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NASA
Systems Engineering Process for Programs and Projects

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NASA Systems Engineering Process for Programs and Projects

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Preface

The overall policy by which NASA handles major system programs and projects was established under NASA Management Instruction (NMI) 7120.4 in November of 1993. However, the need exists for a common set of suggested processes, products, and terminology regarding the technical management of all programs and projects. These processes, products, and terminology have been established by an intercenter team and are contained in this document. In addition, this document contains a common project management terminology, established by the intercenter team.

This work was conducted under the direction of NASA executive management, including: the NASA Chief Engineer, the Code Q Associate Administrator, and the Engineering Management Council. The program manager for the team was Mr. Shahid Habib from NASA Headquarters (Code QW), while the project manager was Dr. James Wade from NASA JSC (ET). The following is a list of the contributors, editors, and reviewers comprising this intercenter team.

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Acronyms and Abbreviations

C	Conceptual
CAM	Computer Aided Manufacturing
CDR	Critical Design Review
CI	Configuration Item
CFO	Chief Financial Officer
CofF	Construction of Facilities
CSCI	Computer Software Configuration Item
DCR	Design Certification Review
DD-250	Standard Delivery Form
DoD	Department of Defense
DR	Decommissioning Review
DRD	Data Requirements Description
DRL	Data Requirements List
E	End Item
EEE	Electrical, Electronic, Electromechanical
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EMP/S	Engineering Master Plan/Schedule
ERP	Energy Radiation Pattern
F	Final
FMEA	Failure Modes and Effects Analysis
FRR	Flight Readiness Review
H/W	Hardware
ISO	International Organization for Standardization
L-1	Launch Minus 1 Year
L-2	Launch Minus 2 Years
MCR	Mission Concept Review
MDR	Mission Definition Review
Mgt	Management
MOE	Measure of Effectiveness
MRR	Mission Requirements Review
Mtl	Materials
NAR	Non-Advocate Review
NHB	NASA Handbook
NMI	NASA Management Instruction
ORR	Operational Readiness Review
OSHA	Occupational Safety and Health Administration
P	Preliminary
PAA	Program Associate Administrator

PCA	Program Commitment Agreement
PD/NSC-25	Presidential Directive / National Security Council Memorandum 25
PDR	Preliminary Design Review
Pgm	Program
Phase A	Preliminary Analysis Phase
Phase B	Definition Phase
Phase C	Design Phase
Phase D	Development Phase
Phase E	Operations Phase
PMC	Program Management Council
PPAR	Program/Project Approval Review
Pre-NAR	Preliminary Non-Advocate Review
Pre-Phase A	Advanced Studies Phase
Pre-PPAR	Preliminary Program/Project Approval Review
Pro	Project
ProRR	Production Readiness Review
PRR	Program Requirements Review
Q	Qualification Item
R&QA	Reliability and Quality Assurance
RFP	Request for Proposal
RID	Review Item Discrepancy
ROM	Rough Order of Magnitude
S/W	Software
SAR	System Acceptance Review
SDR	System Definition Review
SE	Systems Engineering
SMP	Safety Management Plan
SoSR	Software Specification Review
SOW	Statement of Work
SRR	System Requirements Review
SSM	System Safety Manager
SSR	System Safety Review
TBD	To Be Determined
TPM	Technical Performance Measurement
TRR	Test Readiness Review
U	Engineering Item
WBS	Work Breakdown Structure
•	Complete
ß	Partial / Top-level
Δ	Update

1. Introduction

1.1. Purpose

The *NASA Systems Engineering Process for Programs and Projects* establishes a common set of suggested top-level technical processes for developing NASA missions. Developed by a NASA-wide team, it consists of a structured set of program/project technical activities and milestones. These are designed to effect a structured evolution of activities and products so that objectives are met effectively and efficiently. The purpose of this document is to provide guidance, criteria, approach, procedure, and product and terminology standards for the successful completion of these activities. Especially important are the progressive, structured, traceable steps of system baselining and configuration control. This document is subordinate to and supports NASA Management Instruction (NMI) 7120.4, Management of Major System Programs and Projects, and the associated NASA Handbook (NHB) 7120.5.

This document addresses the definition, production, and operation of the total operational system (hardware, software, personnel, facilities, data, and so on) used to accomplish mission objectives. Topics include a definition of the activities and logical flow (life cycle model), a description of the required maturity at given points in the cycle (control gates), descriptions of the required intermediate products (data dictionary) and a standardized set of definitions (lexicon).

It is anticipated that this work will provide three closely related needs:

1) a common and mutually understood starting point so that logical and consistent plans are easier to develop,
2) a ready reference to help ensure that critical activities are not forgotten, and
3) a distillation of recognized successful practices that can be used as a firm foundation for improvement.

It is taken as an axiom that a thorough understanding of what has worked in the past provides the best starting point for developing better ways to do things in the future. This document is not a new and radical departure, nor is it business as usual. It is a lean compendium of a proven and logical engineering process undertaken in the belief that much is to be gained simply by doing things as well as we know how, every time. However, one should note the following.

- The technical process is parallel to, yet distinct from, the specific procurement approach. A project must accomplish the same technical tasks whether performed in-house or by contractors.
- The technical process itself must be managed and controlled. This is distinct from the administration and organization of resources and personnel.
- Compromising the technical process entails grave risks. On the other hand, proceeding too slowly wastes resources.

- Cost and schedule are always paramount concerns. Too little, too much, or out of sequence activity can seriously jeopardize cost and schedule.

1.2. Application

This document applies to programs and projects conducted entirely by the agency as well as to those conducted by contractors under the direction of NASA. It is further assumed that application of this document will be appropriately tailored to the size and nature of the subject program or project. Simply stated, some projects will not require all details; some may require additional details.

Even though the models presented are scoped for relatively large and complex space systems, application to smaller, simpler projects is of the same relative importance and benefit.

Although this document certainly centers on guidance for those responsible for preparation, execution and evaluation of the technical milestones, it is more pervasive in terms of bringing periodic technical and management focus on propitious points of complete system evaluation, risk assessment, option selections, decision making and replanning.

This document is not a complete description of the way that NASA manages projects. The current work is focused primarily on the technical activities and does not deal with the programmatic or acquisition activities except to describe the major relationships between the technical efforts, project management, resources management and management review process. A full description of the NASA process will require a number of companion documents that are outside the scope of this document .

2. Related Documents

The following documents provide further information. The list is not all inclusive; it indicates major sources of information.

1. NMI 7120.4, *Management of Major System Programs and Projects*, November 8, 1993
2. NHB 7120.5, *Management of Major System Programs and Projects Handbook*, November, 1993
3. NMI 7100.14B, *Major System Acquisitions*, Program Operations Division (Code HS), NASA Headquarters, February 27, 1990
4. NMI 7120.3, *Space Flight Program and Project Management*, Office of Management (Code N), NASA Headquarters, February 6, 1985.
5. NMI 8010.1A, *Classification of NASA Payloads*,
6. NHB 5600.2, *Statements of Work Handbook*.
7. *NASA Systems Engineering Handbook (draft)*, edited by Dr. R. Shishko (JPL), NASA Headquarters (Code FT), September, 1992.
8. *The NASA Mission Design Process*, NASA Engineering Management Council, December 22, 1992.
9. MIL-STD-499B, *Systems Engineering*, draft May 6, 1992.
10. MIL-STD-490A, *Specification Practices*, October 30, 1968.
11. MIL-STD-1521B, *Technical Reviews and Audits for Equipments and Computer Software*., June 4, 1985.
12. DOD-STD-2167A, *Software Development*, June 4, 1985.
13. ISO 9000, Quality Management and Quality Assurance Standards, 1987.

3. Overview

3.1. Correspondence to Program/Project Phases

This life cycle model supports and is subordinate to NASA Management Instruction (NMI) 7120.4 and NASA Handbook (NHB) 7120.5. Figure 3.1-1 summarizes the overall life cycle of a project from programmatic and technical perspectives. The life cycle divides the technical activities of a project into different technical stages that mark increasing maturation of the System. These stages are related both temporally and logically. Subsequent stages require the products of previous stages as input. The control gates govern the transition from one technical stage to another.

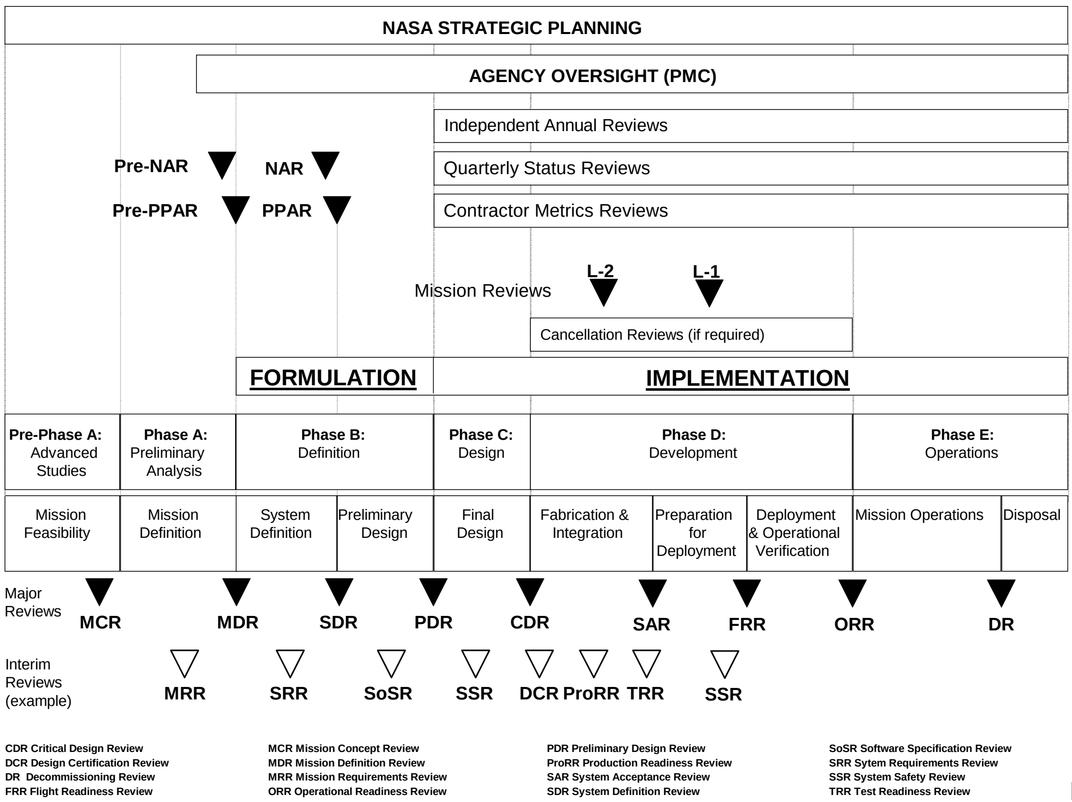

Figure 3.1-1. NASA Project Life Cycle.

