

3. Blanchard & Fabrycky. "Systems Engineering and Analysis" (3rd ed.). Prentice Hall, 1998, pp. 657-661.

4. Conrow, Edmund H. "Effective Risk Management." American Institute of Aeronautics and Astronautics, Inc., 2000.

5. DoD 4245.7-M. "Transition from Development to Production." Chapter 9-8.

6. DOT H 1350.252. Departmental Guide to Risk Management Planning. May 1999.

7. DSMC. "Risk Management Guide." Available: http://www.dsmc.dsm.mil/pubs/gdbks/risk_management.htm

8. DSMC. "Systems Engineering Management Guide." Chapter 15, 1990.

9. EIA 632, 8/09/02. Rev. 99, Chg.H.

10. FAA AMS Paragraph 2.9.14.

11. FAA Acquisition Program Baseline Template.

12. FAA Orders 1900.47, 1050, 1600, 3900, and 1370.82.

13. FAA-P-1810. "Acquisition and Program Risk Management Guidance." December 1996.

14. FAA Report No. WP-59-FA7N1-97-2. "Risk Assessment Guidelines for the Investment Analysis Process." July 1999.

15. GAO/AIMD (Accounting and Information Management Division)-10.1.13. "Assessing Risks and Returns: A Guide for Evaluating Federal Agencies' IT Investment Decision-making." February 1997.

16. GAO/AIMD-99-139. "Information Security Risk Assessment." August 1999.

17. GAO/OCG-00-12. "Determining Performance and Accountability Challenges and High Risks." August 2000.

18. Grady, Jeffery O. "Requirements Analysis." McGraw-Hill, 1993, p.462-465.

19. Grady, Jeffery O. "System Engineering Planning and Enterprise Identity." CRC Press, 1995, p. 168-177.

20. Grady, Jeffery O. "System Integration." CRC Press, 1994, p. 149.

21. NASA. "NASA Systems Engineering Handbook.," 1995, p. 37-44.

22. OMB Circular No A-11, Part 7 "Planning, Budgeting, Acquisition, and Management of Capital Assets", June 2003

23. PMBOK Chapter 11.

24. Ross, J.F. “Living Dangerously.” Perseus Publishing, March 2000.

25. US Navy Best Practices, NAVSO P-8871

4.12 Validation and Verification

Validation and Verification is the System Engineering (SE) process that confirms that system requirements are correct and satisfied (Figure 4.12-1). The Validation process confirms that the right system is being built (i.e., that the system requirements are unambiguous, correct, complete, consistent, operationally and technically feasible, and verifiable). The Verification process ensures that the design solution has met the system requirements and that the system is ready for use in the operational environment for which it is intended. This section describes the Validation and Verification process, including the inputs, outputs, and specific tasks of Validation and Verification.

Figure 4.12-1. Validation and Verification's Role in System Development Process

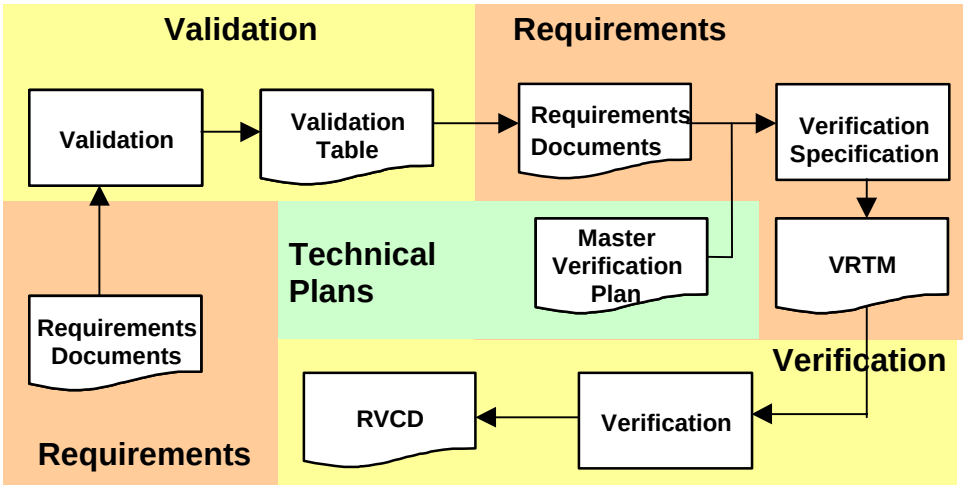


Figure 4.12-2. Validation and Verification Activities

The Validation and Verification activities, illustrated in Figure 4.12-2, are summarized below:

- Requirements feed Validation. During Validation activities, a Validation Table is developed that is included in a Validation Report when completed. The Validation Report is an input to the requirements document. The Validation Table becomes the basis for later Verification activities.
- At the same time, work begins on Verification planning and is documented in a "living" joint SE and Test and Evaluation (T&E) Master Verification Plan (MVP)(described and developed under Integrated Technical Planning (Section 4.2)).

- After Verification planning is completed, a specification/approach for verifying each requirement is developed in Requirements Management (Section 4.3) and documented for each requirement in the Validation Table. This update to the Validation Table transforms it to a Verification Requirements Traceability Matrix (VRTM), which becomes the foundation for the next activity and is included in the MVP as an update.
- After Verification activities are performed, the VRTM is updated with evidence of completion of activities. Using the updated VRTM, the Verification team develops the Requirements Verification Compliance Document (RVCD) to record completion of the Verification effort. The RVCD also identifies system compliance or noncompliance with the set of requirements used for the Verification activities. Program management uses this information for the Risk Management process (Section 4.10).

4.12.1 Validation

As stated earlier, the Validation process (Figure 4.12-3) confirms that the right system is being built (i.e., that the system requirements are unambiguous, correct, complete, consistent, operationally and technically feasible, and verifiable). The process is conducted in order to demonstrate that the requirements for a system are clearly understood and that it is possible to satisfy the requirements through design work using available state-of-the-art technology, funding, and schedule.

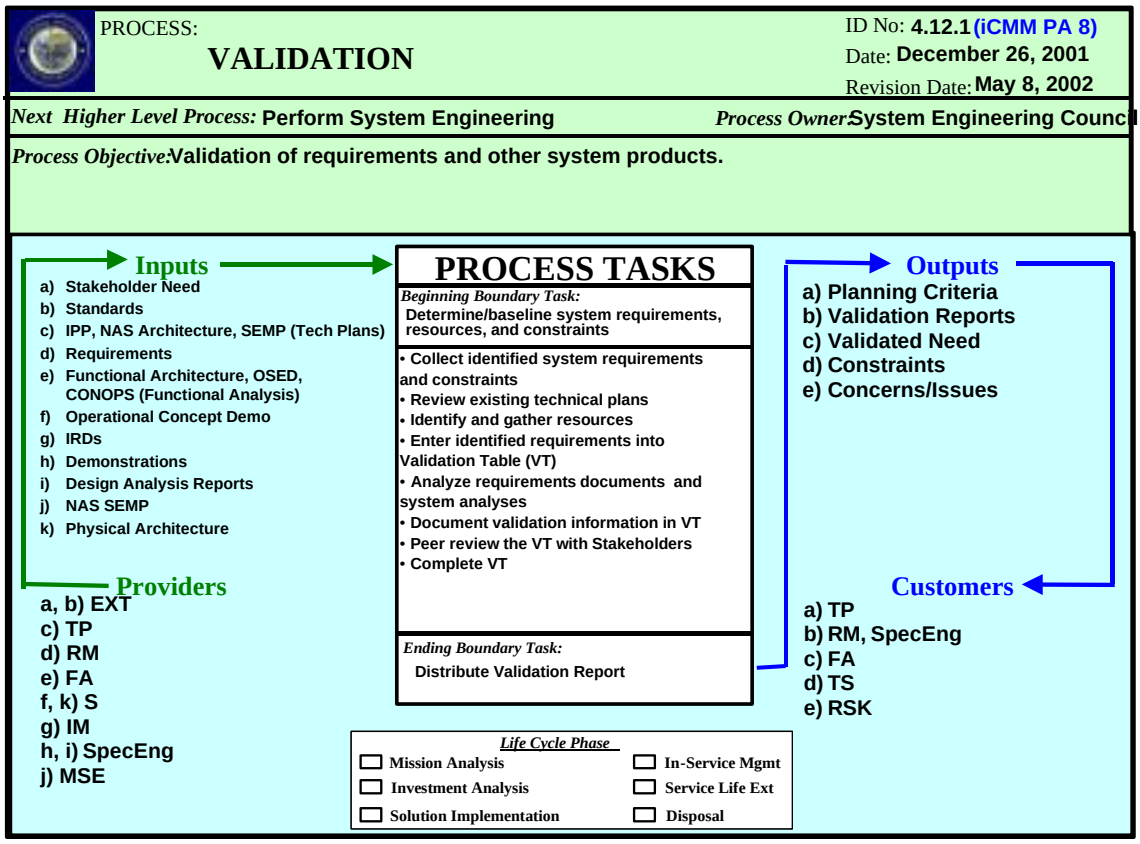


Figure 4.12-3. Validation Process-Based Management Chart

The Validation process is repeated incrementally at all stages of requirements development to ensure that the design at all levels is consistent with the intended mission. Validation follows the development of system requirements. Since these requirements are hierarchical in nature and developed in increasing detail as the lifecycle progresses, Validation is a staged process (Figure 4.12-4). Thus, as each level of requirements is developed, the requirements at that level undergo Validation, after which each validated requirement undergoes Verification.

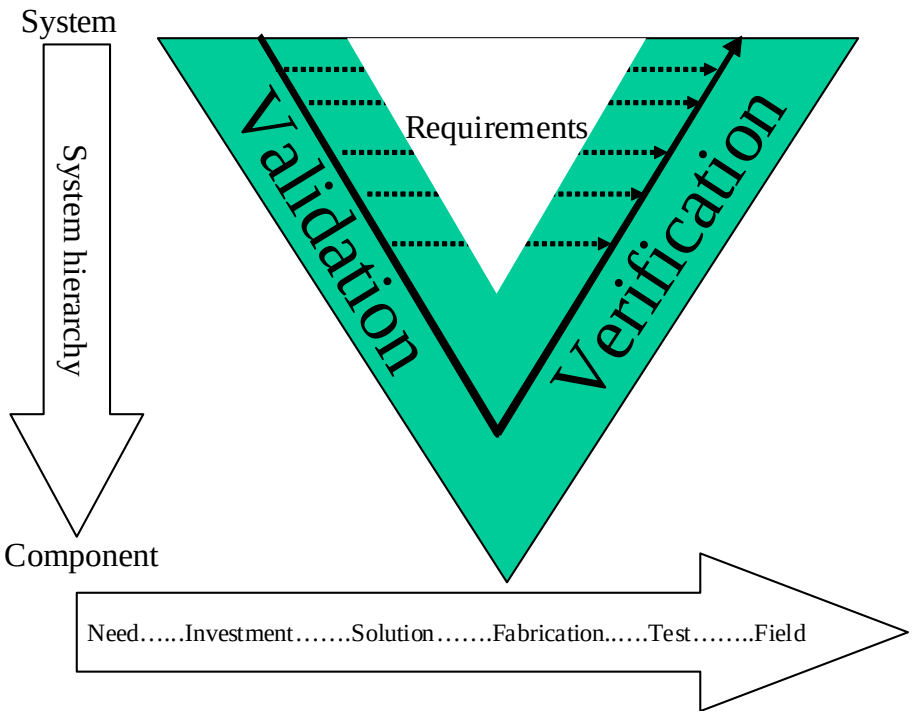


Figure 4.12-4. System Engineering "V" Diagram

A large part of this SE activity is challenging the requirements need and the requirements' associated values before development of solutions. This activity helps to ensure that an economy of effort exists on the project and that resources are not wasted on developing solutions for unnecessary requirements. At each stage, the Validation process provides increasing confidence of the correctness and completeness of system requirements.

4.12.1.1 Definition of Validation

There are multiple definitions of the Validation process, but, for the purposes of this manual and the Federal Aviation Administration (FAA), the accepted definition of the Validation process is:

> *"the determination that the requirements for a product are sufficiently correct and complete." (SAE ARP 4761, 1996)*

4.12.1.2 Objective of Validation

The primary objective of the Validation process is to ensure that requirements are correct and complete. In addition, the Validation process ensures that requirements defined for a system

are consistent with the characteristics listed in Requirements Management (Section 4.3). Successful Validation confirms that the identified requirements are justified, relevant, and logically correct in terms of the customer's needs and operating environment. In addition, the Validation process also ensures that the identified set of requirements is complete (i.e., containing all essential elements). To achieve Validation's objective, Validation activities are performed as early as possible in the development phase after requirements are identified; thus, Validation follows requirements development and precedes design solution.

The Validation process is conducted in order to find and correct poor requirements, which stem from three sources:

- Ambiguous requirements statements
- Incorrect (including unnecessary) requirements statements
- Incomplete (or omitted) requirements statements

4.12.1.3 Interfaces With Other System Engineering Processes

The SE elements that interface with the Validation process appear in Figure 4.12-5 and are described in "Inputs to Validation" (Paragraph 4.12.1.4).

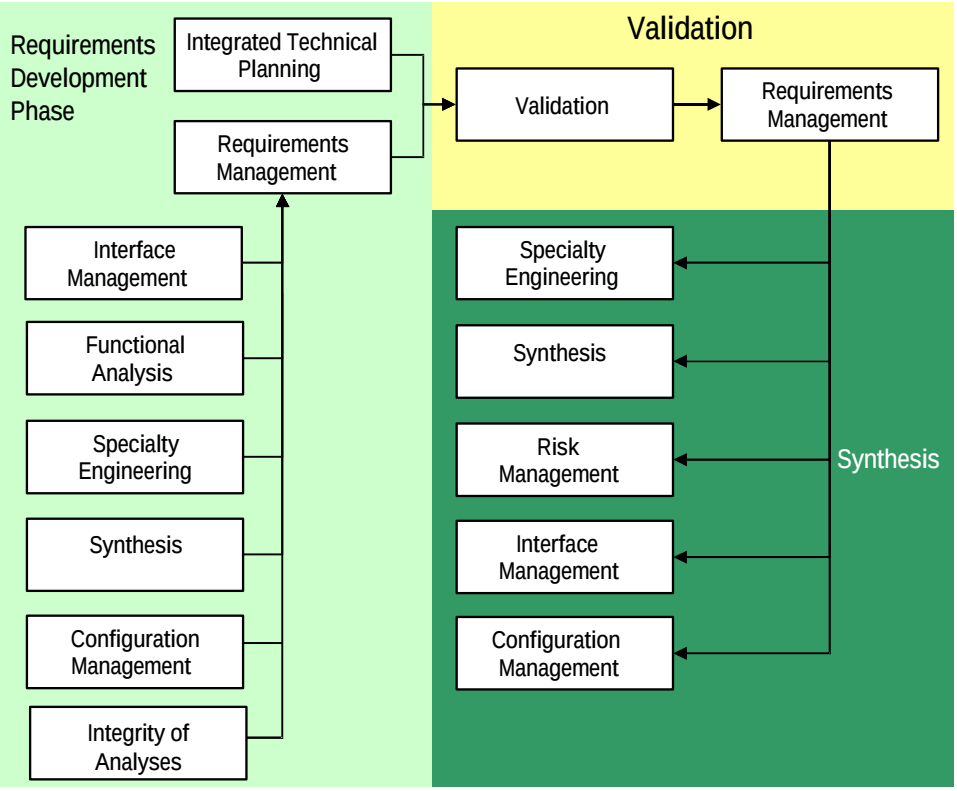


Figure 4.12-5. How Validation Interfaces with Other System Engineering Processes

4.12.1.4 Inputs to Validation

The inputs to the Validation process include:

- Stakeholder Needs
- Standards
- Technical Plans (Integrated Program Plan (IPP), National Airspace System (NAS) Architecture, and program System Engineering Management Plan (SEMP))
- Requirements
- Functional Analysis (Functional Architecture, Operational Services and Environmental Description (OSED), and Concept of Operations (CONOPS))
- Operational Concept Demonstrations
- Interface Requirements Document(s) (IRD)
- Demonstrations
- Design Analysis Reports (DAR)
- NAS SEMP
- Physical Architecture

4.12.1.4.1 Stakeholder Needs

The original Stakeholder Need generated from a NAS stakeholder (or stakeholders) to identify a capability shortfall requires Validation. Once a Stakeholder Need is validated, SE continues to ultimately provide a balanced solution to the need.

4.12.1.4.2 Standards

Industry and government standards are additional inputs to the Validation process. These documents often contain information required to validate the Requirements of a system not found in higher-level requirements documents. They include publications and standards from the Society of Automotive Engineers (SAE) and/or the International Organization of Standards (ISO), as well as U.S. Government advisory circulars and FAA regulations.

4.12.1.4.3 Technical Plans

Technical plans are an output of the Integrated Technical Planning process (Section 4.2). These plans define the program's tailored tasks for conducting Validation and Verification for a specific program. The IPP lays out the overall program and details the program's planned activities. The FAA Acquisition System Toolset (FAST) (http://fast.faa.gov/ams/ippdesc.htm) supplies a complete description of the IPP, and Integrated Technical Planning discusses SE's role in producing the IPP. In addition to the IPP, the program's SEMP and the NAS Architecture shall be used as inputs to the Validation process. The NAS Architecture is considered a part of the technical plans package in that it defines the FAA framework for future systems in the NAS. This architecture is a useful resource for validating the Requirements for systems developed for NAS Modernization.

4.12.1.4.4 Requirements

Requirements documents are outputs from the Requirements Management process (Section 4.3). These documents include the initial Requirements Document (iRD) and final

Requirements Documents (fRD) (as they become available), as well as supporting documents such as:

- Program and technical requirements
- Customer operational requirements, including the Mission Need Statement (MNS)
- Regulatory, agency, and statutory requirements

The Requirements are classified under several categories described in “Requirements Category” (Paragraph 4.3.3.2.1.4.3). The two major categories are (1) program requirements and (2) technical requirements. Program requirements are imposed on vendors through contracts, not specifications. Technical requirements apply to the system or service under acquisition, and they are described in requirements documents, system specifications, and IRDs.

4.12.1.4.5 Functional Analysis

The Functional Analysis process (Section 4.4) is an SE tool that provides a functional (what the system does, not how) description of a system that becomes a framework for synthesis and requirements development. It is recommended that the output of this process be used to validate Requirements. The outputs of this process are:

- Functional Architecture(s)
- OSED; RTCA/DO-264, Appendix C, System Safety Handbook (SSH), Sections 4.1.1 and 3.8
- CONOPS

4.12.1.4.6 Operational Concept Demonstrations

Operational Concept Demonstrations (“Demonstrations” (Paragraph 4.8.0.4.8)) are conducted to determine and validate high-risk Requirements associated with an unvalidated CONOPS.

4.12.1.4.7 Interface Requirements Documents

IRDs are another example of system design information. These documents, which are outputs of the Interface Management process (Section 4.7), provide a deeper understanding of the underlying interfaces, functions, and reasons for the Requirements. These descriptions include the system-level interface definitions. Part of the Validation of a system is the assurance that the Requirements for these interfaces are correct.

4.12.1.4.8 Demonstrations

Specialty engineers, as deemed necessary, often conduct Demonstrations (“Demonstrations” (Paragraph 4.8.0.4.8)) as part of analysis efforts (e.g., maintainability demonstration or human factors demonstrations). These Demonstrations provide useful feedback on the effectiveness and value of various design alternatives. Additionally, the Demonstrations may generate information for use while validating Requirements are being validated.

4.12.1.4.9 Design Analysis Reports

DARs are outputs of the Specialty Engineering process (Section 4.8). These reports document the results of the Specialty Engineering analyses, which may contribute to the identification, Validation, and Verification of Requirements.

4.12.1.4.10 National Airspace System System Engineering Management Plan

The NAS SEMP defines the overall plan for SE in the Acquisition Management System (AMS). This plan details *who, what, when,* and *why* SE tasks are performed in support of AMS programs. The System Engineering Manual (SEM), on the other hand, defines how the SE processes are performed.

4.12.1.4.11 Physical Architecture

The Physical Architecture is essentially the engineering design of the system that is produced via the Synthesis process (Section 4.5). This information may vary in detail, depending on the phase of the program. This input is essential so that the persons responsible for the Validation process understand the product Requirements and configuration (if available). Information includes:

- Drawings (if updating current systems, and if they exist in the Validation phase)
- Design descriptions
- System descriptions

4.12.1.5 The Validation Process

The following sections describe the purpose, general outcomes/expectations, and tasks of the Validation process.