The products of the technical activities support many of the programmatic reviews and reports. Major technical interfaces occur at the Non Advocate Review (NAR) and the Program/Project Approval Review (PPAR). Tables 3.1-1 through 3.1-3 provide examples of the necessary products, their sources, and responsible organizations. Section 5 and appendix A provide guidance as to the maturity and content of these products.

Table 3.1-1 Technical Products associated with the Non-Advocate Review.

NMI Rqt	Relevant Technical Product	Responsibility
Pgm/Proj Mgr's Presentation to NAR Team	Design Disclosure, EMP/S, Project Plan	Pgm
Mission Need Statement	Mission Need Statement	Pgm
Acquisition Strategy	Risk Analyses, EMP/S, Cost Estimates	Pgm
Announcement of Opportunity	Mission Concept, System Specification	PAA
NASA Research Announcement	Technology Development Plan	PAA
Phases B/C/D RFP	EMP/S, Statement of Work	Pgm
Project Plan	Project Management Plan	Pgm
System Performance Requirements	Preliminary System Specifications	Pgm
Environmental Analysis	Environmental Assessment/Impact Statement	Pgm
Preliminary Systems Specification	Preliminary System Specifications	Pgm
Phase A Study Report	Design Disclosure, Trade & Analysis Results	Pgm
Life Cycle Cost Estimate	Life Cycle Cost Estimate Design Disclosure, WBS, EMP/S	Pgm

Table 3.1-2 Technical Products associated with the NAR Report.

NMI Rqt	Relevant Technical Product	Responsibility
• System/Subsystem Specifications	System Specifications	Pgm
• Program/Project Plans	Program/Project Management Plan	PAA/Pgm
• Program Commitment Agreement (PCA)		PAA
• Descope Plan	Design Disclosure, Risk Analyses	Pgm
• Mission Success Criteria	Concept/Design Evaluation Criteria	Pgm
• Preliminary SRR Results	Trades & Analyses, SRR presentation Materials	Pgm
• WBS/WBS Dictionary	WBS	Pgm
• Schedules	Engineering Master Plan/Schedule	Pgm
• Environmental Analysis Update	Environmental Assessment/Impact Statement	Pgm
• Interface Control Documents	Interface Requirements, Interface Control Documents	Pgm
• MOUs, MOA's, other	Program/Project Management Plan, EMP/S	PAA/Pgm
• Technology Transfer Plan	Technology Development Plan	Pgm

Table 3.1-3 Technical Products associated with the Program/Project Approval Review.

NMI Rqt	**Relevant Technical Product**	**Responsibility**
Mission Need Statement	Mission Need Statement	Pgm
Integrated Program Summary (Appendix B)	Design Disclosure, EMP/S, Project Plan	PAA
Independent Cost Estimate (ICE)	Design Disclosure, WBS, EMP/S	CFO/Comptroller
NAR Report	see above	NAR Team
Program Commitment Agreement (PCA) (@ final PPAR)	Cost estimates, Proj Plan, EMP/S	PAA

3.2. Life Cycle Model Overview

The NASA Program/Project Life Cycle Model is an idealized model for the complete technical life cycle of a NASA mission from initial mission conception through mission operations to final system disposal. The model partitions the life cycle into ten stages based on the objectives of the technical activity and the level of maturity of the System under development. Successive stages mark increasing system definition and maturity. A transition to a new stage entails a major shift in the nature or extent of technical activities. Control gates assess the propriety of progressing from one stage to another. Table 3.2-1 gives an overview of the model. For each stage, the table identifies the objectives of the stage and its major technical products.

The life cycle tailors the basic steps of identify, analyze, design, construct, operate, support, and dispose to NASA Missions. It must be stressed that the Program/Project life cycle model is not an actual process but rather an idealization that captures the basic logic and flow of information and products. In practice the stages are unlikely to be strictly sequential. Unfolding events may invalidate or modify goals or assumptions. This may necessitate revisiting or modifying the results of a previous stage. The entities comprising the System often have different development schedules and constraints. This is especially evident with the Final Design and Fabrication and Integration stages where some items or subsystems may be under development while others may be in construction or test.

Table 3.2-1. Program/Project Life Cycle Model Summary

Stage / Control Gates	Major Objectives	Major Products
Mission Feasibility • Mission Concept Review (MCR) During Pre-Phase A	• Define mission objectives and top-level functional and performance requirements • Ensure mission technical and programmatic feasibility • Confirm customer's mission need	• Mission Needs and Objectives • Mission/Science Requirements • Strawman Mission Concept • Prioritized Evaluation Criteria • Conceptual System Architecture • Conceptual Designs • Preliminary Feasibility Assessment • Technical Concerns & Risks • Cost & Schedule Estimates
Mission Definition • Mission Definition Review (MDR) During Phase A	• Establish validated (segment level) requirements which meet mission objectives • Establish architectural and top-level operations concept • Identify technology risks and mitigation plan • Refine programmatic resource need estimates	• Top-level System Architecture • Preliminary System Specification(s) • Final Feasibility Assessment • Technology Development Plan • Risk Assessment & Mitigation Options • Refined Cost & Schedule • Disposal Requirements
System Definition • System Definition Review (SDR) During Earlier Phase B	• Complete system architecture and requirements allocation • Demonstrate System can be built within constraints • Develop test and verification program • Establish end item acceptance criteria • Refine information necessary to complete program definition	• Preliminary Design- To Specifications • Interface Requirements • Technology Development Results • Engineering and Technical Management Plans • Firm Cost & Schedule Estimates
Preliminary Design • Preliminary Design Review (PDR) During Later Phase B	• Establish a design solution that fully meets mission needs • Complete test and verification plan • Establish design dependent requirements and interfaces • Complete "implementation" level of design	• Final Design-To Specifications • Preliminary Build-To Specifications • Preliminary Interface Control Documents • Verification Plans • Qualification Plans • Engineering Test Data

Table 3.2-1. Life Cycle Model Summary (cont'd)

Final Design • Critical Design Review (CDR) During Phase C	• Establish complete, validated detailed design • Complete all design specialty audits • Establish manufacturing processes and controls • Finalize & integrate system interfaces	• Final Build-To Specifications • Interface Control Documents • Engineering Test Data • Qualification items and test results • Preliminary Operations Procedures • Integration & Test Plans • Manufacturing Plans
Fabrication and Integration • System Acceptance Review (SAR) During Earlier Phase D	• Produce items that conform to specifications and acceptance criteria • Assemble and integrate the System • Validate and verify System • Develop capability to use System to perform mission • Prepare facilities for production, maintenance and operation	• Validated & Verified H/W and S/W • Support Equipment • As-Built Documentation • Verification Report • Acceptance Data Package • Training Materials • Operations Plans & Procedures
Preparation for Deployment • Flight Readiness Review (FRR) During Phase D	• Configure System for launch / deploy • Establish readiness to launch / deploy	• System Configured for Launch • Readiness data • Trained Personnel
Deployment & Operational Verification • Operational Readiness Review (ORR) During Later Phase D	• Launch / deploy System • Establish operational envelope of System • Establish System logistics	• System Configured for Operations • Operational System Data & Documentation • Approved Support Plans
Mission Operations • Decommissioning Review (DR) During Phase E	• Perform mission • Sustain System • Improve/augment System	• Mission products • Sequential Production • System modifications
Disposal During Phase E	• Decommission/dispose of System	• Decommissioned / disposed items

The design stages may be viewed in terms of an approach that uses increasingly refined approximations to a solution. Mission Feasibility outlines the problem space and the solution space (goals, constraints, evaluation criteria) and demonstrates the existence of a solution in the solution space (strawman concept). The Mission Definition stage refines the definition of the problem and solution space (Mission Analysis) and identifies an optimal region of the solution space (Architecture). The subsequent stages continue this process of refinement until a particular solution is obtained (Build-To Baseline).

Mission Feasibility occurs in Pre-Phase A and initiates the life cycle. Activities focus on understanding the mission and establishing both technical and programmatic feasibility. Technical efforts transform top-level goals and objectives into mission concepts and mission requirements. The effort firms goals, formulates preliminary mission concepts and requirements, and develops preliminary top-level system requirements and architecture. Conceptual designs for the implementation and realization of the candidate System are also prepared to demonstrate feasibility and to support programmatic estimates. The process is typically somewhat informal with the emphasis on establishing desirability and feasibility rather than optimality. Analyses and designs are accordingly limited in both the depth and the number of options. Mission Feasibility is typically done by the government but the effort may let special study contracts. The feasibility studies may extend for several years and may be a sequence of various paper studies that are only loosely connected in a formal sense. The Mission Concept Review (MCR) is the control gate associated with Mission Feasibility. Its objective is to validate the mission objectives and the mission requirements. The primary focus of the MCR is to ratify that the effort produced a sufficiently full, understandable, and unambiguous definition of the mission and to ensure that the satisfying the preliminary requirements for the mission will lead to fulfilling the mission objectives. The feasibility of meeting the mission is indicated with an example of a workable mission concept.

Mission Definition occurs in Phase A. It focuses on analyzing mission requirements and establishing a mission architecture. Activities become formal and the emphasis shifts to establishing optimality rather than feasibility. The effort addresses more depth and considers many alternatives. Goals and objectives are solidified and the project develops a firm definition of the specific mission, operations concepts, system requirements, and top-level system architecture. Conceptual designs are developed and exhibit more detail (e.g. to the subsystem level) and engineering that in Mission Feasibility. Technical risks are identified in more detail and technology development becomes focused. The Mission Definition Review (MDR) control gate results in the release of a preliminary functional baseline for the System. The primary focus is validating that the functional and performance requirements defined for the System, together with the program plan, meet the mission objectives that were defined at project initiation.

In the *System Definition* stage in early Phase B, the focus shifts to allocating functions to particular items of hardware, software, and personnel. System functions and architecture solidify and implementation and performance become firm as end items and their performance and quality characteristics are baselined for development. Major products include an accepted functional baseline and preliminary design-to baselines for the System and its major elements. Technology development and demonstrations mature the technology needed for the implementation and reduce the risk for its subsequent realization in the Preliminary and Final Design. The effort produces various engineering and management plans to prepare for managing the full scale development. The System Definition Review (SDR) is the associated control gate. The objective of the SDR is to ratify that concept definitions are acceptable and requirement allocations are complete for all functional elements of the System. The primary focus is to show that a system can be built which will meet the mission objectives defined at project initiation.

The *Preliminary Design* stage in later Phase B begins the full scale development of the System and its end items. This stage establishes a functionally complete design solution (Design-To Baseline) that fully meets the mission needs. The System is completely defined through the implementation aspect of design. Design dependent requirements and the interfaces among all entities are established. Engineering test articles may be developed and used to derive data for design. The associated control gate is the Preliminary Design Review (PDR). Typically PDRs are held for each of the end items and the higher hierarchic levels of the System. The objective of the PDR is to demonstrate that the System design is functionally complete, optimized, and can be expected to meet all system requirements in the system specifications. The primary focus of the PDR is to show that the correct design has been selected and considers all aspects of system requirements, production, and operations, as well as the constraints of program cost and schedule.

The *Final Design* stage occurs in Phase C. It establishes a complete, validated design (Build-To Baseline) for manufacturing. The System is completely defined through the realization aspect of design. Detailed interfaces are defined and controlled. Qualification articles are built and tested to establish that the design will function in the expected environment. The manufacturing process is validated. The associated control gate is the Critical Design Review (CDR). Typically CDRs are held for each of the end items and the higher hierarchic levels of the System. The objective of the CDR is to ratify that the design is verified to meet mission needs and satisfies all requirements documented in the system specifications. The focus of the CDR is verification of the design, based on the plan that was provided at PDR. Final Design results in an accepted Build-To Baseline for the System and its end items.

During the *Fabrication and Integration* stage in the earlier parts of Phase D, the System is built, tested, and integrated. Production facilities are readied and used to produce items that conform to design. The end items are assembled into a system and the system validated and verified. Operations develops the capability to use the System to perform the mission. Personnel gain experience from the actual end-items and support equipment. After acceptance testing, the System Acceptance Review (SAR) control gate marks the readiness to deliver end items. The objective of the SAR is to demonstrate that the end items as constructed will meet all the system requirements. A prime focus is on results which verify the workmanship in constructing a production copy of the design, including the testing of the software code. In practice Final Design and Fabrication and Integration are very intertwined at the higher levels of the system hierarchy.

During the *Preparation for Deployment* stage later in Phase D, the System is configured and prepared for the first mission. Specifics depend significantly on the particular System and its mission. Typical activities involve completion of operational plans and procedures, training, launch integration, and so on. The Flight Readiness Review (FRR) control gate marks readiness to begin the mission. The objective of the FRR is to ratify that the System is configured for launch and that operation support portions of the System are ready.

During the *Deployment and Operational Verification* stage in late Phase D, the System is deployed and configured for the mission. Operational capability is reached as operational characteristics are demonstrated and personnel gain actual experience in use of the System. Specifics depend significantly on the particular System and its mission. The Operational Readiness Review (ORR) control gate marks operational readiness to support the mission. The objective of the ORR is to demonstrate that the operation support portions of the System are ready to support mission operations. The prime focus is on the results of demonstrations showing the capability to support vehicles in flight and the completeness of operational procedures, plans, and software. Its purpose is to review the state of operational readiness prior to transitioning control of the space vehicle from the development team to the organization with operational responsibilities.

The *Operations* stage occurs in Phase E. It entails the use and support of the System and its parts. Specifics depend significantly on the System, its mission, and its evolution. Systems using expendable or repeated items exhibit multiple production. For complex systems like a space station or a lunar base, the System may evolve by stages that mark levels of capability. Each of these increments may require activities that repeat the previous stages to some extent to develop the new capabilities.

The *Disposal* stage entails the final disposition of the System and its elements. It should be noted that for some items this may be an extended stage involving long-term storage or monitoring of valuable or hazardous items. For a complex system, disposal and operations typically overlap. For example, a launch system may use expendable and reusable parts.

3.3. Discussion

NASA projects typically lead to the production of a very small number of unique end items. The mix of industry, government, and university groups involved is highly varied as are the roles of the government organizations. NASA projects may involve relationships which range from working with a small, inexperienced team providing subsystems and support for a flight project for the first time to oversight of a large experienced team from a large aerospace systems contractor. The range of projects undertaken by NASA, and to which a life cycle model should be applicable, is broad. They vary from ground based facilities (e.g., wind tunnels and other test facilities) to aeronautical projects (e.g. airplanes and components) to operational satellites (e.g., LANDSAT and GOES) to purely scientific satellites (e.g., IUE, COBE) to manned systems (e.g., STS, Space Station). The project organizations and how they function are particularly affected by the numbers of people involved, the numbers of organizational interfaces, the efficacy of communications, and the level of verification required of the System. At one end of the spectrum, there might lie a small team building a small science instrument and operating in a near "skunk works" mode. In this case, the required information may be shared and changes controlled in a semi-informal manner with the form of the documentation determined primarily by the internal requirements of the team. Similar approaches might be used by a fully integrated concurrent engineering team with highly efficient communications and information exchanges. In this case, formal interface and document agreement and change control will be partially replaced with control of the technical engineering database. At the other end of the spectrum, there might be a very large, complex manned project that involves many people in dispersed organizations and that requires a very high level of verification, particularly for issues involving safety. In this case the need for formal documentation and tight change control is driven by the difficulty of coordinating the efforts of a large dispersed team and by the need to integrate products generated by a large number of different groups. While this problem can be alleviated by electronic communications and computerized engineering tools, it is not yet possible for thousands of people spanning dozens of organizations to work like a small "skunk works" team.

To be useful across this spectrum, a life cycle model must be descriptive rather than prescriptive. The model should also be tailorable to the needs of the specific groups and projects involved. Failure to address these issues will lead to irrelevance of the model. A single, fixed and immutable life cycle model would not be useful to all of these groups.

The model of NASA projects presented here is expected to be a starting point from which any of these groups could develop a tailored life cycle applicable to their own needs and requirements. An unnecessary driver of costs is the imposition of new formats into work and documentation standards where pre-existing formats contain all necessary information. It is a tenet of the work described here that the contents are more important than the packaging. It is intended that these standards should establish common approaches and terminology for the NASA projects and reviews. When tailored and imposed as part of a contract, the standards will establish minimum goals for contractor-conducted activities. Preferably, they will be provided as guidance documentation, and be used to develop tailored project plans, review schedules, and review contents that meet the same objectives as this work.

3.3.1. A Technical Process Model

The model presented here is primarily a process model. As such, it provides three basic functions: 1) it identifies the major stages of a project, 2) it identifies the activities in the stages, and 3) it establishes transition criteria for progressing between stages. The model intentionally avoids particulars of methodology, i.e., the specifics on how to accomplish a stage and how to format and to represent data. The intent is that the model be compatible with a broad range of practice; thus, methodology is discussed at a high level and only when necessary. The intent is to reflect general, well established, engineering methods and practices and yet provide a wide latitude as to the specifics of techniques, methods, and formats. An implementation of the model would identify specific tools and product formats as well as how the tools and products are used to accomplish the objectives of different stages.

Potential benefits from the application or consideration of this model include the following.

- Guidance in what to do and when to start and to stop doing it
- Checklist or template for planning

- Common framework to communicate, to identify, and to resolve issues and options.
- Benchmark from which to develop a tailored plan and to evaluate changes

The life cycle model covers technical rather than programmatic aspects of a NASA program. Since it is not desirable to totally avoid programmatic concerns, references to them are intended to be incidental and generic. In particular, the model was designed to be consistent with the various acquisition models used by NASA and the DoD. These acquisition models identify major programmatic milestones and responsibilities for meeting the milestones. Indeed, to a large extent the "pure" process is independent of acquisition models. The technical model addresses what technical work is to be done, whereas the acquisition model addresses who does the work.

3.3.2. Tailoring

The life cycle was designed to be applicable to a wide range of NASA programs with various levels of complexity. It is generic in the sense that it provides a set of features common to many NASA projects. It is not intended to be generic in the sense of all encompassing or of exhibiting all possible features and options.

In any NASA program, tailoring of this model to specific needs and issues should be an important task. The life cycle model is neither intended nor designed to be prescriptive; the model, if properly understood and properly applied, should stimulate and enhance the thought and planning process.

The life cycle model was designed to provide a template that planners may use to construct an engineering network for a specific project. Depending on the scope and nature of the project, a planner will omit, shift, expand, or combine features of the model (e.g., omit sequential production). To expand the template, the planner fills in details appropriate to the particular undertaking and the methodologies employed. The following steps summarize one method of doing this.

1. Identify major milestones and their associated control gates. The generic model provides guidance as to logical relations and phasing.
2. Identify what is needed at control gates. The product dictionary in Appendix A provides guidance on the contents and maturity of products at various control gates.
3. Identify activities that will lead to control gates.
4. Identify the specific tools and activities used to produce and manage intermediate products and activities, e.g., initial system requirements analyses may use tools such as System Hierarchy, Function Decomposition, N^2 Charts, Function Flows and Allocation Matrices.
5. Identify the specific information and products that the project must access and generate.
6. Network and schedule the specific products.

3.3.3. Types of Projects

As presented, the generic model is most typical of large space systems such as the Hubble Space Telescope or Space Station Freedom. The same basic logic applies to smaller or larger NASA projects, although the depth and extent of products will vary. In particular, the model reflects the following assumptions.

- Production levels are low, restricted to at most several units.
- Significant technology enhancements or improvements are needed.
- A full suite of testing is required, including early technology and concept demonstrations, engineering tests, qualification tests, verification and validation, formal acceptance testing, and operational demonstrations.

3.3.4. Acquisition Templates

Although the model was designed to be independent of acquisition models, for illustrative purposes, it is at times convenient to discuss the interactions of the technical effort with the acquisition process. In such cases, the following template for acquisition is assumed. The government conducts early stages in-house with contractors taking a significant role in system definition. Contractors then perform most of the project work during preliminary design through system integration. The effort transitions from contractor to government during deployment and activation. Operations and disposal are primarily government. Besides activities to acclimate new participants, it is not expected that there would be critical technical differences in other templates, e.g., in-house development through system definition.

3.3.5. Engineering Methodology

The life cycle model was designed to be consistent with a broad range of good engineering practices. It is not the intent of this document to prescribe specific processes or tools. It is, however, assumed that the technical effort embraces a basic systematic, structured approach that a) identifies functions and requirements; 2) generates alternative approaches to meeting the requirements; and 3) analyzes and tests alternatives to arrive at an optimal approach. It is furthermore assumed that the technical effort successively refines decisions and baselines in a top down manner.