4.12.1.5.1 Validation Process Purpose

Validation is primarily performed to ensure the correctness and completeness of the requirements that define a system. Aerospace Recommended Procedure (ARP) 4754, Paragraph 7.1, defines correctness and completeness as follows:

- Correctness of a requirements statement means the absence of ambiguity or error in its attributes
- Completeness of a requirements statement means that no attributes have been omitted and that those stated are essential

System requirements are analyzed to ensure that the defined set of Requirements is consistent with the operational need defined in the CONOPS, Specialty Engineering analyses, and MNS. The Validation process is conducted to provide objective evidence that the services provided by the system, as defined in the requirements document, comply with the Stakeholder Needs, as defined in the analyses, CONOPS, and MNS. When variances are identified, they are recorded and used to guide corrective actions. Because Validation is a comparative assessment of Requirements against needs, it also results in confirmation that Stakeholder Needs are correctly identified and requested. Stakeholders normally ratify Validation of Requirements at the system level.

"Task 5: Analyze Requirements Documents and System Analyses" (Paragraph 4.12.1.5.3.5) describes the desired attributes of Requirements. The Requirements Management (Section 4.3) also describes the desired attributes of individual Requirements.

4.12.1.5.2 Validation Process Objectives

The general objectives of the Validation process include:

- Development of the Validation Table and inclusion of the Validation Table in a Validation Report
- Appending to or referencing by the existing requirements documents of the Validation Report
- Confirmation that the system services required by stakeholders are properly documented in the Requirements
- Confirmation that the stakeholder requirements faithfully describe the required system services
- Reporting of nonconformance, which is used to guide corrective actions
- Traceability of all requirements to higher-level Requirements
- Documentation of the program's concerns/issues and constraints

4.12.1.5.3 Validation Process Tasks

All Requirements in all categories are required to be validated. In general, the Validation of higher-level Requirements serves as a basis of Validation for lower-level Requirements. The tasks involved in the Validation process are conducted in three phases: planning, evaluation, and documentation. The recommended process tasks for validating Requirements are shown in Figures 4.12-3 and 4.12-6 and are described in the following paragraphs.

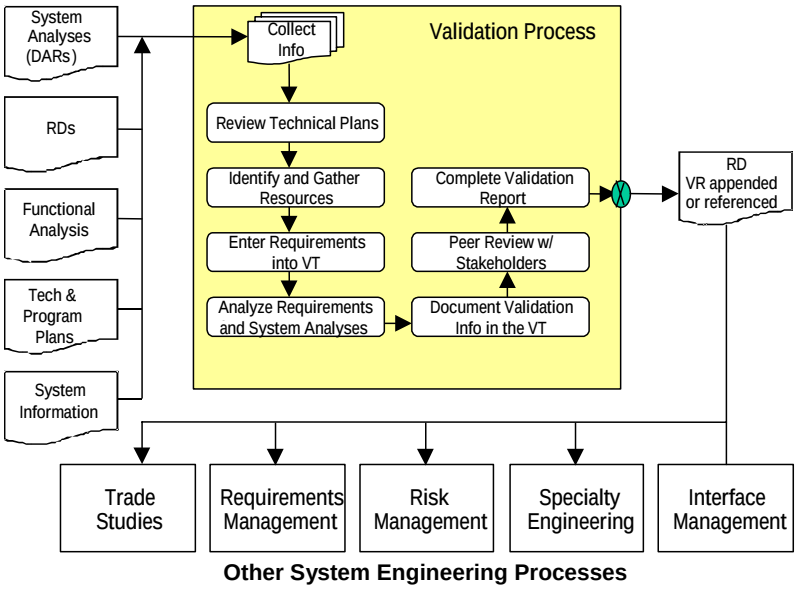


Figure 4.12-6. Overall Validation Process and Outputs

4.12.1.5.3.1 Task 1: Collect Identified System Requirements and Constraints

The initial step in the Validation process is to accept the set of Requirements to be validated from the Requirements Management process (Section 4.3). In addition, the information required for Validation is gathered, which documents the baseline system requirements, resources, and constraints. These documents are described in “Inputs to Validation” (Paragraph 4.12.1.4) and include the requirements documents, technical plans, and system description information.

4.12.1.5.3.2 Task 2: Review the Existing Technical Plans

The next step is to review the program and acquisition plans, such as the IPP and the MVP, if it exists. These plans include the Validation tasks to be performed; allocation of responsibility to organizations; schedule; and costs. The objective is to define the strategy for validating the system’s services in its operational environment and achieving customer satisfaction in accordance with these plans. This strategy depends on the lifecycle stage (e.g., whether a model, prototype, or actual product is being verified); on risks (e.g., novelty, safety, technical, and commercial criticality issues); and on the agreement and organizational constraints of the stakeholder requirements. It is required that, where appropriate, Validation steps (e.g., various operational states, scenarios, and missions) be defined that progressively build confidence in compliance of the installed system and assist diagnosis of any noncompliance.

NOTE

Where Stakeholder Needs are unable to be specified in advance or change frequently, repeated Validation of (often rapidly developed) increments in system evolution may be employed to refine stakeholder requirements and mitigate risks in the correct identification of need. For example, ISO 13407 describes an iterative lifecycle that involves users.

4.12.1.5.3.3 Task 3: Identify and Gather Resources

At this stage, the Validation resources are formed from the appropriate SE resources. These resources include tools, information, and organizations, including the execution teams, stakeholders, and SE.

4.12.1.5.3.4 Task 4: Enter the Identified Requirements Into a Validation Table

This step involves entering or copying the Requirements from the requirements document into a table, spreadsheet, database, or other SE tool appropriate to managing the Validation of Requirements. Table 4.12-1 shows an example of a typical Validation Table. Each Requirement and specification that defines a system, at all levels, shall be listed in a Validation Table.

Table 4.12-1. Example Validation Table

(PUI)	Requirement	Requirements Document or specification?	Validated? Y/N	Source(s)	Location in Source	Conformance information	Corrective Action Owner
Program Unique Identifier. Enter a unique number here to ID the Requirement. This ID is the paragraph number from the requirements document.	Copy the Requirement here verbatim from the requirements document and specification.	Identify where the Requirement is found.	Indicate whether the Requirement was validated.	…of Validation. Explain the source of the Validation, (e.g., a safety analysis or other means).	Where specifically in the source the Requirement is validated.	State conformance basis. If nonconformance is found, state recommended or required corrective action.	Organization or individual that owns the conformance or corrective action
3.2.1.1.1	The ADS-B system shall continue to operate normally in icing conditions up to heavy icing, as defined in 14 CFR FAR 25. (example only)	iRD	YES or check	IRD, ADS-B, OSA	IRD: Paragraph 3.2.1.1.1 OSA: Paragraph 2.5.5	System safety confirms that icing is expected in the operational environment description.	AND-710

4.12.1.5.3.5 Task 5: Analyze Requirements Documents and System Analyses

During Task 5, a review of the existing requirements documents is performed. Also during this task, the set of Requirements that is being evaluated for validity is compared to the existing higher-level requirements documents. The Validation of higher-level Requirements may serve as the basis for Validation of lower-level Requirements, if traceability is demonstrable. If the existence of a validated Requirement in a higher-level requirements document is shown, then lower-level Requirements that are traced from the validated Requirement may be partially validated on this basis. The lower-level Requirements still need to meet the characteristics listed in “Validation Process Purpose” (Paragraph 4.12.1.5.1). For example, assume that a Requirement is listed in a validated MNS and the current task is to validate the functional requirements. If the functional requirement is traceable to a Functional Architecture based on the MNS (higher level), then the functional requirement (lower level) is considered partially validated by virtue of this traceability. However, the functional requirement in this example still requires evaluation of the characteristics listed in “Validation Process Purpose.” Once complete, the Requirement is considered validated.

If a Requirement is not contained in a higher-level requirements document, then it is evaluated by detailed review of Functional Analyses, results of prototype evaluations, Specialty Engineering analyses in documented DARs, specified design guides, CONOPS, the NAS Architecture, and other industry and government standards that describe the system and assess the system’s needs and capability shortfalls. These documents often contain information needed to validate Requirements not found in higher-level requirements documents. In these

documents, the Verification team looks for candidate requirements, recommendations, functional requirements, and other information that confirm the need for the stated Requirement.

The following Validation principles shall be employed when performing Validation activities:

- Ensure that stakeholders and testers are an integral part of the Validation process
- Perform research and analysis to find information and/or related Requirements that confirm the need for a particular Requirement (e.g., a set of related Requirements may confirm the need and validity of a derived Requirement)
- Note Requirements that are unable to be confirmed; these Requirements are noted as nonconforming[1] and evaluated for removal in the Requirements Management process (Section 4.3)
- Conduct Validation activities to detect (in the system or services) the existence of random and systematic nonconformance to stakeholder requirements
- Ensure that the Validation process is undertaken in a manner consistent with defined and documented organizational practices to minimize uncertainty in the replication of Validation actions, conditions, and outcomes
- Maintain objective and authenticated records of Validation actions and outcomes
- Conduct fault resolution of a nonconformance in the Requirements Management process to a level of resolution consistent with cost-effective remedial action, including revalidating following defect correction and/or organizational quality improvement actions
- Conduct Validation activities to determine the correctness and completeness of the Requirements

When Validation is performed, the following correctness and completeness checks (may be tailored by expansion) shall be completed at each level of the Requirements hierarchy:

Correctness

1. Requirements correctly stated:
    - What is required (design independent)
    - Unambiguous
    - Statements lead to appropriate design
    - Achievable with current or emerging technology
    - Requirement is verifiable
    - Stated for appropriate environmental conditions (ambient and operational)

[1] Nonconformance means that a needed Requirement is missing, or an existing Requirement is unable to be validated. In accordance with agreement terms or organizational objectives, Validation is conducted to isolate the part of the system that gives rise to a nonconformance, which may result in the need for corrective action and/or changes in quality management policy. “Objective of Validation” (Paragraph 4.12.1.2) discusses the sources of nonconformance.

- Stated for normal and abnormal operations
- Derived Requirements supported by analyses
- Each Requirement has an identified source

2. Requirements correctly reflect the analyses:
   - Appropriate analyses completed correctly
   - System hazards correctly identified and classified according to risk
   - System characteristics in DARs correctly identified and classified
   - Reliability, availability, fault detection, and tolerances identified
3. Functions correctly identified:
   - Requirements based on functions
   - Functions significant to Requirements
   - Documented
   - Traced to higher functions
   - Constrained by higher-level Requirements

Completeness

1. Requirements traceable to an identified source:
   - Functional Analysis
   - Higher-level requirements documents
   - Safety assessments
   - Reliability, maintainability, and availability (RMA) analyses (Failure Modes and Effects Analysis (FMEA), Failure Modes and Effects Criticality Analysis (FMECA))
   - Requirements identified in DARs (Specialty Engineering" (Paragraph 4.12.2.3.4))
   - Derived Requirements
   - Regulations, standards, or statutory requirements
   - OSED
   - Integration requirements
2. Constraints defined, substantiated, and addressed:
   - State of the art
   - Safety
   - Environment
   - Industry and FAA standards
   - Specify system implementation

3. System implementation specified:
    - Functional analysis completed
    - Requirements allocated to systems
    - Architecture defined at each functional level
    - Interfaces (internal and external) defined—human, hardware, software, physical, functional, procedural, and environmental (ambient and operational)
4. All prohibited behaviors and characteristics explicitly stated
5. All technical performance measures explicitly stated

4.12.1.5.3.6 Task 6: Document the Validation Information in the Validation Table

During this task, Validation data is collected, classified, and collated in the Validation Table described in "Task 4: Enter the Identified Requirements Into a Validation Table" (Paragraph 4.12.1.5.3.4) and in accordance with criteria defined in the program and acquisition plans. This process categorizes conforming and nonconforming Requirements according to their source and corrective action owner. The Validation data is then analyzed to detect essential features, such as trends and patterns of failure, evidence of systemic failings, and emerging threats to system services.

4.12.1.5.3.7 Task 7: Peer Review the Validation Table With Stakeholders

During this task, the stakeholders of the system's Requirements are identified. Once the Validation Table is filled, the stakeholders review it. Stakeholder comments are incorporated into the table, and the table is finalized.

4.12.1.5.3.8 Task 8: Document the Requirements Validation Analysis in the Validation Table and Include the Validation Table in a Validation Report

The results of the Validation analysis are documented in the Validation Table, and the Validation Table is included in a Validation Report. The Validation Report is transmitted to Requirements Management (Section 4.3). This report is appended to or referenced by the requirements document.

The Validation Report summarizes the Validation effort and results and communicates the Validation Table to other SE processes. The following format shall be used as a guide for the contents and organization of a Validation Report.

Validation Report format:

I. Summary of Validation efforts and results
    a. Summarize the Validation results when locating conforming and nonconforming Requirements

II. System and program description

III. Methodology used

IV. Unvalidated Requirements

a. List of nonconforming Requirements

b. Recommendations for correction of nonconforming Requirements

V. Validation Table

VI. Discussion of trends and patterns of failure, evidence of systemic failings, and emerging threats to system services.

4.12.1.6 Tailoring of Validation Activities

Tailoring of a program's Validation activities is limited to the following:

- The specific means of Validation may include the techniques and tools employed and described in SAE ARP 4754, Section 7.7, if desired by the program
- The specific contents of the Validation Report may be tailored to include additional information as specified in "Task 8: Document the Requirements Validation Analysis in the Validation Table and Include the Validation Table in a Validation Report" (Paragraph 4.12.1.5.3.8)

4.12.2 Verification

The Verification process ensures that the design solution has met the system requirements and that the system is ready for use in the operational environment for which it is intended. This description means that a verified system is able to demonstrate (show evidence) that it complies with mission need; functional, performance, allocated, derived, and interface requirements; and design and allocated constraints that achieve stakeholder needs. The Verification process (Figures 4.12-4 and 4.12-7) supports system evolution at all levels of the system's lifecycle, from concept to advanced studies and preliminary analyses to design and development, culminating in the production, product acceptance, operational, and disposal phases.

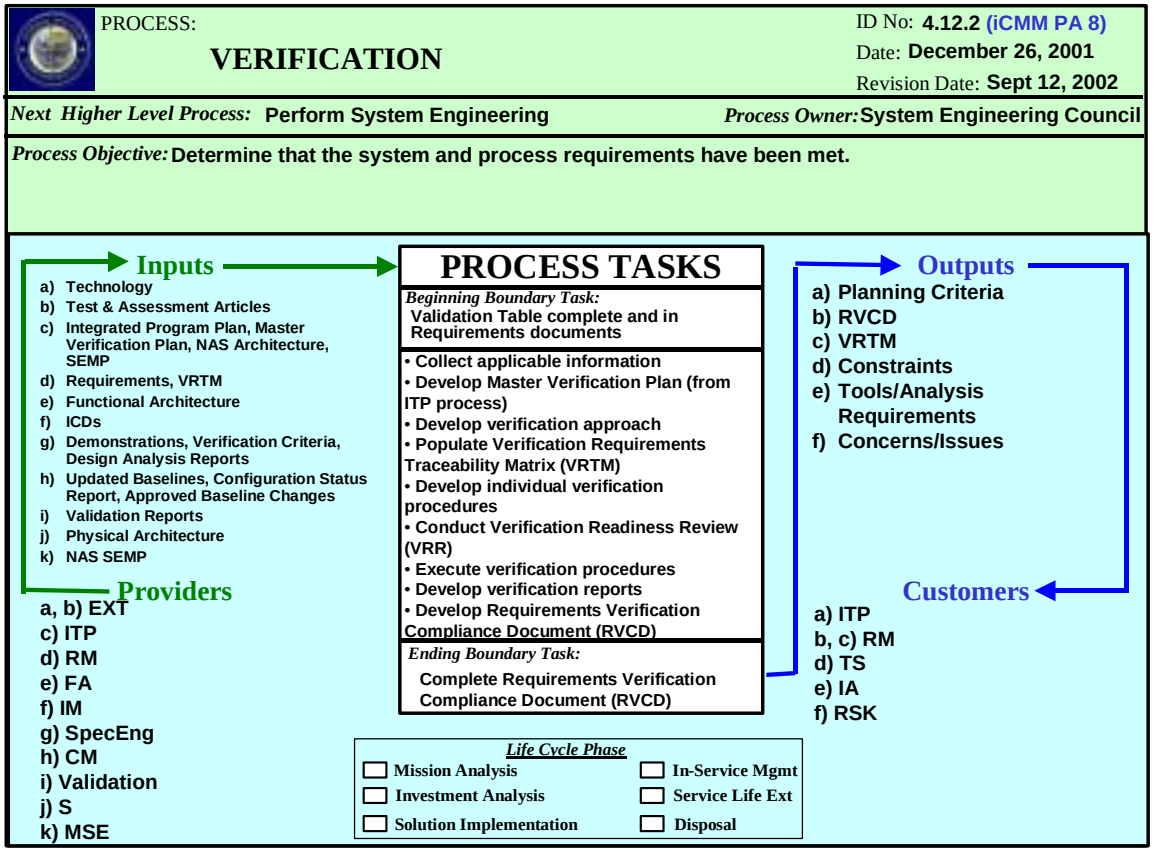


Figure 4.12-7. Verification Process-Based Management Chart

4.12.2.1 Objectives of Verification

The major objectives of the Verification process are to confirm that:

- Intended functions are correctly implemented and that the system is operationally ready and acceptable to the users
- Requirements are satisfied
- Specialty Engineering analyses, including lifecycle, remain valid for the system as implemented

Successful Verification confirms that the development process has provided a system consistent with stakeholder needs and compliant with the system's validated requirements. It is a basic principle to verify all requirements in the system's requirements documents. This principle does not imply that a test is required for every requirement, but it does imply the need to conduct some form of Test and Evaluation (T&E) and/or SE Assessment at an appropriate level to ensure that all requirements are satisfied.

The broad range of product development cycles and levels of product development complexity require that the Verification process be tailored to each project.

The expected outcomes of Verification are the development of:

- MVP (from the Integrated Technical Planning process (Section 4.2))
- VRTM
- Individual T&E and SE Assessment plans
- T&E procedures
- Verification Readiness Reviews (VRR) (if applicable)
- T&E and SE Assessment reports, which detail specific test results and assessments
- RVCD, which provides documentation that the system product conforms to system requirements and includes nonconformance reports

4.12.2.2 Definition of Verification

The accepted definition of verification for this manual and the FAA is:

> *"the evaluation of an implementation [system] to determine that applicable requirements are met." (SAE ARP 4761, 1996)*

Verification is the composite of all tasks, actions, and activities performed on system elements that are required in order to evaluate the progress and measure the effectiveness of evolving system products and processes in meeting system requirements. There are two basic and complementary methods of Verification: T&E and SE Assessment, as shown in Figure 4.12-8.

4.12.2.2.1 Test and Evaluation Verification

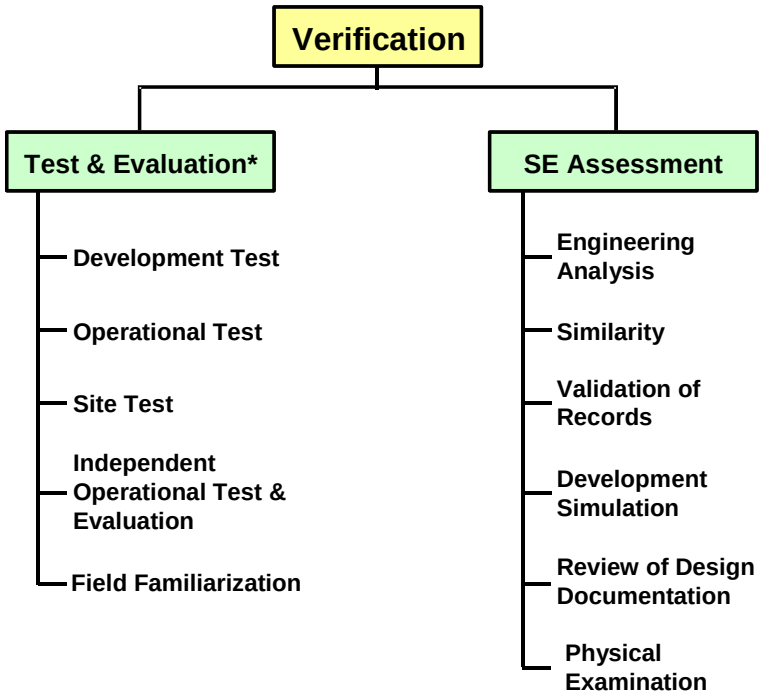
It is recommended that T&E programs be structured to:

- Provide essential information to support decisionmaking
- Provide essential information to assess technical and acquisition risk
- Verify the attainment of technical performance specifications and objectives
- Verify that a system is operationally effective and suitable for its intended use

It is also recommended that T&E objectives for each AMS lifecycle phase be designed to mitigate potential operational risks and to demonstrate system performance appropriate to that phase. Quantitative criteria provide substantive evidence for analysis of hardware, software,

and system maturity and readiness to proceed through the acquisition management process.

Figure 4.12-8. Components of Verification



*** For more information, refer to the Test and Evaluation Process Guidelines Document on the FAA AMS Toolset (http://fast.faa.gov).**

It is recommended that each T&E phase have specific milestones (entrance and exit criteria) that are satisfied before the next T&E phase is entered. Parallel testing is encouraged when it is more efficient and at least as effective as serial testing.

It is highly desirable that system performance be established by test under actual (or simulated) operating conditions; however, these conditions may not be possible until the system is deployed. Problems uncovered at deployment are costly to correct; therefore, a combination of inspection, analysis, and test often is employed during program development to detect problems early, thereby reducing risk and helping to ensure a successful, cost-effective program.

Compliance with each requirement in a specification shall be verified by one or more of the methods described in this manual and as indicated in the VRTM.

T&E methods include:

- **Verification by Demonstration**. This method includes Verification accomplished by operation, adjustment, or reconfiguration of items performing their design functions under specific scenarios. The items may be instrumented and quantitative limits of performance monitored; however, only check sheets are required rather than recordings of actual performance data. This method is used when actual demonstration techniques may be used to verify compliance with a requirement. Observations made by engineers or instrumentation are compared with predetermined responses based on the

requirements. An example of this Verification method is the demonstration of installing and uninstalling an aircraft engine in a specified amount of time . Demonstration is often used to verify compliance with requirements in servicing, reliability, maintainability, transportability, and human factors engineering.

- **Verification by Test**. This method is accomplished through systematic exercising of the application item under appropriate conditions, with or without instrumentation, and the collection, analysis, and evaluation of quantitative data.
- **Verification by T&E Analysis**. This method is accomplished by technical or mathematical evaluation, mathematical models or simulation, algorithms, charts, circuit diagrams, and representative data.
- **Verification by Inspection**. This method is accomplished by visually examining the item, reviewing descriptive documentation, and comparing the appropriate characteristics with predetermined standards to determine conformance to requirements without the use of laboratory equipment or procedures. Inspection is generally nondestructive and uses the senses of sight, hearing, smell, touch, and taste; simple physical manipulation; mechanical and electrical gauging and measurement; and other means of investigation. Inspection often verifies the physical design features of a system as well as construction features, workmanship, dimensions, quality, and physical conditions, such as cleanliness, installation, and finishing. Inspection may include reviews of documentation, system descriptions, and other materials to compare the actual system with predetermined standards.

The Test and Evaluation section of the FAST (http://fast.faa.gov/toolsets/index.htm) provides specific guidelines to conduct T&E.

4.12.2.2.2 Verification by System Engineering Assessment

It is recommended that Verification by SE Assessment be conducted to support the development of products, services, and processes necessary to verify that system end-items satisfy their requirements. Verification assessment addresses Verification requirements and criteria for solution alternatives; definition of Verifications to demonstrate proof of concept; and development, qualification, acceptance, pertinent operational, and other testing. The assessment may also consider the requirements and procedures needed to verify critical Verification methods and processes (e.g., Verification of key methods and assumptions and the data used in Verification by analysis).

It is suggested that Verification assessment be initiated when a design concept is established. The Verification assessment is drawn from the MVP and the results of the Validation effort. According to the Integrated Technical Planning process (Section 4.2), the objective of the MVP is to define all Verification activities that demonstrate the system's capability to meet the requirements of its specification. These activities shall be fully integrated to ensure that adequate data is provided at minimum cost within the allotted timeframe. A continuing feedback of Verification data throughout product development, test, and evaluation is necessary to reduce risk and to detect problems early. The goal is to completely verify the system's capability to meet all requirements before production and operational use.

SE Assessment methods include:

- **Verification by Engineering Analysis**. This process includes the techniques of SE analysis, Specialty Engineering, statistic and qualitative analysis, simulations, and modeling. Engineering analysis is used when testing is not feasible, similarity is nonapplicable, and inspection is inadequate.
- **Verification by Similarity**. This process assesses compliance with requirements by reviewing a similar system's test data, configuration, and applications. This method is only used when the systems are similar in design and manufacturing, and the prior system was qualified to equivalent or greater specifications. Great care is taken to ensure that the intended application environment of the emerging system is identical or less rigorous than the environment of the previous system testing.
- **Validation of Records**. This process reviews manufacturing records at end-item acceptance to verify features and requirements of the system.
- **Simulation**. This process verifies design features, system behavior, and performance using simulated models of the system.
- **Review of Design Documentation**. This process uses the disciplined review of design documentation, such as reports and drawings from Acquisition Reviews, Design Reviews (preliminary and critical), and other evaluations.
- **Physical Examination**. This process assesses compliance with requirements by visually inspecting a physical item or configuration according to preestablished criteria.

4.12.2.3 Interfaces With Other System Engineering Processes

Verification has multiple interfaces with other SE elements. These interfaces are shown in Figure 4.12-9 and described in the following paragraphs.

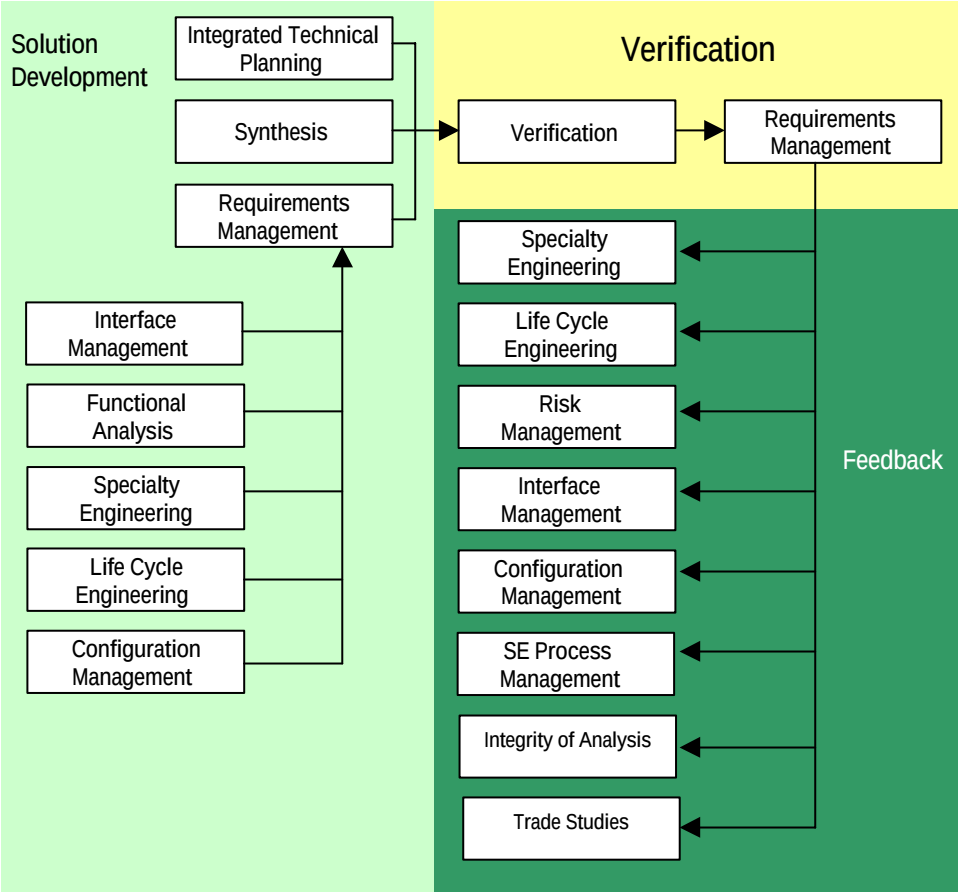


Figure 4.12-9. Verification Interfaces With Other System Engineering Elements

4.12.2.3.1 Requirements Management

Requirements documents are outputs from the Requirements Management process (Section 4.3). These documents include the iRD and fRD, as well as underlying documents, such as customer operational requirements, system and technical requirements, and regulatory, agency, and statutory requirements. These documents also include the MNS and any Verification specification documents. The execution teams manage these documents.

4.12.2.3.2 Synthesis

System, subsystem, component, and procedural designs comprise the outputs of the Synthesis process (Section 4.5). The information contained in these designs and, in some cases, test articles and/or prototypes is required for Verification.

4.12.2.3.3 Integrated Technical Planning

Technical plans are an output of the Integrated Technical Planning process (Section 4.2). They define the program's tailored tasks for a specific program. The IPP lays out the overall program; The MVP comes from the Integrated Technical Planning process but is a separate plan.

4.12.2.3.4 Specialty Engineering

Specialty Engineering (Section 4.8) both feeds and is fed by the Verification process. Specialty Engineering often is a source of requirements and design constraints that require Validation and Verification. In addition, Specialty Engineering analyses often are used to assist in the Verification of requirements as part of assessment. Specialty Engineering DARs are the major outputs of the Specialty Engineering process. These reports document the results of the Specialty Engineering analyses, which may result in the identification and Validation and Verification of requirements. Once Verification is complete, the verified requirements are checked to ensure that the Specialty Engineering DARs reflect the Verification.

4.12.2.3.5 Risk Management

Risk Management (Section 4.10) is another SE element that both feeds and is fed by the Verification process. Risk Management is able to drive the Verification of high-risk requirements. In addition, all requirements that fail to meet verification criteria are considered a risk to the program. These requirements become inputs to the Risk Management process for mitigation.

4.12.2.3.6 Interface Management

Results of the Interface Management process (Section 4.7) provide a deeper understanding of the underlying physical and functional interfaces of the system requirements. The interface documentation includes the system-level interface definitions.

4.12.2.3.6.1 Lifecycle Engineering

Lifecycle Engineering (Section 4.13) is another SE element that both feeds and is fed by the Verification process. This element provides supportability, deployment and transition, real estate and disposal requirements, and design constraints. These requirements and design constraints undergo the Verification process to ensure compliance.

4.12.2.4 Inputs to Verification

There are four major input categories to Verification:

- Technology
- Technical Plans
  - IPP
  - MVP
  - Program SEMP
  - NAS Architecture
- Requirements
  - Requirements documents and associated Validation Reports
  - VRTM templates populated with Requirements
- Design information and Test and Assessment articles

- Functional Architecture
- Physical Architecture
- Interface Control Documents (ICD)
- Demonstrations
- Verification Criteria
- DARs
- Updated Baselines
- Configuration Status Report
- Approved Baseline Changes

4.12.2.4.1 Technology

State-of-the-art Technology constrains the means of Verification. Therefore, it is critical that this factor be considered in the development of the Verification approach.

4.12.2.4.2 Technical Plans

These plans, developed via the Integrated Technical Planning process (Section 4.2), detail the overall vision for executing the program, including the timing and sequence of Verification. The plans that need to be collected to properly conduct Verification include the IPP, the MVP, and program SEMP. The NAS Architecture is also a valuable input in that it defines the FAA framework in which the system being verified eventually operates.

4.12.2.4.3 Requirements

Requirements documents are an output of the Requirements Management process (Section 4.3). These documents include customer operational requirements, as well as regulatory agency and statutory requirements. With Validation Reports (and associated Validation Tables) and Verification specifications included, these documents are the primary source of information for the Verification process. Phase-specific implementation teams maintain requirements documents. It is recommended that these documents include the most up-to-date information from interfaces, Functional Analyses, Specialty Engineering analyses, and system configuration.

4.12.2.4.4 Design Information and Test and Assessment Articles

This input is essential to understanding the product configuration. (Configuration Management (Section 4.11) supplies a complete description of this process.) To develop the MVP and the individual test plans, the system engineer needs any available design information, including Physical Architectures, drawings, interface documents, system design specifications, functional specifications, product specifications, and test equipment designs. This information also includes Specialty Engineering DARs used for the assessment. In addition, Functional Architectures and their associated analyses need to be available. The results of the Functional Analyses provide a deeper understanding of the underlying functions and reasons for the Requirements. ICDs, if they exist at the time of Verification, are also required. These documents provide detailed information on the interfaces involved in system operation. Part of the Validation and Verification of a system is the assurance that the Requirements for these

interfaces are correct and satisfied. The Test and Assessment Articles are the constituent pieces of the system, or the system in its entirety, on which Verification is performed.

4.12.2.5 The Verification Process

Verification is accomplished through a combination of T&E and SE Assessment. The general Verification process tasks are grouped into three distinct phases: planning, Verification activities, and documentation. Planning and documentation are common to both T&E and SE Assessment. Planning includes determination of the resources required, sequence and timing of activities, data and documentation to be produced, and establishment of the assessment criteria. The results of the planning effort are documented in the MVP. The documentation phase includes those tasks taken to ensure that evidence of completion is recorded and collated. The activity phase includes the processes or tasks in which the actual Verification methods are employed, whether they are T&E or SE Assessment. These processes are described below.

4.12.2.5.1 Process for Verification by Test and Evaluation

Specific guidelines for planning and conducting a T&E process are included in the FAA AMS Test and Evaluation Process Guidelines located under Test and Evaluation in the index of the FAST (http://fast.faa.gov/toolsets/index.htm).

4.12.2.5.2 Process for Verification by System Engineering Assessment

Verification by the SE Assessment is accomplished simultaneously and is fully coordinated with other SE processes—Integrated Technical Planning (Section 4.2); Requirements Management (Section 4.3); Interface Management (Section 4.7); Specialty Engineering (Section 4.8); and Risk Management (Section 4.10)—and test functions to ensure project costs, schedules, and risk implications are managed efficiently. The program plan for the Validation and Verification process is documented in specific detail in the MVP and in general in the IPP. Figure 4.12-10 depicts the overall Verification process.

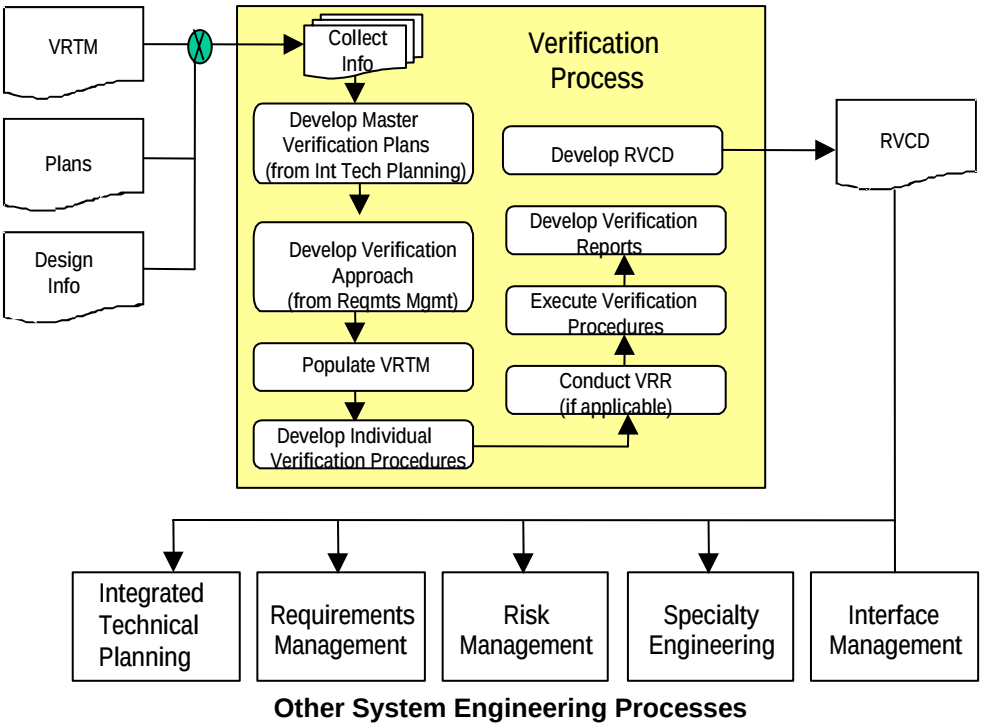


Figure 4.12-10. General Verification Process and Outputs

4.12.2.5.2.1 Verification Process Purpose

Through assessment of the system product, the Verification process demonstrates that system behavior and characteristics comply with the specified Requirements. Verification provides the information required to effect the remedial actions necessary to correct nonconformance in the realized system or the processes that act on it.

4.12.2.5.2.2 Verification Process Tasks

The recommended process tasks for conducting Verification of Requirements by SE Assessment are shown in Figure 4.12-7 and are described in the following paragraphs.

4.12.2.5.2.2.1 Task 1: Collect Applicable Information

At minimum, the inputs discussed in Paragraph 4.12.2.4 shall be collected and reviewed for impacts on the Verification process. For instance, the DARs generated by Specialty Engineering (Section 4.8) may have identified special Verification procedures or needs.

4.12.2.5.2.2.2 Task 2: Obtain Master Verification Plan From Integrated Technical Planning or Develop It Now

As the Verification approach is refined, the facilities, budget, schedules, personnel, test articles, instrumentation, and data necessary to accomplish the Verification events are also identified, coordinated, and approved with the appropriate decision authorities, resulting in an approved Verification plan for the program. This strategy and overall plan for the Verification process is documented in the MVP, which is delivered from the Integrated Technical Planning process (Section 4.2) to “Task 7: Execute Verification Procedures” (Paragraph 4.12.2.5.2.2.7). The MVP

is required to provide the content and depth of detail necessary for understanding the Verification activities. Each major activity is defined and described in detail. The MVP covers all qualification, acceptance, predevelopment, operational, and disposal Verification activities for hardware, software, and procedures. The MVP provides a general schedule and sequence of events for major Verification activities. It also describes test hardware and software, support equipment, and facilities required to support Verification activities. The MVP is developed by design, system, and test engineers with a thorough understanding of the requirements document, segment requirements and specifications, and Validation Table.

It is recommended that the following activities be completed during the planning stage:

- Identify the system and system configuration, including definition of test equipment and telemetry, facilities, and support equipment
- Identify and collate all Requirements appropriate to the (level of) Verification
- Define the specific Verification method employed for each Requirement
- Define the criteria used to evaluate the evidence from each Verification for each Requirement

4.12.2.5.2.2.3 Task 3: Develop Verification Approach

Simply put, the Verification approach is how the Requirements are going to be verified. This approach is developed in Requirements Management (Section 4.3) and documented in the VRTM. This task includes the activities of receiving, updating, analyzing, decomposing, and summarizing Requirements to ensure that they are economically and efficiently measurable and are able to be appropriately distributed for Verification planning. The purpose of the Develop Verification Approach activity is to determine and document the Verification approach to ensure that the product is compliant with the identified Requirements.

In this step, the Verification specification (from Requirements Management) is used to develop a Verification approach for each Requirement documented in the Validation Table. The Validation Table is further refined into a VRTM. The VRTM is the heart of the Verification process. The strategy or method used to verify each Requirement is specified in a Verification Requirement, and the Verification Requirements are listed in the VRTM. The VRTM defines how each Requirement (functional, performance, design, etc.) is to be verified, the stage in which the Verification is to occur, and the applicable Verification levels. The VRTM essentially establishes the basis for the Verification program. SE and the Verification team develop the VRTM together. The T&E and the SE Assessment methods available for use are discussed in detail in Paragraphs 4.12.2.2.1 and 4.12.2.2.2. Table 4.12-2 is an example VRTM. Specific guidelines for the VRTM are included in the Test and Evaluation section of the FAST (http://fast.faa.gov/toolsets/index.htm).

Table 4.12-2. Sample Verification Requirements Traceability Matrix

Section 3 Requirements Paragraph Reference for Specification SCN (Paragraph No./Title)	Requirement Description	Verification Method (Test, Demonstration, Analysis, Inspection, Engineering Analysis, Similarity, Validation of Records, Simulation, Documentation)	Verification Plan (Indicate which plan describes the Verification of the requirement)	Remarks
3.1.1.1 Aircraft I.D.		T = Test		
3.1.1.2		D = Demonstration		
3.1.1.3		A = Analysis		
3.2.1.1 System Alignment		I = Inspection		
3.3.1.1 Transmit Time		EA = Engineering Analysis		
3.3.1.2 Receive Time		SY = Similarity		
3.3.1.3 Process Time		VR = Validation of Records		
3.3.1.4 Display Time		SM = Simulation		
3.3.1.5 System Check		DC = Documentation		

4.12.2.5.2.2.4 Task 4: Populate the Verification Requirements Traceability Matrix

Verification is performed at all levels in a system. Each Requirement is verified either by test, SE Assessment, or both, as appropriate. As mentioned earlier, the strategy or method used to verify each Requirement is specified in a Verification Requirement, and the Verification Requirements are documented in the VRTM. It is recommended that a description of the test or SE Assessment and the criteria used to determine conformance and disposition of each Verification Requirement be included in the VRTM.

4.12.2.5.2.2.5 Task 5: Develop Individual Verification Procedures

This process is the detailed development of Verification procedures and resources that achieve specified Verification objectives using approved agency and regulatory procedures. Specific guidelines on content and format are included in Sections 6 and 7.1 of the FAST and Test and Evaluation Guidelines (http://fast.faa.gov/toolsets/index.htm).