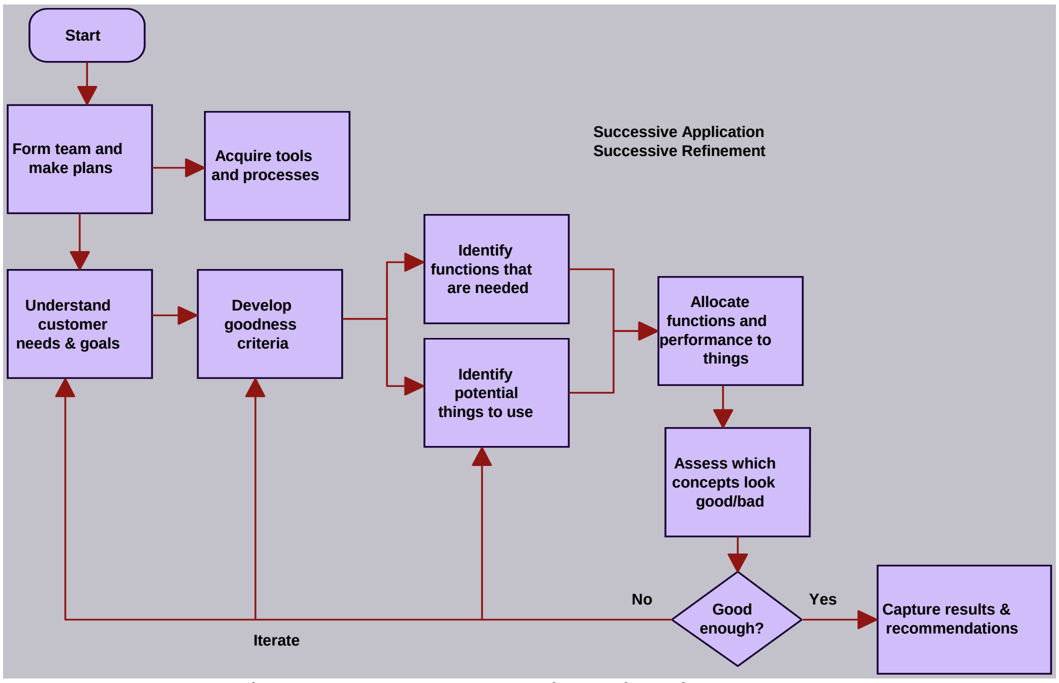

Figure 3.3.5-1. A Systematic Engineering Process.

There are a variety of ways to organize the flow of a such a process. Figure 3.3.5-1 depicts typical, general features of such a systematic engineering process. Initial efforts focus on forming the team and acquiring the resources needed to accomplish goals. This includes developing plans and schedules and may also involve defining process and roles for the team. Initial technical activities focus on a proper statement of the design problem. To reduce the risk of producing the right answer to the wrong problem, the team must understand the relevant needs, goals, and constraints of its customer. This may require a dialog to clarify and elucidate desires and wants. Depending on the maturity of the System and mission definition, this dialog may address various layers of detail. Criteria are developed in order to judge the merits of options and to direct analysis efforts. This typically involves focusing on the cost and effectiveness of the System, setting priorities, and defining and calculating measures of merit. This also facilitates identifying success criteria. Based on the customer’s needs and constraints, the team identifies the functions that must be performed. The team identifies potential assets that can be used for these functions. These assets may include hardware, software, or personnel. The functional perspective gives rise to functional and performance requirements that are allocated to various design options and analyzed. This process iterates until a suitable solution is reached. During initial cycles, the effort tends to focus primarily on functions. During later cycles, the focus shifts to the design of the specific items. To support this process, the team identifies and develops the necessary tools. These may include Function Flow Block Diagrams, Physical and Functional Hierarchies, N^2 charts, and so on. The value of this step is to make explicit to team members where and how information will be captured.

3.4. Summary of Key Features

The following summarize key characteristics that the model was designed to have. These are expanded in sections 4 and 5.

- Be compatible with a wide range of processes and methodologies
- Be compatible with a wide range of acquisition templates
- Be tailorable to a wide range of programs and projects
- Codify established best practices
- Identify evolving roles and skill needs
- Characterize key relations among products, activities, and objectives
- Provide concise, consistent terminology for major products and their maturity
- Provide concise, consistent criteria for control gates
- Stress structured, traceable development
- Stress built-in quality and incremental, on-going testing and evaluation

4. General Characteristics

This section establishes the basic logical foundation of the life cycle model. The general focus is on substantive aspects of the model, i.e., the things encountered in the life cycle. In particular, the intent is to identify key concepts and to establish a consistent, concise terminology. The terminology and definitions are intended to provide a common basis for communication rather than for strict formal use. It is assumed that the reader has some familiarity with Systems Engineering concepts and methods (see reference 7). When feasible, the terminology does not distinguish between software and hardware.

4.1. Control Gates

A Control Gate is a major review process that marks progress in technical maturity and risk reduction. In the sense used in this document, a control gate is a process rather than a single formal meeting or review. It is a tool to achieve consensus about the status of a project. It is a gate in the sense that the effort must successfully complete the review in order to move to the next step in the project. There are three basic decisions that can be made at a control gate: 1) accept recommendations and continue to next stage, 2) reject recommendations and terminate the project, 3) redirect efforts and continue the current stage. It is not the purpose of the control gate to develop or to discriminate specific options in detail. The technical process itself provides the synthesis of alternatives and the selection of recommendations. The technical process is also the foundation for the diverse dimensions of quality such as completeness, accuracy, currency, consistency, and traceability. Instead, the control gate ratifies the technical process and its results. Although baselines may be formally released and established as a result of a control gate, the consideration and review of most details occur during activities preceding the formal meetings.

Since a control gate addresses a transition from one stage to another, it has two distinct purposes. The first purpose is to take a technical look back to determine whether the project has sufficiently met the objectives and requirements of the current stage. The second purpose is to take a technical management look forward to determine whether the project is prepared to enter the next stage. Often, different organizations with distinct goals and activities will perform the two stages. Thus the two review objectives will often be addressed by different groups with distinct perspectives. Even when the same organization will conduct both stages, the members should be aware of their changing roles and purpose.

The organizations involved and the time between stages may have a significant effect on tailoring the life cycle model. There may be a significant time lag between the stages, e.g., due to procurements. In such cases it will be necessary to break the control gate into two reviews that address the two purposes separately. It may also be necessary for a new organization to back track somewhat in order to come up to speed. For example, the government may define requirements for a system that contractors design and build. The government holds a review to ascertain that it is ready to release requests for proposals as applicable. The technical management look forward may involve plans for plans in this case. Shortly after start of contracts, contractors will hold reviews to demonstrate that they understand the customer and are proceeding in the right direction. The technical management look forward then involves actual plans.

4.2. Readiness and Completion Criteria

Early in each technical stage, projects should define criteria to direct the efforts of that stage. *Readiness criteria* are guidelines for the maturity that the project and individual products must have in order to enter a specific control gate. They determine the readiness of the project to hold a review. *Completion criteria* are guidelines for evaluating whether the quality and quantity of work is sufficient to progress to another stage. They determine successful closure of a control gate.

The completion criteria establish specific objectives for the stage and should be established early in the stage when identifying other evaluation criteria. The completion criteria are project dependent and are derivable from factors such as measures of effectiveness, performance requirements and project constraints. When assessing readiness for a control gate, a project should again review the completion criteria in light of the experience gained during the stage, and, if necessary, modify them. Readiness criteria are derivable from a project's completion criteria and its tailored product table. Table 4.2-1 shows an example of readiness and completion criteria for a spacecraft communications system at a Preliminary Design Review (PDR).

Table 4.2-1. Communications Subsystem PDR Criteria Table

Completion Criteria	Readiness Criteria
Satellite can be expected to communicate with ground control in S-band at an altitude between 22,000 miles and 22,200 miles with a 10 dB margin	• Antenna design shows antenna diameter • Antenna engineering item data is available for antenna gain estimates • Design analysis exists for expected receiver sensitivity based on proposed design • Projected ERP data will be available for space and ground antenna • Estimated gain measurements will be available for the ground antenna. • Link analysis will be complete • Thermal analysis complete for Communication Subsystem • EMI/EMC preliminary analysis complete

4.3. Other Technical Reviews

Various other types of technical reviews occur during the project as part of the ongoing activities. Examples are *audits*, *engineering reviews*, *technical interchange meetings*, and *project status reviews*. They are part of the ongoing activities and do not represent gates which the project must pass before beginning a new activity. However, the results may be used at a control gate to demonstrate the state of project readiness to pass through the gate. Table 4.3-1 summarizes these other technical reviews.

Interim Reviews are reviews driven by programmatic and/or agency milestones which are not necessarily supported by the major reviews. They often entail multiple processes to provide important information for major reviews, programmatic decisions, and agency commitments. Program tailoring will dictate the need for and scheduling of these reviews. Chapter 6 provides further details on interim reviews that are applicable to many projects. For example a *System Requirements Review* (SRR) may occur during the initial part of System Definition. The review examines the requirements that have been imposed on the System and its segments. The objective is to validate that these requirements are complete and that they effectively and efficiently meet the mission objectives. The successful completion of the review marks the release of preliminary specifications for the relevant system or segment. Complicated systems with many segments may require multiple SRRs.

Table 4.3-1. Other Types of Technical Reviews

Type	Scope	Examples
Engineering Reviews	• Method Specific • Informal • Promote communication among team members • Encourage creative thinking in team decisions	• Peer Reviews • Design Options Review • Finite Resources Review
Audits	• Examination of tangible evidence to determine adequacy, validity and effectiveness of the activity or documentation under review	• Producibility/Manufacturability Audit • Interface Audit • Software Audit
Technical Interchange Meetings	• Present technical information on a specific technical issue to outside organizations and the customer.	• Technical Interchange Meeting
Interface Working Group Meetings	• Between organizations with development responsibilities for interfacing entities. • Focus on issues involving interfaces and exchanging interface information • Working group level	• Interface Working Group Meeting
Project Status Reviews	• Management level meetings • Provides information on current status	• Quarterly Status Review

Engineering Reviews are methodology-specific informal reviews occurring every few weeks during a project. The purpose of the concurrent engineering reviews are to status various activities occurring during the stages, support communication between the different groups working on the project, encourage structured creative thinking regarding mission solutions and foster progress towards development of a complete, optimized system concept by SDR. Other reviews may be appropriate to individual projects to provide technical and design interchanges between the associated design groups in relation to the ongoing activities in these phases.

Audits are systematic independent examinations of tangible evidence to determine the adequacy, validity or effectiveness of the activity or documentation under review. The number and types of audits are determined early in the project. The group responsible for the audit will present the schedule of audits in their engineering plans. Results of audits (along with recommendations and action items) are often presented at the control gates along with the reactions to the results (answers to the recommendations and closure status of action items).

Technical Interchange Meetings occur to present technical information on a specific technical design issue to outside organizations and the customer. For example, this may be the forum for presenting the results of completed or ongoing studies.

Interface Working Group Meetings are held between two or more organizations with development responsibilities for interfacing entities. Resolution of issues involving interfaces and their associated interface control documents and interface information exchange are the focus of these meetings. They are at a working group level and provide the means for smoothing the formal path for interface control documents approval (done at the control gates) and interface control documents updates (done at Configuration Control Board).

Project Status Reviews are management level meetings providing information on current status to the customer (for contractors) or to upper level management (in-house projects).

4.4. Baselines

This document uses the term *baseline* in a generic sense to mean a reference configuration from which to identify and to control change. Baselines must be explicit and specific. Baselines may have varying degrees of firmness, detail, and formality. In the earliest baselines, frequent or significant changes will be expected. Later, changes will be less frequent and require very compelling rationales. As the design matures, the baselines will represent a willingness to make a contractual commitment. Very mature baselines may be immutable for all practical purposes.

Baselines may vary as to what they address. Technical baselines address the configuration of system products. In addition to technical baselines, there are business baselines that address matters such as funding, staffing, and schedule. This document identifies the following general types of progressively mature technical baselines.

Functional Baseline : states the technical performance of an entity.

Design-To Baseline : allocates performance and design requirements to particular entities.

Build-To Baseline : specifies the configuration of the entities to be produced.

As-Built Baseline : is the actual configuration of the entities that are produced.

As-Deployed Baseline : is the actual configuration of entities as deployed and operated.

4.5. Aspects of Design

The life cycle and control gates reflect a systematic design process wherein the more abstract considerations are established before the specific and concrete. Here, the term *design* is used in a broad sense to cover all aspects of the form and characteristics of a solution to a particular need. Thus design is not limited to a specific physical or logical rendering of the solution, i.e., the drawings. To clarify the evolution of products, the following model identifies three basic aspects of an entity's design. *Architecture* describes the top-level form or structure with an emphasis on function. This aspect identifies functions, their groupings, and their interactions. Functional block diagrams typically document architecture. *Implementation* describes theoretical and mechanistic aspects in terms of functional units and processes. This aspect identifies subsystems, technology, operating principles, interfaces, etc. Schematic block diagrams typically represent implementations. *Realization* describes the concrete and physical aspects in terms of specific measurable parameters. This aspect identifies specific components, parts, physical layout, tolerances, data representation, etc. Detail drawings typically document realizations.

At any particular time, one must address all three aspects; however, the focus and firmness shifts as the design matures. Thus the SDR tends to focus on architecture, the PDR on implementation, and the CDR on realization.

4.6. Specifications

The term *requirement* is used to connote a verifiable statement of function or performance. The term *specification* is used to connote information that describes necessary features and characteristics including requirements, system concepts, and operations concepts. The discussion identifies the following types of specifications.

- Mission Needs Statement: A high level document that defines the mission requirements.
- System Specification: Defines the functional, performance, and interface requirements for the System or segments. They establish a functional baseline and include a top-level description of architecture and operations. (System Specifications correspond to the Type A Specifications in MIL-STD 490.)
- Design-To Specification: States the requirements for the design or engineering development of a product. They disclose implementation aspects and establish a design-to baseline and are typically prepared for prime or critical items. The primary focus is on the allocated performance and includes pertinent direction to designers regarding characteristics and features. (Design-To Specifications correspond to the Type B Specifications in MIL-STD 490.)
- Build-To Specification: Describes an item in sufficient detail to enable procurement or fabrication. The specification may correspond to any item below

the system/segment level, and may be functional or fabricational. Functional specifications describe all characteristics (performance, quality, interface, etc.) of an item that are essential for its intended use. Fabrication specifications disclose realization aspects and establish a build-to baseline and provide detail direction on the proper construction of the item (parts, assembly, performance, test/inspection, etc.). (Build-To Specifications correspond to the Type C Specifications in MIL-STD 490.)

Verification establishes that requirements are met. *Validation* establishes that mission needs or objectives are met. *Qualification* establishes that a design works properly under the intended conditions. *Certification* establishes that an end item works properly for a mission.

4.7. System Hierarchy Model

Space systems consist of multiple layers of structure. Particular projects will potentially require different layers of structure: an instrument project for a science instrument may not need to distinguish as many layers whereas a broad initiative may need to distinguish more layers. Projects should accordingly establish their own terminology for classifying and referring to entities and structural levels. To facilitate the discussion, it is useful to have an explicit example in mind. This document assumes the following model of a system hierarchy for a large space system. Note that here, *the System* refers to the operational product system that consists of the total hardware, software, facilities, and personnel used to conduct the mission. This is distinct from the producing system embodied in a development project. The term *end item* is used generically to indicate some entity in the System. Figure 4.7-1 provides an example.

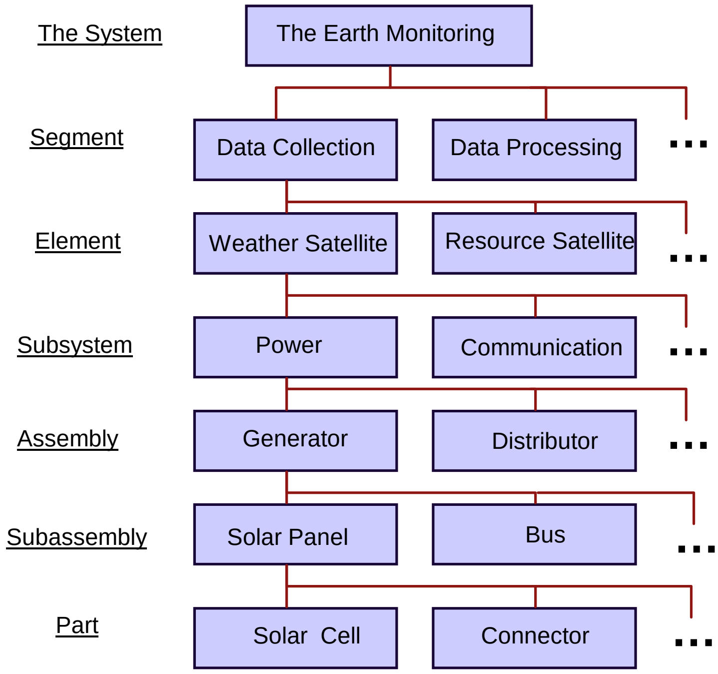

Figure 4.7-1. Sample System Hierarchy and Product Breakdown Structure.

- The System - The totality of hardware, software, personnel, and so on needed to perform the designated function or mission. Example: Earth Monitoring System.
- Segment - grouping of elements that are closely related. These elements often interface physically. A segment often corresponds to a top-level function of the System. Example: Data Collection Segment.
- Element - complete integrated set of subsystems capable of an operational role. Typically constructed as a physically separate entity. Example: Weather Satellite.
- Subsystem- functional grouping of components that provide a major function or related functions. Example: Power generation and distribution.
- Assembly - functional unit viewed as an entity for analysis, manufacturing, maintenance, etc. Example: A power generator.
- Subassembly - Two or more units joined together to form a stockable unit capable of disassembly. Example: A solar panel.
- Part - Smallest functional entity that can not be disassembled without damage. Example: A solar cell.

Appropriate software terminology depends to a large extent on languages, environment, and methodology. For the life cycle and control gates, the following levels are identified and are typical of procedural languages such as Ada or C. Note the duality between data and instruction.

- Process: totality of software and data that perform a major function.
- Program/file: separately executable or storable item from the viewpoint of the operating system.

- Module / class: collection of related data structures and operations that perform related services or transformation.
- Function / procedure / data structure: separate entities that can be invoked or referenced.
- Statement: syntactically complete construction of the language.

4.8. Product Model

The technical project model reflects a systematic technical development process that transforms mission goals and objectives into an operational system. This process entails a myriad of interrelated, evolving products that are specific to each development system. Here the term *product* is used in a general sense to indicate some particular data or item rather than a complete document or separate deliverable. To make the discussions tractable and clear, it is useful to have an overall framework or model that establishes terminology; major categories, key relations, and maturity gauges for technical products. Figure 4.8-1 illustrates this model with a typical flow down and maturation of the primary products and items in a development effort.

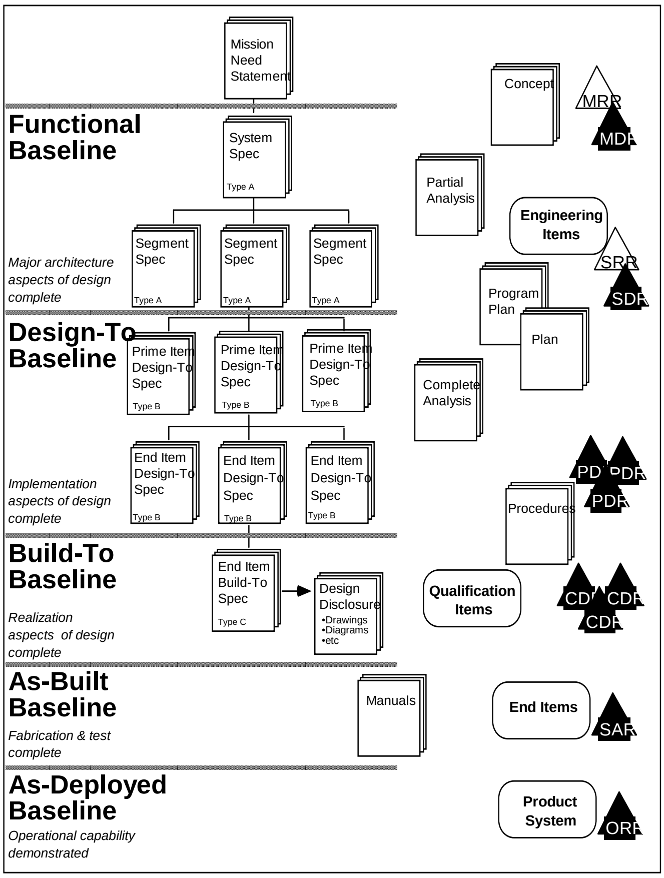

Figure 4.8-1. Overview of Product Maturity Model.