The product Verification procedures consist of step-by-step directions to conduct the actual product Verification at any level. Traceability to all Requirements in the VRTM shall be shown as an integral part of these procedures. The procedure is tailored to the Verification activity that is to be performed to satisfy Requirements and may be a test, SE Assessment, or a combination of both. The as-run and certified copy of the procedure is maintained as part of the project's archives as test or SE Assessment plans.

All Verification procedures for both hardware and software include development of test plans, procedures, and test cases. The process includes performing timing and sizing analysis Verification at the subsystem and system levels. The results of these analyses are maintained in the test or SE Assessment plans.

The process also performs abnormal and erroneous condition testing at the subsystem and system levels. The process includes the use of regression test procedures for hardware and software integration, subsystem test, and integration and system test, including the use of a core test process, if planned.

The Verification process incorporates any commercial-off-the-shelf (COTS) software or hardware in the system integration and test planning.

4.12.2.5.2.2.6 Task 6: Conduct Verification Readiness Review

A VRR or equivalent is held before each major Verification or groups of smaller Verifications with common elements. The VRR is conducted to ensure that all SE considerations are satisfied and that the readiness of all support, test, and operational systems is in order to perform the Verification process. The VRR includes a detailed review of the status of the facilities, ground support equipment, Verification design, software, procedures, and Verification Requirements. In addition, Verification activities and schedules are outlined, and organizational/personal responsibilities are identified. Emphasis is on ensuring that all Verification Requirements identified for each Verification method or technique are included in the Verification design and procedures.

A key feature of the Verification approach is the non-advocate aspect (i.e., it is a principle of the Verification process that the person or group performing the design not execute the Verification activities). The same principle applies to planning and conducting the Verification design itself. The VRR is conducted to ensure that Verification activities are planned adequately and that risks are controlled. It is recommended that the VRR be chaired by senior personnel not associated with the program but who possess some expertise in the systems and operations under evaluation. The program implementation teams manage the VRR.

4.12.2.5.2.2.7 Task 7: Execute Verification Procedures

This task is the actual product of the Verification process (i.e., the conduct of tests or SE Assessment). The process of product Verification confirms through documented evidence of Verification activities that production-representative hardware and software are in compliance with functional, performance, and design requirements.

The Verification team is responsible for performing product Verification, which consists of preparation for product Verification, execution of product Verification activities, and product post-verification and documentation. Specific guidelines for the test process are found in the Test and Evaluation Guidelines in the FAST (http://fast.faa.gov/). When performing test Verification, the Verification team shall consult this document for specific instructions. Specialty Engineering (Section 4.8) supplies specific guidelines on conducting system (specialty) engineering assessments.

Responsibilities of the Verification team during the preparation phase of a Verification program using testing and demonstration may include:

- Design, fabrication, and/or preparation of the Verification setup

- Verification facility
- Verification fixture and/or stations
- Data acquisition, reduction, and archive system
- Verification control system
- Instrumentation system
- Design and fabrication of Verification article hardware/software
- Conduct of make-or-buy analyses for Verification setup hardware and software
- Coordination of Verification article delivery
- Coordination of Verification setup hardware/software delivery
- Coordination of support equipment and special Verification
- Preparation of Verification safety, hazard, and environmental compliance plans
- Assembly and installation of the Verification article, fixture, and setup
- Implementation of serial numbered component installation/removal records
- Installation of Verification instrumentation
- Preparation of instrumentation installation drawings
- Implementation of instrumentation installation/removal records
- Management of Verification configuration control
- Verification articles
- Instrumentation and measurements
- Data acquisition and reduction system
- Verification support software
- Checkout and maintenance of the Verification setup hardware and software
- Coordination of Verification article configuration buyoff and/or conformity approval inspections
- Conduct of preverification conference or VRR (or equivalent)
- Management and status reporting of Verification preparation activities

During the preparation phase, quality-control members of the Verification team establish/verify conformity of Verification articles, establish/verify conformity of the Verification methods, and check/verify systems and operations.

Responsibilities of the Verification team during the product Verification execution may include:

- Maintenance of detailed Verification notes/logs, including all deviation from the MVP
- Management of Verification configuration control
- Verification facility
- Verification fixture and/or stations

- Verification article
- Instrumentation and measurements (if required)
- Data acquisition and reduction system (if required)
- Verification support software
- Coordination of Verification article configuration and/or conformity approval inspections (if required)
- Coordination of Verification witnessing
- Checkout and maintenance of the Verification setup hardware and software
- Management of calibrated equipment (if required)
- Execution of Verification in accordance with approved MVP
- Validation, collection, reduction, archive, and delivery of Verification data
- Management and status reporting of Verification activities
- Conduct of post-verification inspections
- Identification of readiness criteria for formal and informal system and subsystem test
- Conduct of unit tests on software code changes before they are incorporated; review of software code changes for correctness and the avoidance of undesired impact on other software and system variables and components

4.12.2.5.2.2.8 Task 8: Develop Verification Reports

When product Verification is complete, the Verification team is responsible for conducting a post-verification review and preparing a report to disseminate the results. The purpose of the Verification report is to determine compliance with the Verification Requirements.

Documentation of product Verification is completed by the Verification team and distributed to all interested parties. This documentation includes reports that detail the Verification results, including nonconformances, failure analyses, and other findings.

It is recommended that a Verification report be provided for each test and SE Assessment and, at minimum, for each major Verification activity. If testing occurs over long periods of time or is separated by other activities, Verification reports may be required for each individual Verification activity. It is recommended that Verification reports be completed within a few weeks following a test and include evidence of compliance with the Verification Requirements for which it was conducted. The Verification report documents the steps that were taken to ensure that the Verification process was followed and that the Verification decisions were sound.

Guidelines for developing and formatting specific types of T&E reports are specified in the Test and Evaluation section (specifically, Section 6) of the FAST (http://fast.faa.gov). For Verification by SE Assessment, it is recommended that the Verification report be documented as a DAR, as defined in Specialty Engineering (Section 4.8).

4.12.2.5.2.2.9 Task 9: Develop Requirements Verification Compliance Document

The RVCD provides the evidence of compliance for each Requirement at all levels and to each VRTM Requirement. The flow down from the requirements documents to the VRTM completes the full Requirements traceability. Compliance with all the Requirements ensures that the system-level Requirement have been met.

The RVCD defines, for each Requirement, the methods of Verification and corresponding compliance information. The results of the Verification activity, including evidence of completion, are recorded and documented in the RVCD. The RVCD contains information regarding the results of each Verification activity and a description and disposition of conformance, nonconformance, conclusions, and recommendations. The compliance information provides either the actual data or a reference to the location of the actual data that shows compliance with the Requirement. The document also includes a section that details any noncompliance; this section specifies appropriate reverification procedures. The RVCD is an input to the Requirements Management process (Section 4.3); decisions regarding what to do with noncompliant Requirements are made during this process.

The specific compliance information may reference a test or SE Assessment report, automated test programs, or any other data generated in the Verification process. These inputs usually occur over a lengthy period of time and may be continuous on large programs.

Up-to-date information shall be maintained in the compliance document (RVCD) for the VRR for elements already verified. The RVCD is not baselined because it is updated throughout the program's lifecycle.

The purpose of this process is to analyze the data and results from "Task 7: Execute Verification Procedures" (Paragraph 4.12.2.5.2.2.7). If the Requirements have not been satisfied, coordination shall occur (with customer/stakeholder involvement, as necessary) to determine the impacts on the Requirements, design, and Verification approach. As a result of the impact analysis, compliance reports are generated, and the appropriate action(s) regarding the noncompliance are taken. This activity is iterative and shall be performed each time "Task 7: Execute Verification Procedures" is initiated. It is recommended that compliance reports include Requirements' identification information, compliance status, and Verification approach information.

The Validation and Verification process is completed when the information in the RVCD documents that all identified Requirements have been addressed by Verification activities and the product is compliant. When product Verification is completed, SE is responsible for completing/updating the RVCD.

4.12.2.6 Disposal of Resources

This process obtains formal direction or consent for shipment, contract transfer, sale, scrap, donation, or abandonment of Verification activity resources. Disposition ensures the safe deactivation and disposal of all system products and processes and that Verification necessary to establish compliance with disposal requirements are finished.

Once product Verification is completed, accepted, and documented by SE and the Verification team, the Verification team is responsible for identifying unused, excess, or obsolete Verification resources. Depending upon resource ownership, required disposal documentation is submitted,

and resource disposal is accomplished. All resource disposal actions are documented and filed or archived, as required.

4.12.3 Outputs of Validation and Verification

The major outcomes of the Validation and Verification process are:

- Planning criteria for the Integrated Planning (Section 4.2) process to develop and complete the MVP (as well as the IPP and program's SEMP)
- Constraints that may affect Trade Studies activities (Section 4.6)
- Concerns/issues (Appendix D) for the Risk Management process (Section 4.10) to analyze
- Outputs unique to the Validation process
  - Validated Need
  - Validation Table documented in the Validation Report
- Outputs unique to the Verification process
  - VRTM populated with Verification results
  - RVCD
  - Tools/Analysis Requirements for conducting planned Verification approach(es)
  - T&E and SE Assessment plans (internal to Validation and Verification)
  - VRRs (internal to Validation and Verification)
  - Verification documentation, including Verification reports (internal to Validation and Verification)

4.12.4 Validation and Verification Tools

There are several dedicated tools available to assist in managing the relationship between requirements, their validity, and their verification method. The selection of tool(s) shall ensure that the data is transportable and able to be integrated with other related SE results. A list of tools that may be used to facilitate this process is available on the International Council on System Engineering Web site (www.incose.org). Smaller projects may successfully manage these relationships with a simple spreadsheet or database application instead of a dedicated tool. (The Validation Table (Table 4.12-1) and the VRTM (Table 4.12-2) further illustrate this topic.)

4.12.5 Unique Tailoring Guidance

The Verification team of a specific project may select the particular means of Verification for that project. For small projects, the project team may perform the function of the Verification team. The project team may perform both the SE and the Verification team functions. Regardless of the scope of the project and depending on the required or desired visibility into the Validation and Verification process, the project team may consider merging the Validation table, VRTM, and compliance data into one consolidated table. Such a consolidated view may be readily produced with any of the following: a simple spreadsheet application (e.g., Microsoft Excel), a robust requirements traceability application (e.g., DOORS), or a relational database application (e.g., Oracle or Microsoft Access). These tools or similar tools may be used to produce this

macro-level view with the capability to filter to some lesser view as needed. Table 4.12-3 illustrates this overarching consolidation view.

Table 4.12-3. Sample Validation and Verification Traceability and Compliance Table

Validation								Verification Traceability						Verification Compliance			
Source Doc (*)	PUI	Reqmt	Valid (Y/N)	Valid Source(s)	Location in Source	Corr Action	Actionee	Method				Level	Verif Reqmts Traceability	Verif Task	Plan Ref	Report Ref	Verif Status
								Test	Anal	Demo	Exam						

4.12.6 References

1. Blanchard, B. "SE Management." 2nd ed. New York: John Wiley & Sons, Inc., NY.
2. Blanchard, B., and W. Fabrycky. "Systems Engineering and Analysis." 2nd ed. Englewood Cliffs, New Jersey: Prentice Hall.
3. Defense Systems Management College. "Systems Engineering Fundamentals." Fort Belvoir, Virginia: Defense Systems Management College Press, 1999.
4. Grady, J.O. "A Grand Systems Development Course, Version 6.0." San Diego, California: JOG SE, Inc.
5. International Council on Systems Engineering. "Systems Engineering Handbook." Version 2.0. 2000.
6. National Aeronautics and Space Administration. "NASA SE Handbook." June 1995.
7. RTCA, Inc. "Guidelines for the Approval of the Provisions and Use of Air Traffic Services Supported by Data Communications." RTCA DO-264.
8. Society of Automotive Engineers. "Certification Considerations for Highly-Integrated or Complex Aircraft Systems." Society of Automotive Engineering, Aerospace Recommended Practice ARP-4754, 1996.
9. Society of Automotive Engineers. "Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment." Society of Automotive Engineering, Aerospace Recommended Practice ARP-4761, 1996.
10. Test and Evaluation Process Guidelines. FAA Acquisition Management System. July 2001 <http://fast.faa.gov/toolsets/index.htm>.

APPENDIX A: ACRONYMS

A

ABD	Architecture Block Diagram
AC	Alternating Current
AMP	Analysis Management Plan
AMS	Acquisition Management System
AND	Associate Administrator for NAS Development
ANSI	American National Standards Institute
APB	Acquisition Program Baseline
AR	Acquisition Review
ARP	Aerospace Recommended Procedure
ASR	Airport Surveillance Radar
ATM	Air Traffic Management
ATM	Automated Teller Machine

C

C&A	Certification and Accreditation
CCB	Configuration Control Board
CDRL	Contract Data Requirements List
CFD	Control Flow Diagram
CFE	Contractor-Furnished Equipment
CHI	Computer-Human Interface
CI	Configuration Item
CM	Configuration Management
CNS	Communications, Navigation, and Surveillance
CONOPS	Concept of Operations
COTS	Commercial-Off-the-Shelf
CSA	Comparative Safety Assessment
CSC	Computer Software Component
CSCI	Computer Software Configuration Item
CSE	Computer Software Elements
CSU	Computer Software Unit

D

DAR	Design Analysis Report
DC	Direct Current
DD	Data Dictionary
DFD	Data Flow Diagram
DoD	Department of Defense
DOORS	Dynamic Object-Oriented Requirements System

E

E^3	Electromagnetic Environmental Effects
ECP	Environmental Compliance Plan
EIA	Electronic Industries Alliance

EM	Electromagnetic
EMC	Electromagnetic Compatibility
EME	Electromagnetic Environment
EMI	Electromagnetic Interference
EPA	Environmental Protection Agency

F

FAA	Federal Aviation Administration
FAD	Functional Analysis Document
FAE	Federal Acquisition Executive
FAR	Functional Architecture Referencing
FAST	Federal Aviation Administration Acquisition System Toolset
FBR	Functional Baseline Review
FCC	Federal Communications Commission
FFD	Functional Flow Diagram
FISMA	Federal Information Security Management Act
FMEA	Failure Modes and Effects Analysis
FMECA	Failure Modes and Effects Criticality Analysis
FMES	Failure Modes and Effects Summary
FRACAS	Failure Reporting Analysis and Corrective Action System
fRD	final Requirements Document
FTA	Fault Tree Analysis

G

GAO	General Accounting Office
GPS	Global Positioning System

H

HERF	Hazard of EM Radiation to Fuels
HERP	Hazard of EM Radiation to Personnel
HMM/EE	Hazardous Material Management/Environmental Engineering
HWCI	Hardware Configuration Item

I

IA	Investment Analysis
IARR	Investment Analysis Readiness Review
IAW	In Accordance With
ICAO	International Civil Aviation Organization
ICD	Interface Control Document
iCMM	integrated Capability Maturity Model
ICR	Interface Change Request
IDEF	Integrated Definition for Function Modeling
IEEE	Institute of Electrical and Electronics Engineers, Inc.
I/F	Interface
IFR	Instrument Flight Rules
IM	Interface Management
IPP	Integrated Program Plan

IPS	Integrated Program Schedule
IR	Infrared
iRD	initial Requirements Document
IRD	Interface Requirements Document
IRT	Integrated Requirements Team
ISE	Information Security Engineering
ISO	International Organization for Standardization
ISRR	Initial System Requirements Review
ISS	Information Systems Security
ISSP	Integrated Safety System Program
ITP	Integrated Technical Planning
IWG	Interface Working Group

J

JRC	Joint Resources Council

L

LCE	Lifecycle Engineering

M

MA	Mission Analysis
M&C	Monitor and Control
MASPS	Minimum Aviation System Performance Standards
MIL-STD	Military Standard
MND	Mission Need Decision
MNS	Mission Need Statement
MOE	Measures of Effectiveness
MOPS	Minimum Operational Performance Standards
MRS	Mature Requirements Statement
MTBF	Mean-Time-Between-Failure
MTTR	Mean-Time-To-Restore
MVP	Master Verification Plan

N

N^2	N-squared
NAS	National Airspace System
NCP	NAS Change Proposal
NDI	Nondevelopmental Item
NIST	National Institute of Standards

O

OMB	Office of Management and Budget
OOA	Object-Oriented Analysis
ORD	Operational Requirements Document
OSA	Operational Safety Assessment
OSED	Operational Services and Environmental Description

OSHA	Occupational Safety and Health Administration
OSI	Open System Interconnection

P

PBM	Process-Based Management
PDR	Preliminary Design Review
PHA	Preliminary Hazard Analysis
PIN	Personal Identification Number
PRS	Primitive Requirements Statement
P-Spec	Process Specification
PTR	Program Trouble Report
PUI	Program-Unique Identifier

Q

QFD	Quality Function Deployment

R

RADHAZ	Radiation Hazard
RCM	Reliability-Centered Maintenance
RDGT	Reliability Development Growth Testing
RF	Radio Frequency
RFP	Request for Proposal
RM	Requirements Management
RMA	Reliability, Maintainability, Availability
ROM	Rough Order of Magnitude
RPG	Radar Product Generator
RVCD	Requirements Verification Compliance Document

S

SAE	Society of Automotive Engineers
SARP	Standards and Recommended Practices
SBD	Schematic Block Diagram
SDP	Software Development Process
SDR	System Design Review
SE	System Engineering
SEC	System Engineering Council
SEM	System Engineering Manual
SEMP	System Engineering Management Plan
SFRA	System Functional Requirements Analysis
SHA	System Hazard Analysis
SI	Solution Implementation
SOW	Statement of Work
SP	Special Publication
SpecEng	Specialty Engineering
SRVT	Safety Requirements Verification Table
SSAR	System Safety Assessment Report
SSE	System Safety Engineering

SSH	System Safety Handbook
SSHA	Subsystem Hazard Analysis
SSMP	System Safety Management Plan
SSP	System Security Plan
SSPP	System Safety Program Plan
SSWG	System Safety Working Group
STD	Standard
STD	State Transition Diagram

T

T&E	Test and Evaluation
TLS	Time Line Sheet
TPM	Technical Performance Measure

U

UML	Unified Modeling Language
URL	Uniform Resource Locator

V

VFR	Visual Flight Rules
VOR	Very High Frequency Omnidirectional Range
VRR	Verification Readiness Review
VRTM	Verification Requirements Traceability Matrix

W

WARP	Weather and Radar Processor
WBS	Work Breakdown Structure
WSP	Weather System Processor

APPENDIX B: SYSTEM ENGINEERING MANUAL GLOSSARY

TERM	DEFINITION
Acceptance Criteria	Various criteria that a system or component shall satisfy in order to be accepted by a user, customer, or other authorized entity.
Allocation	Top-down distribution of system-level requirements to the subsystem, element, component, or to the project team that delegated to meet the requirement. This approach tends to promote a top-down "system approach" in helping to establish specific design requirements for all levels of the system hierarchy as appropriate. The allocation process may be properly applied with reliability, maintainability, supportability, lifecycle cost, and related characteristics in mind. Allocation is also the assignment of performance requirements to functions.
Analysis	Logical examination or study of a system to determine the nature, relationships, and interaction of its parts and environment. Analysis emphasizes baseline system performance and/or compares development, production, or usage alternatives. Analysis is concerned with understanding the existing system and establishing the system requirements. Analysis is also a type of verification. It may be any kind of mathematical, computational, or logical task performed to verify a requirement that may not be verified in any other manner, including simulation and similarity analyses.
Article	Any product, including systems, subsystems, elements, components, or parts.
Availability	The probability that a system or constituent piece will be operational during any randomly selected instant of time, or, alternatively, the fraction of the total available operating time that the system or constituent piece is operational.
Behavior Diagram	Graphical representation of system dynamics that incorporates system responses to inputs. A type of functional flow diagram. The behavior diagram differs from functional flow diagrams in general in that behavior diagrams contain data flow and control elements. (See Functional Flow Diagram.)
Compliance	Determination that the requirements have been met.
Component	A part of the product being designed or produced.
Concept of Operations	Description of what is expected from the system, including its various modes of operation and time-critical parameters.
Configuration Item	Aggregation of hardware, software, processed materials, services, or any of its discrete parts that is demonstrated for configuration management and treated as a single entity in the configuration management process. (ISO)

TERM	DEFINITION
Configuration Management	A basic system engineering element. A management process for establishing and maintaining consistency of a product's performance, functional, and physical attributes with its requirements, design, and operational information through out its life. The CM program consists of CM functions associated with the following program elements: program management, design requirements, document control, change control, and assessments. (See Section 4.11, Configuration Management.)
Critical Design Review	Formal technical review of detail design documentation to establish compatibility with applicable requirements and interfaces and to identify specific engineering documentation required for release to production.
Data Dictionary	A definition of all system data representations in the system models that binds the models together.
Data Flow Diagram	Graphical means for modeling the processes that transform data in a system.
Decomposition	Partitioning/dividing a requirement into its lower-level discrete elements or parts.
Demonstration	Type of verification. Similar to test except that it does not require instrumentation.
Derived Requirements	Any requirement that is not explicitly identified by the Customer. For example: · Decision to select a separate power supply for equipment performing a specific function leads to derived safety requirements. · Architectural choices, such as selecting hydraulic versus electrical power, would have different consequences and different requirements for achieving the same objective. · Hardware-software interfaces.
Deviation	Specific, written authorization to depart from a particular requirement(s) of an item's current approved configuration documentation for a specific number of units or a specified period of time, and to accept an item that is found to depart from specified requirements, but nevertheless is considered suitable for use "as is" or after repair by an approved method. (A deviation differs from an engineering change in that an approved engineering change requires corresponding revision of the item's current approved configuration documentation, whereas a deviation does not allow a revision of the item's current approved configuration documentation.)
DOORS (Dynamic Object-Oriented Requirements System)	Commercial tool licensed to the FAA for capturing and managing requirements.