4.8.1. Product Classification

It is useful to have a general scheme to identify the myriad of potential products in a development project. Table 4.8.1-1 provides a top-level classification scheme based on the use or purpose of the item. This approach provides a uniform criterion for classification, simplifies correlating products to process, and elucidates evolution. For example, a trade study may generate many trajectories in search for suitable optima. Eventually several may be chosen as mission options and would become part of the mission design. Finally a particular trajectory might be used as a standard for the design of equipment, planning, etc. This progression from trade to engineering requisite is quite general. The Classification Scheme should not be mistaken for a document tree. The scheme identifies the types of data and items, not specific deliverables or documents. Indeed, a document tree should reflect the structure of the system with the individual documents containing several types of information.

The *product system* consists of those entities that accomplish the mission, i.e., the things to be developed and the *raison d'être* of the project. The products associated with the product system include hardware and software articles, data and manuals, facilities, trained personnel, etc. The *producing system* develops the product system and supporting processes. The operational *system* consists of those deployed entities that perform the mission. The approach taken here is to emphasize development aspects and to maintain a simple framework. Thus the majority of categories are addressed as producing system products. In particular, the Management/Control category addresses the producing system, whereas the various operations and support plans address the product system.

It is also useful to distinguish whether a product pertains to output or process. Table 4.8.1-2 provides a scheme for doing so. The modifier *Program Plan* indicates a specific approach to develop a comprehensive plan (e.g., a Reliability Program Plan). The modifier *Plan* indicates a comprehensive product that formulates how an activity will be accomplished (e.g., an Integrated Logistics Support Plan). They typically identify organization, responsibility, general flow, and key events. The modifier *Procedures* indicates detailed, step by step material (e.g., Operations Procedures). The modifier *Concept* indicates a top-level plan that identifies basic goals and principles (e.g., an Operations Concept).

Table 4.8.1-1 Classification Scheme for Technical Products.

	Area		Subarea	Description
P	Product System			Versions of mission/support artifacts
		U	Engineering/Technology	Built for R&D
		Q	Qualification	Built to confirm design
		E	End Items	Match mission/support items
		D	Manuals / Supporting Data	Describe item operation/support
		F	Facilities	Support mission & training
		X	Other	
R	Engineering Requisites			Define what must be done
		R	Requirements/Specifications	State characteristics of product system
		S	Standards	Binding standard data, handbooks, etc.
		X	Other	
V	Verification & Other Test			Confirm compliance of product system
		V	Verification/Validation	Confirm requirements are met
		O	Operational	Confirm product ready for mission
		X	Other	
D	Design & Execution			Enable products and their use
		D	Design & Architecture	Define product's form, function, features
		F	Fabrication/coding	Assemble products
		O	Operations	Define how product system will be used
		S	Integrated Logistics Support	Support product system
		X	Other	
A	Analyses/Evaluations			Support decision and synthesis
		C	Criteria & Metrics	Measure goodness of product system
		T	Trades / Studies	Define/evaluate alternatives
		D	Development Test	Generate engineering, design data, technology
		X	Other	
T	Tools			Support development effort
M	Management/Control of Producing System			Control producing system
		T	Technical Status	Measure technical quality & progress
		P	Plans, Methods, & Process	Nature, scope, logic of development work
		B	Budget & Resources	Control project resource use/allocation
		S	Schedule	Control activity & event
		C	Configuration Management	Control structure and content
		R	Risk Management	Control risks
		O	Organization	Control work interfaces, accountability
		X	Other	

Table 4.8.1-2. Codes and Relations to End Products and Process.

Meta-level*	**Relation**
0	Product is in product system (e.g., flight hardware, support hardware, software, data).
1	Product describes or characterizes product system.
2	Product is a plan or process for generating meta-level 1 products.
3	Product is a program plan, i.e., a plan to develop a plan.

*Combinations of codes indicate products that encompass several meta-levels, e.g., 12 would indicate an omnibus product that contains a plan and assessments.

Figure 4.8.1-1 depicts the top-level logical relationships between the various technical products. In the technical product arena, needs and objectives drive the contents of requirements and evaluation criteria and priorities. The requirements give rise to various features that actualizations must exhibit. Based on the criteria, analyses and assessments focus on the quality and appropriateness. Test and demonstrations confirm that the intended results are obtained. The technical management products include identification of the actual technical products to be produced and their interrelationships.

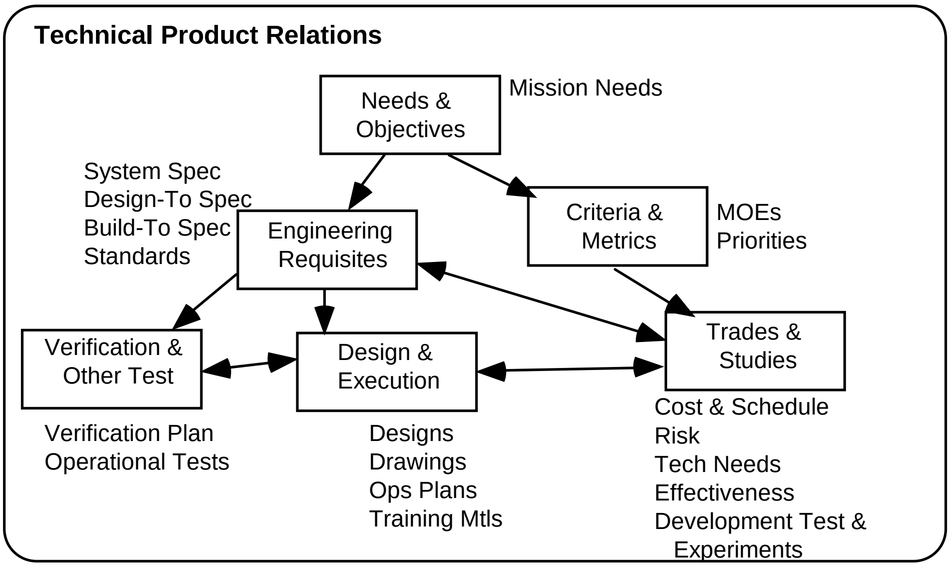

Figure 4.8.1-1. Top-level Product Relations.

4.8.2. Product System Articles

Projects generate various product system articles reflecting different levels of maturity and serving different risk reduction purposes. *Engineering items* are articles used to generate information important to designing end items. They typically entail non-flight parts and workmanship standards and may be bread-boards or mock-ups. Their uses include technology demonstrations, proof of concept, and design data generations. *Qualification items* are used to demonstrate that the proposed design will function properly in the required environment under the required conditions. They are of a new design in form, fit or function but are not intended for operational use. *End items* are the products that are used. When multiple items are built, production articles are the as-built baseline. These may differ from the articles used for the initial flights and demonstration of operational capability.

Table 4.8.2-1 summarizes the terminology and the uses of the articles and provides other common names. In practice, a project balances technical risk, schedule, and budget in choosing the articles that it builds. Projects may use the same article for different purposes. For example, a *protoflight* item might serve both as a qualification and an end item. It would be an initial flight item that is also subjected to qualification levels and flight durations equivalent to a flight acceptance test project. It is recommended that projects develop their own clear terminology for articles.

Table 4.8.2-1. Types of Items.

Article	Uses	Configuration Management	Other Names
Engineering Item	Show technology is feasible Make design decisions - Generate data - Evaluate alternatives Show design functionality	Mostly informal	Proof of Concept Breadboard Mockup Demonstration Software Prototype, Flight Equivalent Unit
Qualification Item	Validate design - Show functionality in environment - Establish envelopes - Demonstrate lifetime	Formal	Hardware Prototype Design & Verification Test Unit Brassboard Protoflight
End Item	Support the mission	Formal	Protoflight Flight Unit First Flight Unit Certification Unit Production Item

4.8.3. Product Maturity Levels

The following discussion distinguishes three broad categories of maturity for technical products that evolve during the life cycle. At the lowest level of maturity are *conceptual* products. They are typically early estimates or drafts in which significant revision is expected. Working products with a significant level of maturity are designated *preliminary*. They exhibit significant engineering effort and are expected to undergo only modest revision. Products with the highest level of maturity are designated *final*. These have had significant review and are deemed stable. Final products are generally under formal configuration control.

Projects also prepare numerous interim studies and assessments that are not maintained and matured as a direct goal of the development process. The term *partial* indicates that a product is not finished and that further expansion or revision is planned in later efforts.

The term *complete* indicates that a products is finished and contains full detail. Table 4.8.3-1 summarizes the maturity levels and the codes used for them in this document.

Table 4.8.3-1. Product Maturity Codes.

Code	**Maturity level**
C	Product is conceptual. Significant change is expected.
P	Product is preliminary. Only minor changes are expected.
F	Product is final and ready for approval. No change or planned or expected.
Δ	Update to existing product.
ß	Partial, incomplete, or top-level.
•	Complete.
U	Engineering Item
Q	Qualification Item
E	End Item.

5. Life Cycle Stages

This section focuses on the evolution aspects of the life cycle model and provides details on each individual stage. Topics include objectives and major decisions, technical activities, management and control, products, and tailoring.

Activity networks elucidate the major logical relationships among top-level activities. These are intended to represent the ideal logical flow and maturation of activities and products. In practice, activities frequently occur in parallel and feed back to their logical precursor. Since a successor should both start and finish after its predecessors, the networks convey only start/start and finish/finish time relationships.

5.1. Mission Feasibility

5.1.1. Overview

Mission Feasibility develops understanding of the problem and potential approaches. A primary product is a preliminary assessment of how difficult it is to achieve goals within constraints. This assessment considers technical, cost, and schedule aspects. The effort avoids committing to a particular approach or solution too early so as to avoid a great answer to the wrong question. By refining mission objectives, constraints and evaluation criteria, the effort lays a proper foundation for understanding what is needed and what is important. Table 5.1.1-1 summarizes Mission Feasibility.

Table 5.1.1-1 Summary of Mission Feasibility.

Objectives:	• Define mission objectives and top-level functional and performance requirements • Ensure mission technical and programmatic feasibility • Confirm customer's mission need
Major Products:	• Mission Needs and Objectives • Mission/Science Requirements • Preliminary Feasibility Assessment • Strawman Mission Concept • Prioritized Evaluation Criteria • Conceptual System Architecture • Conceptual Designs • Associated Flowdown Requirements • Technical Concerns & Risks • Cost & Schedule Estimates
Major Decisions:	• What is the mission? • Is mission technically & programmatically feasible?
Program Phase	During Pre-Phase A.
Control Gate:	Mission Concept Review
Features:	• Initiates life cycle. • Typically done in-house. Specific study contracts may be let. • May be a sequence of various paper studies that are formally only loosely connected. • Analysis and concept definition limited in depth • Focus on finding a concept for operations and implementation that establishes feasibility • Typical team is full time lead with part-time expert team members.