TERM	DEFINITION
Effectivity	Designation defining the point in time, an event, or a product range (e.g., serial, lot number, model, date) at which changes or variances to specific products are to be effected. The authorized and documented point of usage for a specific configuration of a part/ assembly/installation, etc.
Electromagnetic Compatibility	The ability of a system to function within its electromagnetic environment and, itself, not be a source of troublesome electromagnetic interference.
Electromagnetic Environment	Consists of the systems and other elements (such as humans and nature) that exist within the area that a given system is (or is to be) operated.
Electromagnetic Environmental Effects (E^3) Engineering	The technical discipline dealing with safe and efficient operation of electronic devices regarding radiated and conducted electromagnetic emissions.
Electromagnetic Pulse	An intense burst of electromagnetic interference caused by a nuclear explosion. Such a pulse may damage sensitive electronic systems or cause them to temporarily malfunction.
Electromagnetic Susceptibility	The weaknesses or lack of resiliency a system may have to certain electromagnetic conditions.
Electrostatic Discharge	An unintentional transfer of static electricity from one object to another.
Environment	Natural and induced conditions experienced by a system, including its people, product, and processes.
Failure Modes and Effects Analysis	An evaluation process for analyzing and assessing the potential failures in a system.
Failure Modes and Effects Criticality Analysis	An analysis method used to identify potential design weaknesses through a systematic analysis approach that considers all possible ways in which a component may fail (the modes of failure); possible causes for each failure; likely frequency of occurrence; criticality of failure; effects of each failure on systems operation (and on various system components); and any corrective action that may be initiated to prevent (or reduce the probability of) the potential problem from occurring in the future.
Function	Characteristic task, action, or activity that shall be performed to achieve a desired system objective (or customer need).
Functional Analysis	One of the basic elements of system engineering. A process for examining a system need to identify all the functions and subfunctions necessary to accomplish the system's operation or mission. (See Section 4.4, Functional Analysis.)
Functional Architecture	Hierarchical arrangement of functions and interfaces providing a complete representation of the system from a performance and behavioral perspective, as captured in the requirements set.

TERM	DEFINITION
Functional Baseline	Set of functions, functional interfaces, timelines, and requirement allocations established for a particular system.
Functional Configuration Audit	Review to verify the functionality of subsystems. These reviews are also part of the reviews designed to accomplish certification.
Functional Decomposition	Approach to reducing functional complexity by allocating functionality and interfaces to sublevel functions, which are more readily understood and managed.
Functional Flow Diagram (or Functional Flow Block Diagram)	Multi-tier, time-sequenced, step-by-step diagram of the system functional flow. (See also Behavior Diagram.)
Functional Interface	Logical or physical association between functions that allows transmission of a quantity across a boundary. Quantities may include electrical, hydraulic, and pneumatic power; mechanical forces and torques; gases; heat; vibration, shock, and loads; data; and other quantities.
Functional Requirements	Requirements necessary to obtain the desired performance of a system under the conditions specified.
Hazardous Material Management/Environmental Engineering	The mechanism applied within the system engineering process to ensure a program's ongoing compliance with applicable environmental laws. It is also the process designed to provide early, pre-deployment planning and coordination to minimize the negative impacts that site-specific environmental conditions may have on a program's operability.
High-Level Requirements	Requirements applicable to the highest tier of the system architecture.
Human Factors Engineering	A multifaceted discipline that generates information about human requirements and capabilities, and applies it to the design and acquisition of complex systems.
"ilities"	Specialty functions that contribute to the design, manufacture, and acceptable performance of the product (e.g., elements of specialty engineering: reliability, maintainability, human engineering, safety, supportability, etc.).
Inspection	Type of verification method. Verification of a requirement by visual examination.
Integrity of Analyses	One of the basic elements of system engineering. A disciplined process applied throughout a program to ensure that analyses provide the required levels of fidelity, accuracy, and confirmed results in a timely manner. Integrity is ensured by competent users iteratively applying a validated set of tools to a clearly defined data set.
Integration	Bottom-up process of system buildup. The task of ensuring that all items work together individually and collectively as a group or as a whole system.

TERM	DEFINITION
Interface	Functional and physical connection at a boundary. (See Section 4.7, Interface Management.)
Interface Control Document	Document that provides basic information about interfaces between two elements, including type of interface (electrical, pneumatic, hydraulic, etc.) and the interface characteristics (functional or physical).
Interface Requirements Document	Document that provides FAA interface requirements between two elements, including type of interface (electrical, pneumatic, hydraulic, etc.) and the interface characteristics (functional or physical).
Lifecycle	Entire spectrum of activity for a given system, commencing with the identification of a need and extending through system design and development, production and/or construction, operational use, sustaining support, and system retirement and phaseout.
Maintainability	The measure of the ability of a system or constituent piece to be retained in, or restored to, its fully operational status. It is generally characterized by the Mean-Time-To-Restore.
Master Verification Plan	Plan describing the overall verification program. (See Section 4.12, Validation and Verification.)
Mean-Time-Between-Failure	The basic measure of reliability for repairable systems or constituent pieces. MTBF is the mean number of life units during which all parts of the system or constituent piece perform within their specified limits, during a particular measurement interval under stated conditions.
Mean-Time-To-Restore	The total elapsed time from initial failure to resumption of operation.
Mission Need Statement	Documentation of needs that is approved at JRC 1.
Model	Representation of an actual or conceptual system that involves mathematics, logical expressions, or computer simulations that may be used to predict how the system might perform or survive under various conditions or in a range of hostile environments. (See Simulation.)
N^2 Diagram	Visual matrix representing functional or physical interfaces between system elements.
Nonconformance	Failure of a unit or product to conform to specified requirements.
Operational Requirements Document	Top-level requirements document normally provided by the customer. It is the intent of the document to specify the requirements for all the operational aspects of the system.
Part	One, two, or more pieces joined together to make a component; these pieces are not normally subject to disassembly without destruction or impairment of designed use.

TERM	DEFINITION
Performance	Quantitative measure characterizing a physical or functional attribute relating to the execution of an operation or function. Performance attributes include quantity (how many or how much), quality (how well), coverage (how much area, how far), timeliness (how responsive, how frequent), and readiness (availability, mission/operational readiness). Performance is an attribute for all systems, people, products, and processes, including those for development, production, verification, deployment, operations, support, training, and disposal. Thus, supportability parameters, manufacturing process variability, reliability, and so forth are all performance measures.
Physical Architecture	Hierarchical arrangement of hardware and/or software components along with associated interfaces depicting the physical definition of the system.
Physical Configuration Audit	Review to determine whether the aircraft was built in accordance with the drawings reviewed at the Critical Design Review. In addition, the audit fulfills the requirements of the audit requirements of certification.
Preliminary Design Review	Formal technical review of initial design concepts and documentation to establish compatibility with applicable requirements and to further define physical and functional interface requirements.
Product	Whole system or process being designed or produced.
Quality Function Deployment	Method for capturing and delineating requirements based on identifying what is desired by the customer or stakeholder, along with how that desire may be satisfied.
Record	Information or data on a particular subject that is collected and input into a system for electronic storage.
Reliability	Ability of a system and its parts to perform its mission without failure, degradation, or demand on the support system. It is generally characterized by the Mean-Time-Between-Failure.
Requirements Analysis	Basic element of the system engineering process. (See Section 4.3, Requirements Management.)
Requirements Document	Collection of requirements and related information/attributes presented in a user-defined format. These documents, when output from the Requirements Management process, are called requirements documents. Examples of requirements documents are an initial Requirements Document, final requirements document , discrete performance and procurement specifications, and requirements traceability matrices.
Risk	Undesirable situation or circumstance that has a realistic probability of occurring and an unfavorable consequence. (See Section 4.10, Risk Management.)
Rule	Standard procedure that governs a task or record through its lifecycle.

TERM	DEFINITION
Similarity	Type of verification by analysis. Applicable to components and subsystems similar in characteristics and usage to those on previous systems. In principle, there are no parts of the subject subsystem more at risk (due to environment or installation), and operational stresses are no more severe than on previous systems.
Simulation	Type of verification by analysis. The verification of a system requirement by a computer simulation or other technique. Simulation also includes hardware-in-the-loop simulations. Execution of a system model to examine the response of the system to injected inputs, usually performed before development of system hardware and software.
Stakeholder	Entity (e.g., person, team, or product) that is responsible for or in some way has a vested interest in the requirement or product under consideration.
State Transition Diagram	Graphical means of modeling the dynamic behavior of a system by depicting the legal states that the system may assume.
Structured Analysis	Disciplined approach to defining a system using a graphical box-and-arrow diagramming language.
Synthesis	A basic element of the system engineering process. A process for identifying one or more physical solutions or embodiments of functionality identified in the Functional Analysis process and associated requirements set. (See Section 4.5, Synthesis, and Section 4.6, Trade Studies.)
System	An integrated set of constituent pieces that are combined in an operational or support environment to accomplish a defined objective. These pieces include people, hardware, software, firmware, information, procedures, facilities, services, and other support facets.
System Design Review	A review of the overall system configuration in lieu of or in addition to individual reviews of equipment items, software, and other system components. The system design review covers: 1) Functional analysis and allocation of requirements 2) Development, process product, and material specifications 3) Design data defining the overall system (layouts, drawings, parts/material lists, supplier data) 4) Analyses, reports predictions, tradeoff studies, and related design documentation 5) Assessment of the proposed system design configuration in terms of technical performance measures 6) Individual program/design plans

TERM	DEFINITION
System Environment	All elements and interfaces external to a system from which the system receives inputs and to which the system delivers outputs.
System Engineer	Individual who concentrates on the design and application of the whole (system), as distinct from the parts, and who looks at a problem in its entirety, taking into account all the facets and all the variables and relating the social to the technical aspects.
System Requirements Review	A review to verify that all the top-level requirements are correct; that is, that they meet with customer approval. Another review function is to present to the customer those "assumed" requirements that have been developed throughout the requirements development.
Technical Performance Measurement	Continuing verification of the degree of anticipated and actual achievement of technical parameter growth toward expected values.
Test	Type of verification that requires instrumentation. Includes both laboratory and flight tests.
Thread	A system input, system output, description of the transformations to be performed, and the conditions under which these transformations are to occur.
Time-Critical Functions	Functions that affect reaction time, downtime, or system availability.
Time-Critical Requirement	An identified, temporal constraint on or characteristic of the system.
Time Line Analysis	Graphical representation that considers functional duration and provides a description of the functional sequences for operation, test, and maintenance functions.
Time Line Sheet	Used to perform and record the analysis of time-critical functions and functional sequences.
Traceability	Characteristic by which requirements at one level of design may be related to requirements at another level. Traceability also encompasses the relationship between a performance requirement and the function from which the performance requirement was derived.
Trade Study	Analysis conducted to determine the preferred option, given two or more options. Trade studies may be either top-level or subsystem-level.
Validation	Determination that the requirements for a product are sufficiently correct and complete. (See Section 4.12, Validation and Verification.)
Variance	Specific, written authorization to depart from a particular requirement(s) of a product's current approved configuration documentation for a specific number of units or a specified period of time. (A variance differs from an engineering change in that an approved engineering change requires corresponding revision of the product's current approved configuration documentation, whereas a variance does not.)

TERM	DEFINITION
Verification	Evaluation of an implementation [system] to determine that applicable requirements are met (See Test, Demonstration, Analysis, and Inspection. Verification for a given requirement may include one or more of these methods. See Section 4.12, Validation and Verification.)
Verification Readiness Review	A review conducted to ensure that all system engineering considerations are satisfied and that the readiness of all support, test, and operational systems is in order to perform the Verification process. The review includes a detailed examination of the status of the facilities, ground support equipment, Verification design, software, procedures, and Verification Requirements. In addition, it outlines Verification activities and schedules and identifies organizational/personal responsibilities. The review emphasizes ensuring that all Verification Requirements identified for each Verification method or technique are included in the Verification design and procedures.
Verification Requirements Traceability Matrix	Matrix correlating requirements and the associated verification method(s). (See Section 4.12, Validation and Verification.)
Waiver	Written authorization to accept an item, which during manufacture, or after having been submitted for inspection or acceptance, is found to depart from specified requirements, but nevertheless is considered suitable for use "as is" or after repair by an approved method.
Working Groups	Cross component groups chartered with the task of working process, design, and development tasks for any common system.

APPENDIX C: INITIAL SYSTEM REQUIREMENTS REVIEW CHECKLIST

The purpose of the Initial System Requirements Review (ISRR) Checklist is to find out the adequacy of the efforts in defining system requirements and to determine initial direction and progress of the System Engineering (SE) management effort and the convergence to an optimum and complete system configuration. The ISRR assesses the understanding of the contract requirements documents.

Checklist:

1. Has the Joint Resources Council approved the Mission Need Statement (MNS)?
2. Is the MNS validated and in accordance with the Acquisition Management System (AMS) SE guidance?
3. Is the Concept of Operations complete and in accordance with AMS SE guidance?
4. Is the Functional Analysis complete to a level equivalent to requirements development?
5. Is the Functional Analysis in accordance with the AMS SE guidance?
6. Are all requirements traceable to a function or functions defined in The Functional Architecture?
7. Have all requirements been validated in accordance with the AMS SE guidance?
8. Are all requirements written in accordance with AMS SE guidance?
9. Did the Specialty Engineering disciplines participate in the validation of requirements?
10. Were the candidate requirements identified in Specialty Engineering Design Analysis Reports considered in the validation of requirements?
11. Are all interfaces identified in accordance with AMS SE guidance?
12. Is each interface traceable to an associated set of requirements?
13. Has the Master Verification Plan (MVP) been developed in accordance with AMS SE guidance?
14. Has the MVP been coordinated and approved by the appropriate approval authority?

APPENDIX D: CONCERNS AND ISSUES

While performing any System Engineering process, the specialist may encounter issues and concerns that surface. These issues and concerns may take many forms, but they usually consist of potential risks to the program. Risk Management (Section 4.10) addresses this topic and is consulted when problems arise. The issues and concerns are collected in a form to use during the Risk Management process to determine if they are a threat to program success. At a minimum, the following information concerning each issue or concern shall be derived or collected:

- Title of issue or concern
- Problem statement
- Causes
- Potential effect on the program
- Who is identifying the issue or concern
- Contact information, such as telephone number or e-mail address

Problem Statements

If a problem arises, a problem statement of one to two sentences shall be generated that succinctly identifies the problem and answers the following questions:

- What is the problem?
- What is the scope of the problem?

The following tips may be used as a guide to develop a problem statement:

- Avoid using jargon
- Focus on the specific problem or the issue; problems are characterized by a need, a shortfall in capability, or a threat
- Avoid confusing symptoms or causes with the problem. Focusing on symptoms or causes diverts resources from solving the real or entire issue
- When possible, use data to support the existence of the problem or issue
- Make a connection between the issue and the organization
- Carefully read and analyze the problem statement. Discuss the problem within a peer group to enhance the overall understanding of the problem. A peer group effort is more effective in identifying the key factors in this type of problem-solving situation. The peer group actively searches for the information necessary to solve the problem
- List what is known. Start a list to record everything known about the situation. Begin with the information contained in the problem statement and add the knowledge that the peer group brings
- Record information that people think that they know but are unsure
- List what is needed. Prepare a list of questions that need to be answered to solve the problem. Record them under a second list: “What do we need to know?” Several types of questions may be appropriate. Some may address concepts or principles that need to

be learned in order to address the situation. Other questions may be in the form of requests for more information. These questions guide future searches for information

- List possible actions, such as recommendations, solutions, or hypotheses under the heading “What should be done?”

Appendix E Integrated Technical Planning Details

E.1 Integrated Technical Planning

Planning provides the basis for effective action and the ability to anticipate and prepare for changes that inevitably affect program progress. Planning keeps all the elements of the organization moving in synchronization toward the same goal by establishing baseline expectations of future and current actions. By establishing these baselines, the organization is better equipped to adapt to the inevitable changes facing it.

In the Acquisition Management System (AMS), the Integrated Program Plan (IPP) details the minimum planning required to meet Joint Resources Council (JRC) 2b. The IPP includes both programmatic and system engineering (SE) planning elements. Additional SE planning ensures a more accurate costing of the program. Performance of these planned elements significantly reduces the percentage of requirements found in an Independent Operational Test and Evaluation. This additional SE planning may either be included in the IPP or in a separate SE Management Plan (SEMP).

The National Airspace System (NAS) Modernization System Safety Management Plan (SSMP) governs system safety efforts conducted in the AMS. The SSMP requires each program to develop, as part of the IPP, an Integrated System Safety Program (ISSP) tailored to the program's safety needs.

E.2 Requirements Management Planning

This planning specifies the tasks, products, responsibilities, and schedule for managing requirements throughout product development. The planning begins in the early stages of Investment Analysis and SEMP development and is baselined at the JRC 2b and is updated as necessary at subsequent exit reviews.

The planning section details the total effort in managing requirements. The work includes identifying and capturing requirements (Paragraph 4.3.3.1), analyzing and decomposing requirements (Paragraph 4.3.3.2), and allocating requirements (Paragraph 4.3.3.3).

E.2.1 Inputs to Requirements Management Planning

The following inputs are normally required for the planning section:

- Internal and external requirements as defined in Paragraph 4.3.1
- Component-specific program guidelines
- Program-specific organizational constraints and assumptions to be used in the program
- Program-specific schedule constraints and events
- Top-level conceptual alternatives, functional analyses, design support alternatives, and initial system evaluations
- Technology availability or constraints
  - Captures those technologies for which requirements necessary to meet requirements and the resulting derived requirements from them
  - Constraints identify the envelope of the technology operation

  - Inputs may include identification of key technologies, performance, maturity, cost, and risks, as well as technology breakthroughs and forecasts
- Derived requirements, which are developed through trade studies and are not provided by external sources, such as the stakeholder or government policies
- Outputs from each stage of the program lifecycle
- Concepts of the product (e.g., operational, maintenance, support, logistics)
- New or revised directions and limitations established by the acquisition decision authority
- Records of meetings, conversations, and agreements with stakeholders, and internal functions relating to documented changes

E.2.2 Requirements Management Planning Steps

Following are the steps in producing a planning section, which is normally coordinated and written by an SE group.

E.2.2.1 Step 1: Collect Inputs

All program organizations that develop and manage requirements are responsible for providing planning section inputs to the planning coordinator.

E.2.2.2 Step 2: Prepare Planning Section

The planning coordinator prepares the planning section. Although no standard format exists for developing the section, it is recommended that the section contain the key elements of tasks, deliverables, responsibilities, and schedule. Developing a standard format may be included in this step. The section provides for deviations from the Requirements Management process (Section 4.3).

E.2.2.3 Step 3: Coordinate and Baseline

The planning coordinator provides drafts of the planning section to all stakeholders for review, and the version approved at the JRC 2b becomes the baseline planning section.

E.2.2.4 Step 4: Maintain Planning section

The planning coordinator monitors the program's progress continually throughout the life of the program, and any program changes in the program are reflected in the planning section.

E.2.2.5 Step 5: Provide Current Planning Section

The planning coordinator provides the planning section to all stakeholders (including, at a minimum, the program manager, users, and project leaders) required to manage by the planning section.

E.2.3 Outputs of Requirements Management Planning

The following outputs are normally required for the planning section.

E.2.3.1 Requirements Management Planning Tasks

It is recommended that the tasks to be described in the planning section reflect the processes detailed in Requirements Management (Section 4.3).

The other two subprocesses in the Requirements Management Process—Develop Verification Approach and Analyze Verification Data—are the subjects of the Verification process in Section 4.12.

E.2.3.2 Requirements Management Planning Products

A key function of the planning section is to define the products of the Requirements Management process. Another key function of the planning section is to assign responsibilities to various subprocesses within the Requirements Management process (Section 4.3).

E.2.3.3 Requirements Management Planning Schedule

A function of the planning section is to provide a schedule of the requirements management tasks. See Section 4.3 for a description of the schedule considerations.

E.2.4 Requirements Management Planning Metrics

The primary planning metric is the publication and approval of the planning section at the Investment Analysis, phase one, exit review and the updating at subsequent reviews. A metric of the requirements process is the number of requirements identified after System Design Review (SDR). This metric may also apply to the planning section as well, since it reflects the quality of the program planning.

E.2.5 Requirements Management Planning Tools

A word-processing tool and Dynamic Object-Oriented Requirements System are needed.

A sample outline for a requirements management planning section appears in Table E-1. Also it is recommended that the planning section be developed in accordance with the Requirements Management process described in Section 4.3 and reflect the principles reflected in government and industry standards, such as MIL-STD-961 or -490 for specifications, EIA 632 for the SE process, and ARP 4754 for commercial aircraft development. The outline (Table E-1) depicts the recommended contents of the Requirements Management planning section.

Table E-1. Table of Contents Requirements Management Section of SEMP

Requirements Management Planning Section Example Outline		
1	SCOPE	
1.1	Overview	
1.2	Process Overview	This section contains a diagram showing the interrelationship between the various process elements, including the requirements management tool, if any.
2	APPLICABLE DOCUMENTS	
3	TASKS	The tasks described are tied to the specific organizational

Requirements Management Planning Section Example Outline		
		and program requirements in accordance with Section 4.3.
3.1	Identify and Capture Requirements	
3.2	Analyze and Decompose Requirements	
3.3	Allocate Requirements	
3.4	Derive Requirements	
3.5	Manage Requirements Changes	
4	PRODUCTS	This section describes the various program requirements documents. The section describes what organizational entity is the recipient of the product; for example, the product team, stakeholder, other project teams, company management, or outside organizations, such as manufacturing, product support, test and evaluation, or supplier management.
4.1	Requirements Documents	This section enumerates and describes the various program requirements documents to be produced.
4.2	Requirements Allocation Matrices	This section describes the characteristics of the requirements allocation sheets to be produced on this program.
5	RESPONSIBILITIES	This section details responsibilities of the various organizational entities to accomplish the tasks of Section 3. The responsibilities are to be tied to the tasks of Section 3.
6	SCHEDULE	The schedule shown in this section is to be tied to the milestones of the IPP.
7	AUTOMATED REQUIREMENTS TOOL	This section describes the planned use of the requirements management tool, if any.
8	NOTES	
	APPENDICES	

E.3 Functional Analysis Planning

The Functional Analysis planning section of the SEMP specifies the tasks, products, responsibilities, and schedule for functional analysis throughout the development of the product. Because there is no program level SEMP in the early phases of the program (i.e., phase 1 of Investment Analysis), Functional Analysis in these phases is guided by the NAS-level SEMP. When the IPP is developed, the Functional Analyses is guided by the program's tailored SEMP. The planning section is baselined at the JRC 2b and is updated as necessary at subsequent

exit reviews. This planning section details the total effort for managing functional analysis. This work includes analysis of the concept of operations and environment, the decomposition of functions into subfunctions, decomposing and allocating requirements to functions, evaluating alternative decompositions, defining functional sequences and timelines, defining functional interfaces, and documenting the functional baseline. The outline (Table E-2) depicts the recommended contents of the FA planning section.

E.3.1.1 Inputs to Functional Analysis Planning

The following inputs are normally required for planning:

- Mission Need Statement (MNS) and final Requirements Document (fRD), which detail the system's expected operational environments
- Component-specific program guidelines
- Program-specific constraints and assumptions, such as nature of the program's project teams
- Program-specific schedule constraints and events
- NAS SEMP, which provides the overall plan for conducting SE as part of NAS modernization

E.3.1.2 Functional Analysis Planning Steps

The planning section is normally coordinated and written by an SE group. Following are the steps in producing this section.

E.3.1.2.1 Step 1: Collect Inputs

All program organizations developing and managing requirements are responsible for providing planning inputs to the planning coordinator.

E.3.1.2.2 Step 2: Prepare Planning Section

The planning coordinator prepares the planning section. No standard format exists for developing the section; however, it is recommended that the section contain the key elements of tasks, deliverables, responsibilities, and schedule. The plan provides for justification and deviations from the Functional Analysis process (Section 4.4).

E.3.1.2.3 Step 3: Coordinate and Baseline

The plan coordinator provides drafts of the plan for review. The version approved at JRC 2a becomes the baseline plan.

E.3.1.2.4 Step 4: Maintain Planning Section

The plan coordinator maintains continuous cognizance of the program progress throughout the life of the program, and changes in the program are reflected in the planning section.

E.3.1.2.5 Step 5: Provide Current Planning Section

The plan coordinator provides the planning section to all parties required to manage this section. At a minimum, these organizations include the program manager, the stakeholders, and project leaders.

E.3.1.3 Outputs of Functional Analysis Planning

The following outputs are normally required for the planning section.

E.3.1.3.1 Functional Analysis Planning Tasks

It is recommended the tasks described in the planning section reflect the processes described in Functional Analysis (Section 4.4). These processes are as follows:

- Define the operational mission, environment, and requirements
- Define top-level functions
- Organize functions into logical relationships
- Decompose functions Into subfunctions
- Define internal and external interfaces
- Evaluate alternative decompositions
- Define sequences and timelines
- Complete functional architecture

E.3.1.3.2 Functional Analysis Planning Products

The products of the functional analysis plan are the (a) functional architecture, (b) Concept of Operations (CONOPS), and (c) Issues and Concerns.

E.3.1.3.2.1 Functional Architecture

The functional architecture primarily is in the form of functional flow diagrams and/or timeline sequences produced in accordance with the directions contained in Section 4.4. The architecture contains a description of the system's functions and their inter-relationships, as well as a description of the functional interfaces and the functional sequences or timelines.

Functional architecture development is conducted in relation to requirements. As requirements are developed in increasing detail, the functional architecture is also developed in like detail. This means that as long as requirements are being developed, so is the functional architecture. Though the functional analysis continues in detail, the functional architecture is baselined at the Internal System Requirements Review or JRC 2b, whichever occurs first. This baseline is a functional description of the proposed system as it is described in the system-level specification.

E.3.1.3.3 Functional Analysis Planning Responsibilities

A key function of the planning is to assign responsibilities to various subprocesses within the Functional Analysis process. In general, one organization (or person) executes the process. In addition, within each process, one organization (or person) is responsible for specific tasks or decisions within that process. The discussion below gives guidance in assigning responsibilities

to the various subprocesses. In the end, these assignments may vary greatly according to the product and the organization.

In general, SE assisted by design, support, program management, and stakeholders, normally performs functional analysis. SE also normally has ownership of the electronic tool with the functional analysis capability.

E.3.1.3.3.1 Responsibility for the Define the Operational Mission, Environment, and Requirements Subprocess

SE normally has overall responsibility for this process; however, the process is to be conducted in close cooperation with the stakeholder.

E.3.1.3.3.2 Responsibility for the Define Top-Level Functions Subprocess

In this process, the operational mission, environment, and existing requirements (including needs) are transformed into the required functions, which are listed.

E.3.1.3.3.3 Responsibility for the Organize Functions Into Logical Relationships Subprocess

The functions listed (see Paragraph 4.3.4.4.1.3.3.2) are organized into logical (input-function-output) and/or sequence relationships.

E.3.1.3.3.4 Responsibility for the Decompose Functions Into Subfunctions Subprocess

This process decomposes functions into subfunctions to a level at which the requirements associated with a specific function may be allocated to specific elements of equipment, software, personnel, procedures, and facilities. The process is normally an SE responsibility with assistance from designers.

E.3.1.3.3.5 Responsibility for the Define Internal and External Interfaces Subprocess

System engineers, assisted by designers, normally conduct this subprocess also. The process shall also include participation of the Interface Working Group (IWG), discussed in Interface Management (Section 4.7).

E.3.1.3.3.6 Responsibility for the Evaluate Alternative Decompositions Subprocess

In this subprocess, the functions are broken down further in increasing detail consistent with the further development of requirements.

E.3.1.3.3.7 Responsibility for the Define Sequences and Timelines Subprocess

SE also normally conducts this subprocess, assisted by design personnel, operations, and the stakeholders.

E.3.1.3.3.8 Responsibility for the Complete Functional Architecture Subprocess

System engineers, who own the electronic tool on which it is produced, publish the functional architecture. The output of this subprocess shall support interaction between the Requirements Management process (Section 4.3) and this Functional Analysis (Section 4.4). Design personnel within each project team are normally responsible for assigning performance

requirements to specific functions and subfunctions. SE records these allocated requirements in the requirements electronic database.

E.3.1.3.4 Functional Analysis Planning Schedule

A planning function is to provide a schedule of the functional analysis tasks. It is recommended that the schedule show the delivery dates of the product, namely, the functional architecture. The schedule, which provides the necessary sequence of events, needs to identify the task start dates and end dates and key them to the events outlined in the IPP template of Figure 4.2-3. Functional analysis is normally accomplished at specific levels in the AMS phases discussed below.

E.3.1.3.4.1 Mission Analysis Through Define Mission Need

It is recommended that, prior to the IA, modes of operation and the top-level functional architecture be established and functional interfaces with other systems identified. The top-level functional architecture is developed during this phase.

E.3.1.3.4.2 Investment Analysis—Alternatives Assessment

It is recommended that, prior to the ISRR, the functional architecture be established to the second level of the system architecture by decomposing the top-level functions. Prior to the SDR, the functional architecture is developed to the lowest level of the functional architecture by further decomposition.

E.3.1.3.4.3 Investment Analysis—Requirements Baseline

Prior to the JRC 2b, the functional architecture is developed to the third (or lower) level of the system architecture by further decomposition of the functions.

E.3.1.3.4.4 Solution Implementation

The contractor or vendor, with government assistance as directed by the contract, is to continue the functional decomposition in support of defining increasingly detailed requirements and specifications.

E.3.1.4 Functional Analysis Planning Metrics

The primary planning metric is the publication and approval of the planning at the JRC 2b phase exit review and the updating at subsequent reviews.

E.3.1.5 Functional Analysis Planning Tools

No templates or standards currently exist for this planning. However, the planning section is developed in accordance with the Functional Analysis process (Section 4.4).

Table E-2. Table of Contents Functional Analysis Planning Section of SEMP

Functional Analysis Planning Section Example Outline		
1	SCOPE	
1.1	Overview	
1.2	Process Overview	This section contains a diagram showing the interrelationship between the various process elements, including tools, if any.
2	APPLICABLE DOCUMENTS	
3	TASKS	The tasks described are tied to the specific organizational and program requirements in accordance with Section 4.4.
4	PRODUCTS	This section describes the various functional analysis outputs in accordance with Paragraph 4.4. The section describes what organizational entity is the recipient of the product; for example, the product team, stakeholder, other project teams, company management, or outside organizations, such as manufacturing, product support, test and evaluation, or supplier management.
5	RESPONSIBILITIES	This section details responsibilities of the various organizational entities to accomplish the tasks of Section 3. The responsibilities are to be tied to the tasks of Section 3.
6	SCHEDULE	The schedule shown in this section is to be tied to the milestones of the IPP.
7	AUTOMATED REQUIREMENTS TOOL	This section describes the planned use of the requirements management tool, if any.
8	NOTES	
	APPENDICES	

E.4 Synthesis Planning — Reserved

E.5 Trade Studies Planning

The Trade Study planning documents the formal management planning regarding how alternative solutions to a problem or design issue associated with a program/project product development is to be assessed in a fair and impartial manner.

Trade study planning:

- Provides the formats for how trade study results and information are to be presented to management at design reviews
- Identifies the organization or person designated to be the trade study leader
- Identifies any tools that are to be used in performing of the trade study (i.e., cost models, computer simulations, test articles and fixtures, analytical tools)

- Provides the criteria (including constraints) under which the trade study is to be conducted
- Provides instructions on where trade study results and data are to be stored for future reference and which organization is responsible for maintaining the data

The outline (Table E-3) depicts the recommended contents of the Trade Study planning section.

E.5.1 Inputs to Trade Study Planning

The following inputs are typically required in preparing the trade study planning section. Other program/project-unique inputs may exist and be considered as appropriate.

- Definition of the problem that is to be studied
- Program/project schedule
- Program/project requirements
- Document preparation tools

E.5.2 Trade Study Planning Steps

E.5.2.1 Step 1: Collect Inputs

Coordinate with the program technical groups to obtain input information, including source data.

E.5.2.2 Step 2: Analyse Inputs

Review and organize input data.

E.5.2.3 Step 3: Define Activities and Effort

Work with the technical experts to document trade study activities.

E.5.2.4 Step 4: Lay Out and Baseline Section

Develop and coordinate the draft planning section, obtain necessary approvals (program management, senior technical experts, etc.), and release the baseline version of the SEMP.

E.5.2.5 Step 5: Interface With Other Processes

Coordinate and interface with other processes throughout planning.

E.5.3 Outputs of Trade Study Planning

The output is a trade study planning section that includes the items described in the following paragraphs.

E.5.3.1 Problem Definition

A clear statement of the problem to be solved by a trade study is required to properly focus the efforts of participants. The problem is usually associated with meeting a specific requirement. The requirement needs to be defined to a level of detail that is appropriate for the project's current product development phase. In addition, it is recommended that any related requirements be listed that may be affected by the trade study. Stakeholder agreement is to be

established on all high-level performance or mission requirements before the trade study is conducted.

E.5.3.2 Evaluation Criteria

A key step in eliminating or minimizing bias in trade studies is to define a consistent set of evaluation criteria before the trade study is started. Technical evaluation criteria are to reflect all technical requirements, and effective evaluation criteria shall:

- Differentiate meaningfully between alternatives without bias
- Relate directly to the purpose of the trade study (i.e., they are requirements-based)
- Be broadly based to ensure coverage of all decision factors
- Be independent of each other as much as possible
- Be universally understood by all trade study participants

E.5.3.3 Alternative Solutions

A broad set of alternative solutions needs to be developed prior to any evaluation is conducted. It is recommended that the affected disciplines conduct brainstorming sessions to develop a large number of alternatives for the trade study and that the trade study leader provide background information to all trade study participants before the brainstorming sessions.

E.5.3.4 Trade Study Tools

It is recommended that tools compatible with the problem under study be selected before the trade study is conducted.

E.5.3.5 Trade Study Schedule

It is recommended that a schedule be developed that identifies personnel responsible and due dates for completing each task associated with the trade study. The schedule is designed to support the overall program/project integrated master schedule.

E.5.4 Trade Study Planning Metrics

The metric for measuring the product of this process is completion of the planning section. Also, the cost to produce and update the section may be measured.

E.5.5 Trade Study Planning Tools

A word-processing tool is needed.

Table E-3. Table of Contents Trade Studies Planning Section of SEMP

Functional Analysis Planning Section Example Outline		
1	SCOPE	
1.1	Overview	
1.2	Process Overview	This section contains a diagram showing the interrelationship between the various process elements, including tools, if any.
2	APPLICABLE DOCUMENTS	
3	TASKS	The tasks described are tied to the specific organizational and program requirements in accordance with Section 4.6.
4	PRODUCTS	This section describes …
5	RESPONSIBILITIES	This section details responsibilities of the various organizational entities to accomplish the tasks of …
6	SCHEDULE	The schedule shown in this section is to be tied to the milestones of the IPP.
7	AUTOMATED REQUIREMENTS TOOL	This section describes the planned use of tools…
8	NOTES	
	APPENDICES	

E.6 Interface Management Planning

Interface management (IM) planning ensures establishment of the formal management system of interface (I/F) controls that enable physical and functional compatibility between interfacing hardware, software, personnel, and facilities. This planning:

- Provides the means for identifying, defining, documenting, and controlling the interfaces at all levels of the system
- Provides the means for changing the interfaces as required by the evolution of the design and for resolving interface incompatibilities
- Guides management, control, and documentation of all system functional and physical interfaces
- Establishes the Interface Working Group (IWG) and its policies and procedures
- Contains requirements and templates for preparing, revising, and processing the interface documentation; identifies products
- Establishes the participants of the I/F management process and their responsibilities
- Establishes the interface management schedule

The IWG Chair drafts the IM planning policies and procedures in the early phase of Investment Analysis concurrent with the IPP Schedule. The IWG Chair updates and reviews the IM

planning section of the SEMP to reflect the system functional and physical architectures developed in later phase of Investment Analysis.

E.6.1 Inputs to Interface Management Planning

There are several inputs typically required to prepare the interface management planning section. A description of each input follows along with a short justification and the sources of the input. Other unique program inputs may exist that are relevant to the preparation of the IM planning section. As appropriate, it is recommended that these be included:

- **IPP**
  - Program Management prepares the IPP with input from system engineering. The IPP is required to enable preparation of the I/F management schedule and to ensure coherent, complete, consistent and timely I/F design at all levels of the system.
- **SEMP**
  - SE prepares the SEMP. IM planning is an important adjunct to the SEMP. The IM planning section depends on products defined and scheduled by the SEMP and is therefore partially driven by it.
- **SE Schedule, which is prepared by SE**
  - The IM planning schedule and products are SEMP-driven.
- **System Requirements Documents**
  - SE generally prepares these documents, but they also are prepared occasionally by stakeholders or outside agencies. The documents define the system external interfaces and the (internal) interfaces between the system segments. They are therefore an important point of departure and basis for planning and controlling the system interfaces.
- **System Functional and Physical Architecture**
  - The system architectures are prepared early in the Investment Analysis through comprehensive trade studies of alternative configuration studies. The architectures determine where the system/segment interfaces exist and are the point of departure for the detailed identification and definition of the interfaces. The architectures also are the basis for allocating responsibilities of interfaces.
- **Design Review Plans**
  - These plans are to be used as the bases for conducting reviews and audits of the interfaces. The corporate design review plans specify the required status of development of interfaces at the various prescribed design review milestones.

E.6.2 Interface Management Planning Steps

Following are the major steps required to develop IM planning.

E.6.2.1 Step 1: Appoint IWG Chair

The program management generally appoints the IWG Chair, who is the key person in the I/F definition and control process. This individual is identified early in the program because he/she

is chartered with the responsibility of developing and establishing the policies and process for identifying, defining, documenting, auditing, and controlling interfaces.

E.6.2.2 Step 2: Collect Inputs

Collect the inputs identified in Paragraph E.6.1.1.

E.6.2.3 Step 3: Analyze Inputs

Review, analyze, and organize the inputs collected. The interfaces and constraints embedded in the requirement documents and the system architectures are to be evaluated and assimilated and used as bases for establishing interfaces and responsibilities, as well as to determine if there are program-peculiar interfaces that need special treatment/attention. The planning sections and schedules are to be used as bases for constructing the interface management schedule.

E.6.2.4 Step 4: Define Activities and Effort

Establish the IWG policies and procedures; delineate and coordinate the processes to be applied for identifying, defining, documenting, changing, auditing, and controlling interfaces; identify the responsibilities of participants; and identify standard formats to be used for documenting interfaces and their change process.

E.6.2.5 Step 5: Lay Out and Baseline

Prepare the IM planning section, which captures the processes, formats, schedule, and responsibilities. The processes and formats embedded in the IM planning section of the SEMP shall be consistent with the IPP. Using the IPP and Integrated Program Schedule (IPS), and the SEMP and SE Schedule as bases, prepare an interface management schedule. The schedule may include all significant control and audit milestones defined by the corporate design review processes.

E.6.2.6 Step 6: Interface With Other Processes

The IM planning section of the SEMP shall be coordinated with the IPP and SE schedule and the design review planning sections.

E.6.2.7 Step 7: Update/Maintain the Planning Section

The IWG Chair shall review the IM planning section of the SEMP at the beginning of each of the AMS phases to determine if adjustments to the processes and schedules are required to ease or ensure effective fulfillment of the objectives of that phase.

E.6.3 Outputs of Interface Management Planning

The principal output is an IM planning section of the SEMP delineating the I/F identification, definition, documentation, approval, change, and control and audit process. In addition, the IM planning section establishes the IWG and its policy and procedures, constituents, and constituents' responsibilities.

E.6.4 Interface Management Planning Metrics

The IM planning section is to be reviewed to ensure completeness and cohesiveness. The interface management schedule and products are to be reviewed for consistency with the rest of the SEMP and SE schedule.

E.6.5 Interface Management Planning Tools

A word-processing tool is needed.

To facilitate preparation of the IM planning section of the SEMP, refer to all applicable sections of the System Engineering Manual. The outline (Table E-4) depicts the recommended contents of the IM planning section.