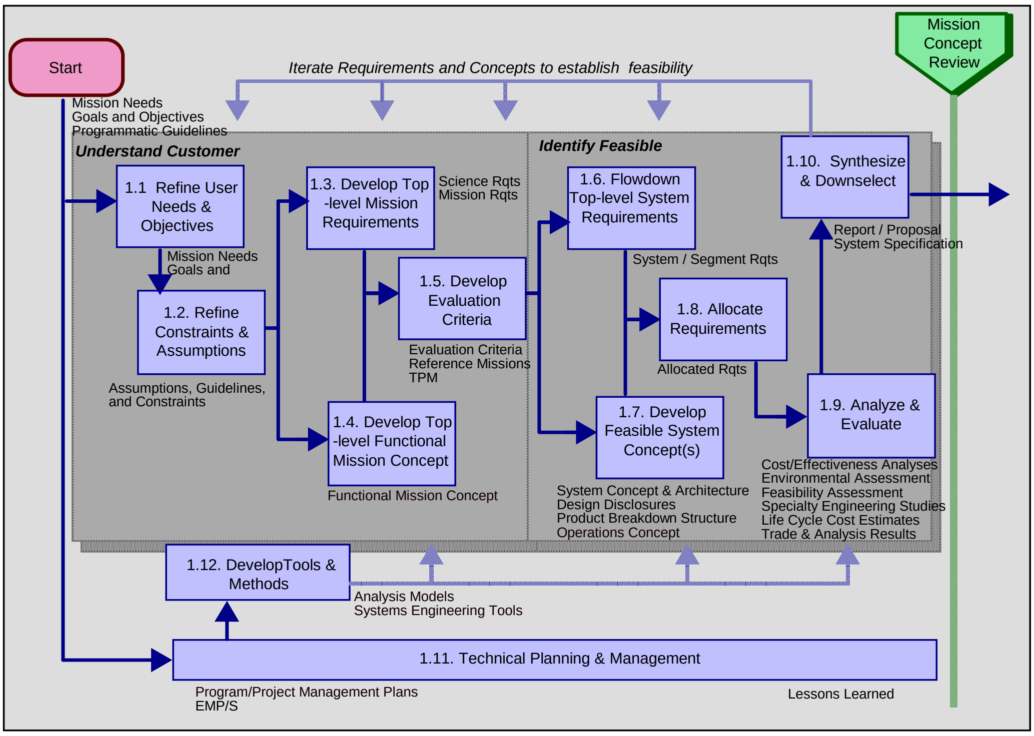

Figure 5.1.2-1. Mission Feasibility Activity Network.

5.1.2. Description

Mission Feasibility consists of multiple quick-turnaround iterations of the functions-design-evaluate-synthesize loop of a systematic engineering process. The initial iterations focus on broad concerns and top priorities. Later iterations provide greater detail. Figure 5.1.2-1 depicts the major activities and their related products. Two basic activities comprise Mission Feasibility: Understand the Customer and Identify Feasible Alternatives. The initial iterations focus on understanding the customer. The focus then shifts to identifying feasible concepts.

Start: Major inputs are Objectives and Programmatic Guidelines. The objectives describe what goals or accomplishments are desired. They may or may not be in the form of top-level requirements. Programmatic Guidelines provide further direction and typically include constraints or conditions on technology, schedule, cost, and so on.

Understand Customer

1.1. Refine User Needs & Requirements: The effort develops a set of commonly understood and committed to statements as to what are the conditions of fulfilling mission objectives. This frequently involves working with the customer to analyze inputs and clarify intent in order to ensure a common understanding.

1.2. Refine Constraints & Assumptions: The effort similarly refines and elucidates the constraints and assumptions. This may entail additional or more detailed assumptions concerning the mission and the potential design approaches.

1.3. Develop Top-level Mission Requirements: The effort establishes top-level sizing and performance requirements for meeting the mission objectives. These are formal statements of what is needed in terms of quantitative, measurable parameters. Functional analyses, often in the context of a mission concept, are generated to identify various options and interactions that merit more investigation or give rise to trades. Initial considerations are restricted to the top-level functions most pertinent to achieving the mission. During later iterations, the effort may consider more detail to validate requirements and approaches, and to understand key or risky areas.

1.4. Develop Top-level Functional Mission Concept: The effort develops conceptual top-level descriptions of ways to achieve mission objectives. This establishes a framework and context for requirements flowdown. It also provides a benchmark from which to analyze and define options.

1.5. Develop Evaluation Criteria: With the customer, the effort develops criteria and metrics with which to discern the quality and acceptability of approaches and options. Criteria for meeting the study objectives are also developed and provide completion criteria for the MCR. The effort also addresses priorities and the relative importance of requirements. These criteria and priorities give a basis to allocate margins and resources. They also determine the types of evaluations and the data needed. This activity continues as higher degrees of resolution are needed. The criteria may cover such considerations as performance, cost, schedule, risk, and robustness.

Identify Feasible Alternatives

1.6. Flowdown Top-level System Requirements: The effort translates the mission requirements and concept into functional and performance requirements that a system must meet to achieve the mission requirements. This generally requires at least some top-level system concept. The flowdown tends to be primarily functional and performance focused. It establishes top-level sizing and performance for the System.

1.7. Develop Feasible System Concept(s): The effort develops at least one conceptual design for a system that meets the system requirements. This conceptual design describes the major parts and how they interrelate and interoperate. The detail is sufficient to support inputs to estimates of cost and schedule, risk assessments, and evaluation criteria. Emphasis is on feasibility not optimality. As shown, the design activity may occur somewhat in parallel with the requirements flowdown.

1.8. Allocate Requirements: Particular functions and performance levels are allocated to various entities involved in the top-level System functions. This may entail parametrics, tradeoffs and analyses to allocate budgets and functions. It includes determining size and features of System entities. As functions are allocated, additional interfaces may emerge or need refinement.

1.9. Analyze & Evaluate: The effort analyzes and evaluates the characteristics of the design concepts and requirements in light of evaluation criteria and priorities. Results include estimates of cost and schedule and assessments of technical risk.

1.10. Synthesize & Downselect: Results of the analyses and evaluations are considered. Based on the insights provided, choices are made or new options defined for further exploration. Synthesis seeks a balanced solution that attempts to combine good aspects of alternatives and eliminate their bad aspects. The synthesis provides feedback to subsequent iterations.

Support

1.11. Technical Planning & Management: Initial activities include forming the team and setting up the study plans and schedules. Subsequent ongoing activities involve monitoring progress, reviewing results, and decision making. Management functions may also include preparation of material and interfacing with customer and other interested parties.

1.12. Develop SE Tools & Methods: As necessary, the effort develops the needed tools, methods, and skills so that team members will have consistent products and information with which to capture and communicate results.

5.1.3. Management and Control

5.1.3.1. General

Organizations typically perform Mission Feasibility in-house. The team consists of a full time lead and part-time team members but may include support contractors and special study contracts. The skills of the analyst and the designer are critical. The environment is fairly informal and dynamic; many issues are often fuzzy. Without adequate communication and coordination, team members may generate inconsistent or incompatible products. Technical management concerns include the following.

- Team formation.
- Team communication.
- Appropriate level of detail, neither too general nor too specific.
- Balance flexibility and creativity with formality and process.
- Maintain traceability among goals, requirements, and concepts.

5.1.3.2. Reviews

The ad hoc nature of Mission Feasibility can cause confusion among participants. The following interim reviews provide forums for exposing and discussing issues and approaches, and communicating decisions to team members.

- Customer reviews: to set and clarify mission requirements and strawman mission concept.

- Peer reviews: These occur at the completion of each iteration. They include outside experts.

The Mission Concept Review (MCR) is the associated stage control gate. It occurs when the activity has reached a level of maturity where the mission objectives can be clearly defined and quantified. If there is sufficient justification to warrant further mission analysis on the objectives and requirements and to support exploration of alternative system concepts to satisfy the mission objectives, activities may go through several iterations before arriving at this point. Each iteration has associated peer reviews where work is reviewed for its technical accuracy. This iterative process should refine the mission objectives until it converges to a point where firm mission requirements can be determined and justification exists for seeking a decision to proceed into Mission Definition activities.

5.1.4. Products

Figure 5.1.4-1 summarizes System maturity at the end of Mission Feasibility. Table 5.1.4-1 summarizes the products of Mission Feasibility and their level of maturity. A preliminary functional mission concept provides a functional description of how mission objectives and requirements can be met. The focus is on *what* is done rather than *how* it is done (e.g., remote sensing vs. orbiting satellite) The concept identifies top-level functional segments, major mission events, and their interactions. System and element design are conceptual and reflect limited engineering. They are used to demonstrate feasibility and to estimate rough sizing and functions. Technical concerns and risks assessments identify needs for inventions, discoveries, improvements, and innovations to enable or enhance the system concept. The Engineering Master Plan / Master Schedule covers the study period in detail and provides a top-level plan for later years to support schedule and cost estimates. Cost and schedule estimates are rough order of magnitude. The results are captured in a report and recommendations.

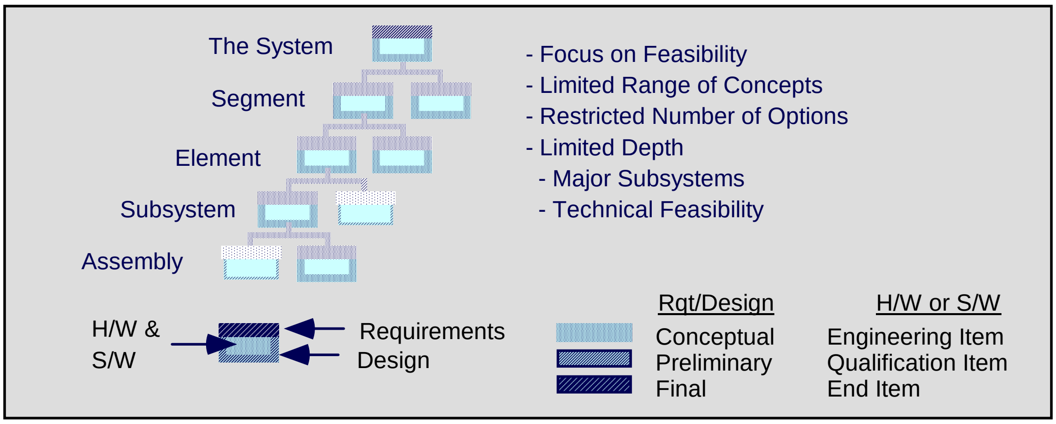

Figure 5.1.4-1. System Maturity at the End of Mission Feasibility.