Table E-4. Interface Management Planning Section Outline of SEMP

Interface Management Planning Section Outline	
1	SCOPE
1.1	Overview
1.2	System Overview
2	APPLICABLE DOCUMENTS
3	INTERFACE WORKING GROUP
3.1	IWG Policy and Procedures
3.2	IWG Membership and Responsibilities
3.2.1	IWG Chair
3.2.2	Interface Custodian
3.2.3	Interface Participant
4	INTERFACE CONTROL PROCESS
4.1	Establishing Interfaces
4.1.1	Identifying Interfaces
4.1.1.1	Scope Sheet
4.1.1.2	Documenting Interface Control Documents (ICDs)
4.1.1.3	Coordinating Interfaces
4.1.1.4	Auditing, Statusing, and Controlling ICDs
4.1.1.4.1	Authorized ICD List
4.1.1.4.2	Review at System Requirements Review
4.1.1.4.3	Review at System Design Review
4.1.1.4.4	Review at Preliminary Design Review
4.1.1.4.5	Review at Critical Design Review
4.1.1.4.6	Review at Functional Configuration Audit/Physical Configuration Audit
5	REVISING INTERFACES

Interface Management Planning Section Outline	
5.1	Change Request Preparation
5.1.1	Review/Coordinate Change Request
5.1.2	Change Approval and Documentation
6	INTERFACE MANAGEMENT SCHEDULE
7	NOTES
Appendices	

E.7 Specialty Engineering Planning

E.7.1 System Safety Management Planning

System safety is the application of engineering and management principles, criteria, and techniques to optimize safety within constraints of operational effectiveness, time, and cost throughout all program lifecycle stages. The SSMP governs system safety efforts conducted in the AMS. The SSMP requires each program to develop, as part of the IPP, an ISSP tailored to the program's safety needs. The ISSP calls for contractors or vendors to develop and maintain a System Safety Program Plan (SSPP) that details the planned safety activities. The SSPP describes safety assessments, tasks, and activities of system safety management and system safety engineering required to support the design process and to identify, evaluate, and eliminate or control hazards throughout the system lifecycle.

Government System Safety engineers in the program are responsible for generating the ISSP, and, typically, the System Engineering Council (SEC) approves it as the first step in the system safety program. Contractor System Safety engineers in the program are responsible for generating the SSPP; the Program Manager approves the document internally, and the SEC approves it externally. System safety is an integral element of system engineering applicable to all design stages. Consequently, the stakeholder typically requires the SSPP as early as possible in the program lifecycle, usually within 60 to 90 days after contract award. Updates to the SSPP are necessary from stage to stage. Significant program changes may also warrant an update.

A comprehensive, approved SSPP provides value to the overall program. Misunderstandings are avoided regarding the safety definitions, scope of safety analysis, and risk-resolution procedures. The SSPP serves to increase safety awareness within the integrated team, building system safety into the product. The SSPP is tailored guidance for the System Safety Manager or engineer. Finally, the SSPP serves as an important audit trail, justifying the safety work performed and the methodology for safety decisions made. The program shall use the format and content guidelines for the SSPP documented in the SSMP. The SSMP is available on the Web (http://fast.faa.gov/).

E.7.1.1 Inputs to System Safety Management Planning

- Requirements for the System Safety effort detailed in the plan may come from stakeholders' requirements, which flows out of the Requirements Management Process (Section 4.3). Compliance shall be with the FAA NAS Modernization SSMP in the AMS FAA Acquisition System Toolset (FAST).

- Available system safety evaluation tools shall be used to determine, validate, and verify requirements in accordance with this manual and the SSMP.
- Inputs typically come from the engineer implementing the SE process. These include, potentially, all design groups and, depending on the program structure, either other specialty engineering groups or SE representatives on design teams. Among others, ensure coordination with Human Factors, Reliability, Maintainability, Quality, and Test and Evaluation.
- Lessons learned from previous programs, incidents, and accidents are to be included.
- The program shall form a program-specific System Safety Working Group (SSWG) that works with the FAA's NAS Modernization SSWG in managing risk.
- Programmatics are made available from the "Manage Program" process.

E.7.1.2 System Safety Management Planning Steps

E.7.1.2.1 Step 1: Collect Inputs

Coordinate with the program technical groups to obtain input information, including source data, tasks to be delineated in the plan, and other information.

E.7.1.2.2 Step 2: Analyze Inputs

Review and organize input data.

E.7.1.2.3 Step 3: Define Activities and Effort

Work with the technical experts to document as specifically as possible system safety assessment activities.

E.7.1.2.4 Step 4: Lay Out and Baseline Plan

Develop and coordinate the draft plan, incorporating revisions; obtain necessary approvals (lines of business, program management, senior technical experts, stakeholders), and release the baseline version of the plan.

E.7.1.2.5 Step 5: Interface With Other Processes

Coordinate and interface with other processes throughout plan deployment.

E.7.1.2.6 Step 6: Update/Maintain the Plan

Repeat this process to produce updates to the plan during the course of the program.

E.7.1.3 Outputs of System Safety Management Planning

Output is the System Safety Program Plan, which contains details on the intent, procedures, requirements, techniques, and criteria of the system safety program. The program shall use the format and content guidelines for the SSPP documented in the SSMP. The SSMP is available on the Web (http://fast.faa.gov/).

E.7.1.4 System Safety Management Planning Metrics

The metric for measuring the product of this process is completion of the plan in accordance with the SSMP. Additionally, the cost to produce and update the plan may be measured.

E.7.1.5 System Safety Management Planning Tools

Refer to the NAS Modernization SSMP (http://fast.faa.gov/).

E.7.2 Human Factors Engineering Planning — See AMS FAST.

E.7.3 Quality Engineering Planning — Reserved

E.7.4 Reliability, Maintainability and Availability Planning — The Reliability, Maintainability and Availability (RMA) planning section of the SEMP is to cover all aspects of RMA as detailed in System Engineering Manual (SEM) Section 4.7.2.

E.7.5 Electromagnetic Environmental Effects (E^3) Planning — The Electromagnetic Environmental Effects (E^3) planning section of the SEMP is to cover all aspects of RMA as detailed in SEM Section 4.7.2.

E.7.6 Hazardous Materials Management/Environmental Engineering Planning — The Hazardous Materials Management/Environmental Engineering planning section of the SEMP is to cover all aspects of RMA as detailed in SEM Section 4.7.2.

E.8 Integrity of Analyses Planning

E.8.1 Analysis Management Planning

The Analysis Management planning section of the SEMP is compiled following JRC 1 approval. It supports the objective of that process: "to create high likelihood that the program's analyses are credible, useful, and sufficient." Analysis Management planning defines the analyses to be performed throughout the program and the operational criteria for the analytic tools to be used, as well as the users and the requirements for verifying that the results are correct and sufficient. As a part of the SEMP, this section is reviewed with any other plans at the JRC 2b. The outline (Table E-5) depicts the recommended contents of the Integrity of Analysis planning section.

Table E-5. Table of Contents Integrity of Analysis Planning Section of SEMP

Functional Analysis Planning Section Example Outline		
1	SCOPE	
1.1	Overview	
1.2	Process Overview	This section contains a diagram showing the interrelationship between the various process elements, including tools, if any.
2	APPLICABLE DOCUMENTS	
3	TASKS	The tasks described are tied to the specific organizational and program requirements in accordance with Section 4.9.
4	PRODUCTS	This section describes the various …
5	RESPONSIBILITIES	This section details responsibilities of the various

Functional Analysis Planning Section Example Outline		
		organizational entities to accomplish the tasks of Section …
6	SCHEDULE	The schedule shown in this section is to be tied to the milestones of the IPP.
7	AUTOMATED REQUIREMENTS TOOL	This section describes the planned use of the requirements management tool, if any.
8	NOTES	
	APPENDICES	

E.8.1.1 Inputs to Analysis Management Planning

To prepare Analysis Management planning, the program team members with a need to perform or to have performed one or more analyses provide inputs. Often in this phase of planning a program, there is an iteration in which initial requests to have each analysis authorized and funded are seen as too extensive and costly for the program. Occasionally, program management determines that other analyses be performed or that analyses may replace tests or improve confidence; however, history shows that usually more analyses are initially requested than are approved. Negotiations then take place between proponents of the analyses and program management until a balanced set of analyses are defined. These negotiations may involve such compromises as reducing the scope of simulations and analyses—and possibly relaxing the precision, which the analyst may wish—to a level that management believes is adequate. Ultimately, each analysis earns its way into the integrated program plan by improving the management-balanced program metrics of cost, performance, and time/schedule. For a more in-depth treatment, see " Integrity of Analyses" (Section 4.9).

The kinds of input data that analysts provide include:

- Title or brief description of the analysis
- Description of programmatic benefit to be gained from the successful performance of the analysis; (i.e., the role the analysis plays in the program)
- Relative place in the project schedule:
  - What tasks may be precursors
  - Which tasks are successors and directly depend upon the analysis (i.e., the interfaces of the analysis to the program)
- The inputs required typically include:
  - System requirements
  - Available technology unique to the analysis (both as used in the system being analyzed and as used to perform or support a part of the analysis)
  - Data sets, as possibly updated by precursor task(s)—a program generally maintains a configuration-controlled set of data (environmental factors (atmospheric models, extent of corrosion conditions, etc., some of which may mature or change through the course of a program)); trade study parameters (range penalty per pound of

weight added, at current design state, etc.); and material properties, etc., to be used in analyses

- The inputs from the planning of successor tasks, which essentially define:
  - The reasons for the analysis to be done
  - System/subsystem/component description, as it is involved in analysis
  - The precision, scope, timing, and quality of results that they may get from the analysis; the nature of the deliverable product of the analysis to each using successor task is to be defined

- Analytical tool(s) selected and basis/justification of selection (is it from an approved list of tools available or did the analyst create it?)
- Process and plan for ensuring competence of the analyst (credentials, training, certification, testing, etc.)
- Process for ensuring the integrity of the results (analyst's say-so, cross-check by independent analysis, detailed review by expert, or test validation within specified accuracy, etc.)
- Subtasks to be performed to begin, perform, and validate the analysis
- Estimate of duration and resources required; resources may include labor hours, charged computer runtime, lab support charges, and similar programmatic cost and schedule burdens

E.8.1.2 Analysis Management Planning Steps

E.8.1.2.1 Step 1: Collect Inputs

Coordinate with program technical groups on analysis needed.

E.8.1.2.2 Step 2: Analyze Inputs

Review and organize the data; check for conflicts in precursor/successor relationships among different analyses; and prepare management summaries of resource needs (cost, equipment, facilities, and talent).

E.8.1.2.3 Step 3: Coordinate With Interfacing Program Functions

Determine details of configuration control of tool and skill inventories, data sets, scheduling, and so that specific and correct references may be made in the Analysis Management planning section.

E.8.1.2.4 Step 4: Lay Out and Baseline the Planning Section

Coordinate the draft planning section; support management/analyst/user negotiations; incorporate revisions; obtain necessary approvals; and release the baseline version of the planning section in the SEMP.

E.8.1.3 Outputs of Analysis Management Planning

The output of this process *is* the Analysis Management planning section of the SEMP, which typically consists of these elements:

- **Introduction**. This section covers scope and purpose. It is recommended that this section include any analysis that involves separate task management and control, or which has stakeholders from the analyst's sub organization, or which is deemed to have a significant influence on the program product. On the other hand, minor analyses that merely fill in details of work within a single sub organization and are small in scope are not intended to be formally controlled by this planning section (although the precepts of the process "Integrity of Analyses" always apply as a best practice).

- **Specific comments on the role of Configuration Management (CM) as it applies to Analysis Management.** It is recommended that approved analytic tools (including special or proprietary procedures, computer programs, networks, and workstations; and physical, computational, and hybrid models) be under CM, as well as rosters of analysts with expertise annotated. It is recommended that data sets especially be under CM, and the AMP requires use of configured data in managed analyses. (Several analyses using conflicting data leads to faulty conclusions that confuses a program.) Within the planning section, it is also recommended that some special notation (like **{CM}**) be appended to any reference of name, tool, or data that is configuration controlled.

  - Abstract of the programmatic approach(es) to ensure the competence of the analysts. This may range from merely listing credentials within each analysis to a rigorous testing and validation program of analysts doing certain work. With the various options chosen by the program, the reference in any one of the analysis coverages is simplified.

- **Tailoring.** This section provides tailoring of specific documentation requirements, where applicable. Coordination with the procuring authorities is recommended so that agreement is reached on what tailoring needs to be done to minimize any delay in getting the planning approved.

- **Organization.** This subsection discusses the organizational aspects of analysis management and typically, is a product of SE. The analyses may be performed in any sub organization or by contractors; if so, a separate contracting plan is to supplement the Analysis Management planning section. When there is more than one stakeholder for an analysis, the analysis coverage shall deal with possibly conflicting needs. Thus, a hierarchical ranking of precision, scope, timing, and quality of the analysis product is to be established, and a single set of requirements levied on the analysis. Analysis Management planning development, deployment, and maintenance are the responsibility of SE within the program. The data to be presented (see the "Inputs to Software/Development Planning" (Paragraph 4.2.4.4.3.1)) for each analysis is the responsibility of an analyst assigned to that analysis. This responsibility covers acquisition, interpretation, analysis, and transmittal of the data to the Analysis Management planning section author.

- **Specific Analyses.** This subsection covers each of the various analyses that qualify for inclusion in the Analysis Management planning. The format follows and addresses the items identified in Paragraph 4.2.4.4.3.1. The final subsection for each analysis is to be the connectivity (precursor and successor tasks) of the analysis, and the duration and level of effort required.

E.8.1.4 Analysis Management Planning Metrics

The metrics for the process of preparing and maintaining the Analysis Management planning section of the SEMP are the completion of the planning, the readiness of the planning section to support management/analyst/stakeholder negotiations, and the costs of the first draft, release, and maintenance of the planning section.

E.8.1.5 Analysis Management Planning Tools

Analysis Management planning is typically prepared using a program-standard word-processing tool. Interfacing tools may be noted, to include the business-control and scheduling tools, and the CM tools, as well as any program-unique tools identified.

E.9 Risk Management Planning

Risk is inherent in every program. Stakeholders know this and expect contractors to address risks in program plans. SE addresses three facets of risk: technical, schedule, and cost. Technical risks include all events that may prevent the program from satisfying contractual requirements, including performance, supportability, maintainability, and regulatory requirements. Schedule risks are events that may prevent timely execution of tasks identified in the IPP. Cost risks are events that may cause actual expenditures to exceed estimated costs.

Risk Management is a key process within SE. The program and functional managers implement it by ensuring appropriate resources are applied to reduce risk to acceptable levels. Risk Management consists of five essential components: identify risks, analyze risks, identify mitigation options, implement risk-reduction plan, and monitor risks.

The risk management planning section describes the approach, methods, procedures, and criteria for risk management and its integration into the program decision process. It is continually updated throughout the program life with the SEMP.

E.9.1 Inputs to Risk Management Planning

Inputs include program goals, constraints, IPP/IPS, Rough Order Magnitude/Basis of Estimate.

The risk management process is tailored according to the complexity and criticality of each specific project. The program manager weighs mission goals with the potential benefits and costs and in determining the acceptable level of risk for a program. Stakeholders and regulatory directives may also affect determination of acceptable risk levels.

E.9.2 Risk Management Planning Steps

Risk Management planning guides the program and functional managers in ensuring that adequate risk management is applied at the key decision points of a program.

E.9.2.1 Step 1: Establish Risk Review Team

The team should include at least the project task leaders. It is recommended that all affected specialty support groups be identified and consulted throughout the risk management process. In addition, it is recommended that independent non-advocate experts and stakeholders, if appropriate, be identified for participation during formal risk reviews.

E.9.2.2 Step 2: Define Risk Management Process

It is recommended that the Risk Management process, or a specially tailored version that is followed by the program, be documented, as well as justification for modification of the process provided. It is further recommended that the process contain the key steps of identifying risk, assessing risk, and mitigating risk, as well as the procedure for implementing contingency plans and risk monitoring. It is also recommended that appropriate tools to implement each step be identified if available.

E.9.2.3 Step 3: Define Risk Assessment Criteria

The risk categories (technical, schedule, and cost) and risk levels defined in the Risk Management process may not be appropriate for every program. Technical risks may be subdivided into such categories as Performance, Supportability, and Software, to emphasize key requirements based on program goals. Acceptable schedule or cost risks may also require adjustment based on program goals or constraints. It is recommended that programmatic risks be added if appropriate; justifications for process modification documented; and criteria for closing a risk item defined.

E.9.2.4 Step 4: Identify Key Decision Points

Risks reside in any technology development program. Risk Management is an essential tool used by program managers to assess the adequacy of the integrated program plan in achieving program goals. At each program review, the decision to proceed with a program shall be based on recognition of identifiable risks and adequacy of contingency plans. It is recommended that risks be identified and assessed and mitigation options identified before each review.

E.9.2.5 Step 5: Define Risk Documentation Procedure

It is recommended that all risks identified, assessed, and mitigated be included in a program's documentation. The risk management planning section includes a risk identification worksheet and instruction for submitting risks. It also provides means of documenting steps taken in the risk management process for each risk until closure of the risk.

E.9.2.6 Step 6: Define Monitoring Procedure

When a risk is identified, immediate action may be taken to reduce or eliminate the risk. This would result in a change to the SEMP and possible closure of the risk. Alternatively, action may be deferred until a specific predetermined trigger event occurs. It is recommended that the procedure and forms for identifying the trigger events and resulting contingency action be documented. It is also recommended that the forum for reviewing risks and status of trigger events be identified.

E.9.2.7 Step 7: Update this Section as Needed or With Any Updates of the Integrated Program Plan

It is recommended that the program progress be periodically reviewed against the Risk Management Planning section.

E.9.3 Risk Management Planning Outputs

The following is the general outline (Table E-6) to be used for the Risk Management Planning section (or as a separate plan if considered necessary).

Table E-6. Table of Contents Risk Management Planning Section of the SEMP

Risk Management Planning Section Outline	
1	SCOPE
1.1	Overview
1.2	System Overview
2	RISK REVIEW TEAM
3	RISK MANAGEMENT PROCESS
3.1	Process
3.2	Risk Assessment Criteria and Mitigation Requirements
3.3	Key Decision Points
3.4	Documentation Requirements
4	RISK MONITORING PROCEDURE
5	RISK MANAGEMENT SCHEDULE
6	NOTES AND REFERENCES
7	APPENDICES
7.1	Documentation Forms
7.2	Risk Management Tools

E.9.4 Risk Management Planning Metrics

Completion (or revision as needed) of the Risk Management planning section before each AMS phase exit review and approval of this section at the review are the primary metrics of success.

E.9.5 Risk Management Planning Tools

Risk Management Planning is typically prepared using a word-processing tool. Refer to the appropriate sections of this manual to ensure that the activities described in the Risk Management Planning section are consistent with the SE planning process. This comparison ensures that risk management is injected into the progressive and iterative SE process steps for this program.

E.10 Configuration Management Planning

Configuration Management planning documents the formal management system of CM to ensure that the integrity and continuity of the design, engineering, and cost tradeoff decisions made between technical performance, producibility, operability, testability, and supportability are recorded, communicated, and controlled by program and functional managers. CM planning provides the means for the:

- Configuration Identification process that identifies the functional and physical characteristics of selected system components, designated as configuration items (CI), during the system's acquisition lifecycle

- Configuration Control process that controls the changes to CIs during the system's acquisition lifecycle
- Configuration Status Accounting process that records/reports change processing and implementation status
- Configuration Audits process that supplies current descriptions of developing hardware configuration items, computer software configuration items, and the system itself

The Configuration Management Organization typically owns this planning section. The planning section may be initiated by inputs from the SE process as early as the Investment Analysis, phase one, but formally starts at Investment Analysis, phase two, and continues throughout the program lifecycle as the system develops and is modified.

E.10.1 Inputs to Configuration Management Planning

Following are the two categories of CM planning:

- **Concepts (initial, baseline).** This data identifies the functional and physical characteristics of selected system components and CIs to be controlled and managed.
- **Integrated Program Plan Requirements.** This data identifies contractual and non-contractual constraints, such as program deliverables, cost, and schedule.

E.10.2 Configuration Management Planning Steps

E.10.2.1 Step 1: Collect Input Data

The beginning task is to collect all input data.

E.10.2.2 Step 2: Define Configuration Items

The planner determines what is to be controlled and managed by identifying the CIs from the initial and/or baseline concept.

E.10.2.3 Step 3: Identify Means for Configuration Change Management

The planner needs to determine how to control and manage each of the identified CIs.

E.10.2.4 Step 4: Identify Means for Configuration Status Accounting

This step determines when and how to document the change processing and implementation status and encompasses establishing the frequency and format of the record and report documents.

E.10.2.5 Step 5: Identify Means for Configuration Verification and Audit

Identify methods to supply current descriptions of the CIs and means to trace all changes back to the baseline configuration.

E.10.3. Outputs of Configuration Management Planning

The output shall be the Configuration Management Planning section that outlines all the tasks with corresponding completion dates and personnel responsible for task completion.

E.10.4 Configuration Management Planning Metrics

The metric for measuring the product of the CM Planning process is completion of the planning section within cost and schedule.

E.10.5 Configuration Management Planning Tools

The CM Planning section is typically prepared using word-processing and drawing tools.

E.11 Validation and Verification Planning

The Master Verification Plan (MVP) contains both validation and verification planning. Validation is the process of proving that the right system is being built (i.e., that the system requirements are unambiguous, correct, complete, consistent, traceable to needs, operationally and technically feasible, and verifiable). The validation planning process is conducted to demonstrate that the requirements for a system are clearly understood and that it is possible to satisfy them through design work using available state-of-the-art technology, funding, and schedule. Verification is the process (tasks, actions and activities) of confirming that evolving system solutions comply with functional, performance, and design requirements that spell out stakeholder (internal and external) expectations of capabilities, as well as performance and characteristics of the developed system. Product verification may occur during any phase of a product development cycle, but is more likely to occur after the product Preliminary Design Review (PDR). Verification is the process that ensures that system requirements have been met by the design solution and that the system is ready for use in its operational environment. This means that a verified system may demonstrate that it complies with mission need and meets functional, performance, allocated, derived, and interface requirements, as well as design and allocated constraints that achieve customer needs.

The MVP objective is to define all verification activities that demonstrate the system's capability to meet the specification requirements.

E.11.1 Inputs to Master Verification Plan

The inputs required for preparing the master verification plan are:

- Existing requirements and specifications documents
- Risk-mitigation plan
- Existing Functional analyses, including CONOPS
- MNS, fRD, and program Statement of Work
- NAS-Level SEMP
- Program-specific schedule constraints and milestones provided by the SEMP and SEM
- IPP, including the test and evaluation (T&E) plans and schedules, safety, and quality sections; and the IPS
- Existing product performance/objectives and physical specifications supplied through system/design engineering, including the results of trade studies, baseline product modeling, CM planning and changes, system specifications, system/segment design document, interface control planning and documents (Interface Control, Interface Requirements Documents/ICDs) and technical performance measures

- External standards and conditions required by government regulatory agencies

E.11.1.1 Master Verification Plan Steps

The MVP for the component through the system-level is normally written by SE in conjunction with T&E and includes coordinating with program multidisciplinary project teams. The following major steps are required for developing of the master verification plan(s).

E.11.1.1.1 Step 1: Collect and Review Inputs

The inputs provided by each responsible organization are required to be collected and reviewed for acceptability and completeness by the MVP coordinator.

E.11.1.1.2 Step 2: Develop Master Verification Plan

Using the inputs collected and reviewed in Step 1, the MVP coordinator prepares the master verification plan(s) using the format described in Figure 4.12-12.

E.11.1.1.3 Step 3: Review Plan(s)

The master verification plan(s) are reviewed both before and during program critical milestones (normally starting at the PDR or equivalent). The master verification plan(s) are baselined upon initial program approval.

E.11.1.1.4 Step 4: Maintain Plan(s)

The MVP plan coordinator maintain continuous cognizance of program progress throughout the life of the program. Changes to the program are reflected in the master verification plan(s).

E.11.1.1.5 Step 5: Distribute Plan(s)

The MVP plan coordinator provides the master verification plan(s) to all stakeholders, who manage by the master verification plan(s). These stakeholders include the program manager, stakeholders, project teams and leads, system engineering, test and evaluation, quality assurance, and safety, as a minimum.

E.11.1.2 Outputs of Master Verification Plan

The output of the MVP planning is the MVP and includes planning that supports development of the following products.

E.11.1.2.1 Master Verification Plan

The MVP describes the overall verification program. It provides the content and depth of detail necessary for full visibility of all verification activities. Each major verification activity is defined and described in detail. The plan provides a general schedule and sequence of events for major verification activities. It also describes test software (including code and documentation), Ground Support Equipment, and facilities necessary to support verification activities. The systems engineer and verification engineer develop the plan with design and test organizations, with all having a thorough understanding of the verification program concept, program requirements at all levels, and the methods identified in the Verification Requirements Traceability Matrix (VRTM) for verification.

E.11.1.2.2 Verification Requirements Traceability Matrix

The VRTM is that portion of a requirements document that defines how each requirement is to be verified, the plan that describes the verification activity, and the results (including traceability to the test of verification report). The VRTM is based on the Validation Table documented in the Validation Report. The design, test, SE, and verification team members jointly develop the VRTM. The VRTM establishes the basis for the verification program.

E.11.1.2.3 Requirements Verification Compliance Document

The Requirements Verification Compliance Document (RVCD) provides the evidence of compliance for each requirement at all levels and to each VRTM requirement. The flow down from the requirements documents to the VRTM completes the full requirements traceability. Compliance with all requirements ensures that the system- level requirements have been met.

The RVCD defines for each requirement the methods of verification and corresponding compliance information. The results of the verification activity, including evidence of completion, are recorded and documented in the RVCD. It is recommended that the RVCD contain information regarding the results of each verification activity and a description and disposition of conformance, nonconformance, conclusions, and recommendations. The compliance information provides either the actual data, or a reference to the location of the actual data, that shows compliance with the requirement. The document also includes a section that details any noncompliances; it is recommended that this section also specify appropriate reverification procedures. The RVCD is an input into the Requirements Management process (Section 4.3). Decisions regarding what to do with noncompliant requirements are made in Requirements Management.

E.11.1.3 Master Verification Plan Metrics

Three fundamental metrics exist to help measure and improve the verification plan:

- Timeliness of developing and reviewing the verification plan
- Quality of developing the verification plan
- Cycle Time to complete development and distribution of the verification plan regarding collecting and reviewing the inputs for verification plan development

E.11.1.4 Master Verification Plan Tools

The MVP shall be completed in accordance with the guidelines documented and tools described in this section and Validation and Verification (Section 4.12).

E.12 Integrated Planning Lifecycle — Reserved

E.12.1 Real Property Management Planning — Reserved

E.12.2 Deployment and Transition Planning — Reserved

E.12.3 Integrated Logistics Support Planning —Reserved

E.12.3.1 Maintenance Planning — Reserved

E.12.3.2 Maintenance Support Facility — Reserved

E.12.3.3 Direct-Work Maintenance Staffing — Reserved

E.12.3.4 Supply Support — Reserved

E.12.3.5 Support Equipment — Reserved

E.12.3.6 Training, Training Support, and Personnel Skills — Reserved

E.12.3.7 Technical Data — Reserved

E.12.3.8 Packaging, Handling, Storage, and Transportation (P, H, S & T) — Reserved

E.12.3.9 Computer Resources Support — Reserved

E.12.4 Sustainment/Technology Evolution — Reserved

E.12.5 Disposal — Reserved

E.13 Maintain System Engineering — Reserved

Appendix F: Acquisition Management System Lifecycle Phase and Associated System Engineering Element Work Products

F.1 Program Lifecycle

This appendix addresses each phase of the Acquisition Management System (AMS) program lifecycle and the System Engineering (SE) elements, inputs, outputs, and activities for each of the phases. Each AMS phase discussion includes a table that:

- Identifies the SE work products that are inputs to and outputs from the AMS phase
- Identifies the SE element that produces the work products
- Identifies work products generated from processes external to SE that initiate SE activities within the given phase

Table F-1 is a legend of all of the terms that are used in the subject tables.

Table F-1. Legend for System Engineering Work Products Inputs and Outputs Tables

Abbreviation		Meaning
C	=	Conceptual draft (precedes initial draft). The general notion and structure of the document has been created with minimum content.
CM	=	Configuration Management
EXT	=	External to SE
F	=	Final draft. The document is complete, accurate and awaiting signature.
FA	=	Functional Analysis
I	=	Initial draft. The document has been populated with the majority of required content, but it still requires review for accuracy of information.
IA	=	Integrity of Analysis
IM	=	Interface Management
IARR	=	Investment Analysis Readiness Review
ISRR	=	Initial System Requirements Review
LC	=	Lifecycle Engineering
MSE	=	Maintain Systems Engineering
RM	=	Requirements Management
RSK	=	Risk Management
S	=	Synthesis

Table F-1. Legend for System Engineering Work Products Inputs and Outputs Tables (Continued)

Abbreviation		Meaning
SD	=	Sustaining Document. For work products that are formal documents, the documents are sustained in the given phase. For work products that are not formal documents, the products are introduced, further developed, or sustained in the given phase.
SpecEng	=	Specialty Engineering
ITP	=	Integrated Technical Planning
TS	=	Trade Studies
Val	=	Validation

F.2 Work Products Associated With the AMS JRC Reviews

In Chapter 3, Table 3.3-2, "AMS/SE Work Products Inputs/Outputs for AMS Phases," presents a high-level view of the various SE work products and the AMS phase in which they are developed. The table shows the JRC decisions that mark the culmination of each of the AMS phases. The following sections discuss the inputs and outputs to the AMS phase work products, the developmental status of the work products, and the producing SE element(s). This is developed for each of the AMS phases (i.e., Mission Analysis, Initial and Final Investment Analyses, Solution Implementation, and Service Management).

F.3 Inputs and Outputs for the Mission Analysis Phase

As discussed in Chapter 3, the primary inputs to the Mission Analysis Mission Analysis (MA) phase are the concept of a given "need" and approval to initiate SE efforts. The primary outputs of the MA phase are the final Mission Need Statement, an initial Requirements Document, initial Solution Alternatives, Concept of Use, an initial Lifecycle Cost Estimate, successful completion of the Investment Analysis Readiness Review and an Initial Investment Analysis Plan. Table F-2 summarizes the MA SE inputs and outputs and the developmental status of each work product at the beginning and end of the MA phase. Column 2 contains the producing SE element.

Table F-2. Mission Analysis System Engineering Inputs and Outputs

WORK PRODUCT	PRODUCING SE ELEMENT	INPUT	OUTPUT
Analysis Criteria	IA		I
Concept of Operations	FA	I	F
Concerns/Issues	ALL		SD
Constraints	ALL except TS		SD
Corporate Strategy and Goals	EXT	SD	
Credible Analysis Results	IA		SD

Table F-2. Mission Analysis System Engineering Inputs and Outputs (Continued)

WORK PRODUCT	PRODUCING SE ELEMENT	INPUT	OUTPUT
Description of Alternatives	S		I
Design Analysis Reports	SpecEng		SD
Design Constraint	S		SD
FAA Management Decisions	EXT	SD	
FAA Policy	EXT	SD	
Functional Architecture	FA		I
Government and International Regulations and Statutes	EXT	SD	
Integrated Lifecycle Plan	ITP		C
Integrated Program Plan	ITP		C
Integrated Program Schedule	EXT		C
Investment Analysis Readiness Review	FA, RM, TS	I	F
Legacy System	EXT	SD	
Lifecycle Cost Estimate	LC		I
Market Research	EXT	SD	
Mission Need Statement	RM	I	F
NAS Architecture	ITP	SD	
NAS Concept of Operations	FA	SD	
NAS System Engineering Management Plan	MSE	SD	
Need	EXT	SD	
Operational Services and Environmental Description	FA		C
Planning Criteria	ALL except ITP		SD
Requirements	RM		I
Stakeholder Needs	EXT	SD	
Technology	EXT	SD	
Validated Need	Val	I	F
Validation Reports	Val		SD
Verification Requirements Traceability Matrix	RM		C
Work Breakdown Structure	EXT	C	
NOTE: See Table F-1 for legend.			

F.4 Inputs and Outputs for Initial Investment Analysis Stage of the IA Phase

As stated earlier, the Investment Analysis (IA) phase of the AMS contains two stages: (1) the initial IA stage, and (2) the final IA stage. The most important output of the initial IA stage is selection of a problem solution from the set of viable alternatives. In addition to the final Requirements Document, a considerable number of important program documents are produced in final form. Table F-3 portrays the Initial IA stage inputs and outputs as well as the SE elements that produce them.

Table F-3. Initial Investment Analysis System Engineering Inputs and Outputs

WORK PRODUCT	PRODUCING SE ELEMENT	INPUT	OUTPUT
Acquisition Program Baseline	ITP		I
Analysis Criteria	IA	I	F
Concept of Operations	FA	F	SD
Concerns/Issues	ALL	SD	SD
Configuration Description	S	C	I
Constraints	ALL except TS	SD	SD
Corporate Strategy and Goals	EXT	SD	
Credible Analysis Results	IA	SD	SD
Demonstrations	SpecEng		SD
Description of Alternatives	S	I	F
Design Analysis Reports	SpecEng	SD	SD
Design Constraint	S	SD	SD
External Environmental Forces	EXT	SD	
FAA Management Decisions	EXT	SD	
FAA Policy	EXT	SD	
Functional Architecture	FA	I	F
Functional Specification	FA	C	I
Government and International Regulations and Statutes	EXT	SD	
Integrated Lifecycle Plan	ITP	C	I
Integrated Program Plan	ITP	C	I
Integrated Program Schedule	EXT	C	I
Interface Requirements Documents	IM	C	I
Investment Analysis Readiness Review	FA, RM, TS	F	SD
Legacy System	EXT	SD	
Lifecycle Cost Estimate	LC	I	SD
Market Research	EXT	SD	
Master Verification Plan	ITP		I
Mission Need Statement	RM	F	SD
NAS Architecture	ITP	SD	
NAS Concept of Operations	FA	F	SD
NAS System Engineering Management Plan	MSE	SD	
Operational Concept Demonstrations	S	SD	
Operational Services and Environmental Description	FA	C	I
Physical Architecture	S	C	I
Planning Criteria	ALL Except ITP	SD	SD
Program Risk Summary	RSK	I	F

Table F-3. Initial Investment Analysis System Engineering Inputs and Outputs (Continued)

WORK PRODUCT	PRODUCING SE ELEMENT	INPUT	OUTPUT
Requirements	RM	I	F
Risk Mitigation Plan Summary	RSK	I	F
Risk Mitigation Plans	RSK	I	F
Stakeholder Needs	EXT	I	F
System Engineering Management Plan	ITP	C	I
Technology	EXT	SD	SD
Tools/Analysis Requirements	ALL Except EXT, ITP, IM, IA, CM, Val		SD
Trade Study Reports	TS	SD	SD
Validation Reports	Val	SD	SD
Verification Criteria	SpecEng		SD
Verification Requirements Traceability Matrix	RM	C	I
Work Breakdown Structure	EXT	C	I
NOTE: See Table F-1 for legend.			

F.5 Inputs and Outputs for the Final Investment Analysis Stage of the IA Phase

Since the alternative selection was made during the initial IA stage, the final IA stage refines the physical architecture and adds maturity to the documentation. The Acquisition Program Baseline and the program functional specification are completed and finalized. Table F-4 contains the final IA stage inputs and outputs as well as the SE element that produces them.

Table F-4. Final Investment Analysis System Engineering Inputs and Outputs

WORK PRODUCT	PRODUCING SE ELEMENT	INPUT	OUTPUT
Acquisition Program Baseline	ITP	I	F
Certification Package	SpecEng	C	I
Concerns/Issues	ALL	SD	SD
Configuration Description	S	I	F
Constraints	ALL Except TS	SD	SD
Corporate Strategy and Goals	EXT	SD	SD
Credible Analysis Results	IA	SD	SD
Demonstrations	SpecEng	SD	SD
Design Analysis Reports	SpecEng	SD	SD
Design Constraint	S	SD	SD
External Environmental Forces	EXT	SD	SD

Table F-4. Final Investment Analysis System Engineering Inputs and Outputs (Continued)

WORK PRODUCT	PRODUCING SE ELEMENT	INPUT	OUTPUT
FAA Management Decisions	EXT	SD	SD
FAA Policy	EXT	SD	SD
Functional Architecture	FA	F	SD
Functional Specification	FA	I	F
Government and International Regulations and Statutes	EXT	SD	SD
Integrated Lifecycle Plan	ITP	I	F
Integrated Program Plan	ITP	I	F
Integrated Program Schedule	EXT	I	F
Interface Control Documents	IM		C
Interface Requirements Documents	IM	I	F
Legacy System	EXT	SD	
Lifecycle Cost Estimate	LC	I	F
Market Research	EXT	SD	
Master Verification Plan	ITP	I	F
NAS Architecture	ITP	SD	SD
NAS Concept of Operations	FA	SD	SD
NAS System Engineering Management Plan	MSE	SD	SD
Operational Concept Demonstrations	S	SD	SD
Operational Services and Environmental Description	FA	I	F
Physical Architecture	S	I	F
Planning Criteria	ALL Except ITP	SD	SD
Program Risk Register	RSK	SD	SD
Program Risk Summary	RSK	SD	SD
Requirements	RM	F	SD
Requirements Verification Compliance Document	RM	I	F
Risk Mitigation Plan Summary	RSK	F	SD
Risk Mitigation Plans	RSK	F	SD
Stakeholder Needs	EXT	SD	
Standards	EXT	SD	
Statement of Work	EXT	I	F
System Engineering Management Plan	ITP	I	F
Technology	EXT	SD	SD
Test and Assessment Articles	ALL Except EXT, ITP, IM, CM, & Val	C	I

Table F-4. Final Investment Analysis System Engineering Inputs and Outputs (Continued)

WORK PRODUCT	PRODUCING SE ELEMENT	INPUT	OUTPUT
Tools/Analysis Requirements	ALL Except EXT, ITP, IM, CM, & Val	SD	SD
Trade Study Reports	TS	SD	SD
Validation Reports	Val	SD	SD
Verification Criteria	SpecEng	SD	SD
Verification Requirements Traceability Matrix	RM	I	F
Work Breakdown Structure	EXT	I	F
NOTE: See Table F-1 for legend.			

F.6 Inputs and Outputs for the Solution Implementation Phase

All products are completed and finalized at various points before completion of the Solution Implementation (SI) phase. During the SI phase, each program may decide when each product is required. For example, it is recommended that final Interface Control Documents be in place before implementation and well established for Preliminary Design Review and Critical Design Review. Table F-5 summarizes the SI inputs and outputs as well as the SE element that produces them.

Table F-5. Solution Implementation System Engineering Inputs and Outputs

WORK PRODUCT	PRODUCING SE ELEMENT	INPUT	OUTPUT
Acquisition Program Baseline	ITP	F	SD
Approved Baseline Changes	CM	SD	SD
Baselines	CM	SD	SD
Certification Package	SpecEng	I	F
Concerns/Issues	ALL	SD	SD
Configuration Description	S	I	F
Configuration Status Report	CM	SD	SD
Constraints	ALL except TS	SD	SD
Corporate Strategy and Goals	EXT	SD	SD
Credible Analysis Results	IA	SD	SD
Demonstrations	SpecEng	SD	SD
Design Analysis Reports	SpecEng	SD	SD
Design Constraint	S	SD	SD
External Environmental Forces	EXT	SD	SD
FAA Management Decisions	EXT	SD	SD
FAA Policy	EXT	SD	SD

Table F-5. Solution Implementation System Engineering Inputs and Outputs (Continued)

WORK PRODUCT	PRODUCING SE ELEMENT	INPUT	OUTPUT
Functional Architecture	FA	SD	SD
Government and International Regulations and Statutes	EXT	SD	SD
Integrated Lifecycle Plan	ITP	SD	SD
Integrated Program Plan	ITP	SD	SD
Integrated Program Schedule	EXT	SD	SD
Interface Change Request	IM	SD	SD
Interface Control Documents	IM	I	F
Interface Requirements Documents	IM	SD	SD
Interface Revision Proposal	IM	SD	SD
Legacy System	EXT	SD	SD
Master Verification Plan	ITP	SD	SD
NAS Architecture	ITP	SD	SD
NAS Concept of Operations	FA	SD	SD
NAS System Engineering Management Plan	MSE	SD	SD
Physical Architecture	S	I	F
Planning Criteria	ALL Except ITP	SD	SD
Program Risk Register	RSK	SD	SD
Program Risk Summary	RSK	SD	SD
Requirements	RM	SD	SD
Requirements Verification Compliance Document	RM, Verification	F	SD
Risk Mitigation Plan Summary	RSK	SD	SD
Risk Mitigation Plans	RSK	SD	SD
Stakeholder Needs	EXT	SD	SD
Standards	EXT	SD	SD
Statement of Work	EXT	F	SD
Test and Assessment Articles	ALL except IM, CM, & Val	I	F
Tools/Analysis Requirements	ALL except IM, CM, & Val	SD	SD
Trade Study Reports	TS	SD	SD
Updated Baselines	CM	SD	SD
Validation Reports	Val	SD	SD
Verification Criteria	SpecEng	SD	SD
Verification Requirements Traceability Matrix	RM, Verification	SD	SD
NOTE: See Table F-1 for legend.			