5.1.5. Tailoring

Complexity and technical maturity can be major drivers in tailoring Mission Feasibility. A complex mission will likely require larger teams, extended schedules, and greater formality. For missions with an extensive evolutionary path (e.g., a lunar base), the conceptualization for later stages of the mission may extend beyond the development of the initial System. As mentioned above, Mission Feasibility may involve a sequence of studies that spans several years. Thus a single clearly defined technical effort may not occur.

Table 5.1.4-1. Typical Mission Feasibility Products and Their Maturity

Product System

-

Engineering Requisites

C Disposal Requirements
C Environmental Specification
C Interface Requirements
C Mission Goals and Objectives
C Mission Needs
C Science Requirements
C System Specification
C Assumptions, Guidelines, and Constraints
C Technology Development Requirements

Verification & Test

C Verification Plans

Execution

• Mission Proposal
C Design Disclosure
C Instrumentation Program and Command List
ß Integrated Schematics
ß Product Breakdown Structure
C System Concept & Architecture
C Integration and Assembly Plan
C Manufacturing Plan
C Disposal Plans
C Functional Mission Concept
ß Operations Concept
C Launch Operations Plan

Analyses/Evaluations

C Concept/Design Evaluation Criteria
ß Reference Missions

Analyses/Evaluations (cont'd)

ß Cost/Effectiveness Analyses
ß Environmental Assessment / Impact Statement
ß Feasibility Assessment
ß Functional Flow Analysis
ß Specialty Engineering Studies
ß Life Cycle Cost Estimates
ß Trade & Analysis Results

Tools

ß Analysis Models
• Systems Engineering Tools

Management/Control

C Payload to Carrier Integration Plan
C Technical Performance Measurement Plan
• Systems Engineering Management Plan
P Technology Development Plan
ß Technical Performance Measures Reports
C Work Breakdown Structure (Product System)
C Work Breakdown Structure (Operational System)
ß Engineering Master Plan / Master Schedule
• Rolling Wave Plan
ß Information Management Plan
C Specification Tree
ß Risk Identification and Characterization
C Program/Project Management Plans
C Statement of Work (SOW)

Other

• Concept Definition Report / Proposal
• Presentation Material
• Lessons Learned

C=conceptual, P=preliminary, F=final, Δ=update ß=partial / top-level, •=complete, U=engineering item, Q=qualification item, E=end item

5.2. Mission Definition

5.2.1. Overview

Mission Definition identifies the complete set of capabilities needed to accomplish the objectives. The focus is on establishing optimality and exploring multiple alternatives. Primary products are accepted mission and system requirements; accepted, optimized top-level system architecture; and refined programmatic estimates. The initial iteration focuses on core mission functions; later iterations consider additional aspects such as aborts and contingencies, mission preparations, and disposal. Technology development plans support risk mitigation effort in System Definition. Table 5.2.1-1 summarizes Mission Definition.

Table 5.2.1-1 Summary of Mission Definition

Objective:	• Establish validated (segment level) requirements which meet mission objectives • Establish architectural and top-level operations concept • Identify technology risks and mitigation plan • Refine programmatic resource need estimates
Major Products:	• Top-level System Architecture • Preliminary System Specification(s) • Final Feasibility Assessment • System Candidates • Technology Requirements • Technology Development Plan • Risk Assessment & Mitigation Options • Refined Cost & Schedule • Disposal Requirements
Major Decisions:	• What is top-level architecture and functional characterization of System? • How will risks be mitigated?
Program Phase	During Phase A.
Control Gate:	Mission Definition Review
Features:	• Primary focus on functions and requirements. • Typically in-house. Specific study contracts may be let. • Focus on finding an optimal approach and architecture. • Multiple alternatives explored. • More formal and rigorous than Mission Feasibility. • Analysis and concept definition to limited depth. • Typical team is full time lead with part-time expert team members.

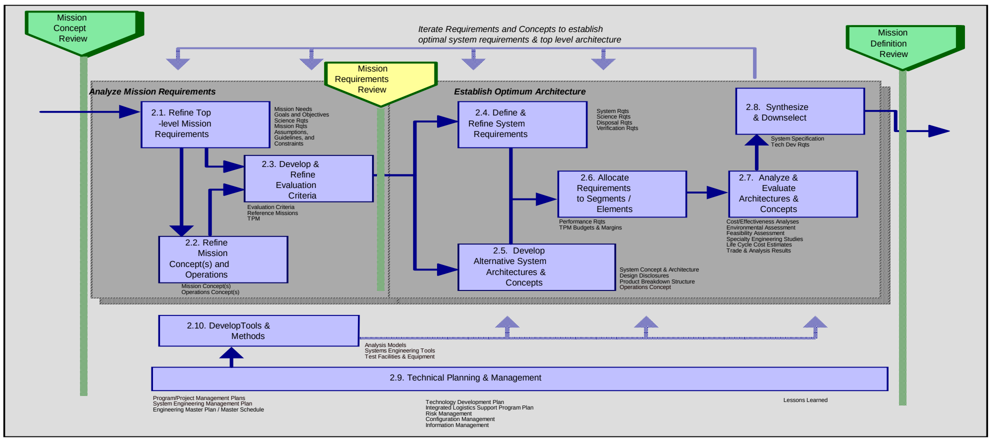

Figure 5.2.2-1. Mission Definition Activity Network.

5.2.2. Activities

Figure 5.2.2-1 is a top-level overview of the activities of Mission Definition. The iterative process is similar to Mission Feasibility but involves greater technical depth and rigor.

Analyze Mission Requirements

2.1. Refine Top-level Mission Requirements: The effort analyzes mission requirements in order to describe objectives in measurable parameters. The effort reviews previous results. Further definition of the mission and quantification of performance and environment may be necessary.

2.2. Refine Mission Concept(s) and Operations: The effort reviews and refines the existing mission and operations concept. The emphasis is on optimality as opposed to feasibility, so the effort involves more detail and considers more alternatives.

2.3. Develop & Refine Evaluation Criteria: The effort reviews and refines the evaluation criteria and priorities that will be used to guide analyses, allocations, and margins. Criteria are identified for meeting Mission Definition objectives and for passing the control gate.

Establish Optimal Architecture

2.4. Define & Refine System Requirements: The effort performs functional analysis and requirements flowdown, exploring more detail and alternatives than in Mission Feasibility. This includes considerations arising from proposed implementations or utilizations of entities. This effort institutes a more formal process to manage and maintain requirements and traceability. The effort is comprehensive enough for a complete preliminary draft of a System/Segment Specification.

2.5. Develop Alternative System Architectures & Concepts: Designs are defined to sufficient depth to insure completeness and validity of requirements. They reflect greater engineering effort that in Mission Feasibility - where sketches and rough estimates may suffice. Designs in critical areas are pursued to greater depth for better technical and programmatic understanding.

2.6. Allocate Requirements: Requirements are allocated to the System components identified in the concepts in a traceable and optimal manner. This includes trades, implementation and utilization analyses, and refinement of interfaces. Designs are updated and elaborated to reflect the allocations.

2.7. Analyze & Evaluate Architectures & Concepts: The effort analyzes and evaluates the results to ascertain acceptability and problem areas. Considerations include evaluation criteria, risk, and programmatics. The effort performs additional studies and analyses to understand and evaluate the System and its requirements. Additional requirements may emerge due to considerations such as safety, logistics, disposal, environment, or mission preparation.

2.8. Synthesize & Downselect: The insights provided by previous steps are used to identify improvements and problem areas that feedback into design or requirements changes. The effort abandons unpromising options, and identifies new ones.

Support

2.9. Technical Planning & Management: The study team is formed and study plans and schedules prepared and maintained. Technical management monitors the process, reviews results, and ensures quality decisions. Controls include top-level technical performance measurements.

2.10. Develop Tools & Methods: As necessary, the effort identifies and develops the needed tools, methods, and skills it will use. Concerns include identifying and tracking options, capturing decisions and rationales, and providing traceability. This may include acquiring tools for the next stage.

5.2.3. Management & Control

5.2.3.1. General

Organizations frequently perform Mission Definition in-house but study contracts may be let. The team consists of a full time lead and team members with part-time experts, but may include support contractors and special study contracts. The skills of the analyst are critical. Management functions include those of Mission Feasibility but there is greater formality, rigor, and control.

- Team formation.
- Team communication.
- Appropriate level of detail, neither too general nor too specific.
- Balance flexibility and creativity with formality and process.
- Maintain traceability among goals, requirements, and concepts.

- Technical Performance Measurement.
- Identify and release baseline and options.

5.2.3.2. Reviews

The following interim reviews provide forums for exposing and discussing issues and approaches, and communicating decisions to team members.

- Customer reviews: These set and clarify mission requirements and strawman mission concept.
- Peer reviews: these occur at the completion of each iteration or major drafts. They include outside experts.
- Mission Requirements Review: this review may be used to ratify mission requirements.

The following types of interim concurrent engineering reviews may help to increase the chances of success, providing a useful forum for review of interim products contained on the evaluation criteria checklist.

- Mission options review.
- Design options review.
- Design concept review.
- Finite resources review.

The Mission Definition Review (MDR) control gate addresses completion of Mission Definition and technical readiness to proceed to System Definition. The Mission Definition Review evaluates the rationale for selecting the recommended mission and system architecture and lays the groundwork for defining the next level of the design. Trades are identified that will be done in the next stage and which will address refining the performance requirements. In conjunction with the MDR, The Preliminary Non-Advocate Review (Pre-NAR) and the Preliminary Program/Project Approval Review (Pre-PPAR) occur at the agency level.

5.2.4. Products

Figure 5.2.4-1 summarizes System maturity at the end of Mission Definition. Table 5.2.4-1 summarizes the products produced and their level of maturity. Mission objectives and requirements are finalized. A preliminary System Specification identifies overall functional requirements for the System as an entity and defines the interfaces between or among the functional areas. Considerations include logistics, safety, quality, verification, delivery, and disposal requirements. An optimized top-level System Architecture is developed and approved. Candidate system concepts are developed for refinement in System Definition. They reflect greater technical depth and provide basis for refined programmatic estimates. A preliminary operations concept to support the mission and system concepts is developed. It defines tasks, responsibilities, infrastructure and activities required for System operation and serves as a basis for estimation of facility and resource requirements. Assessments demonstrate the technical and programmatic feasibility of meeting objectives within imposed constraints and guidelines. Technology risks are assessed and mitigation plans are developed for implementation in System Definition.

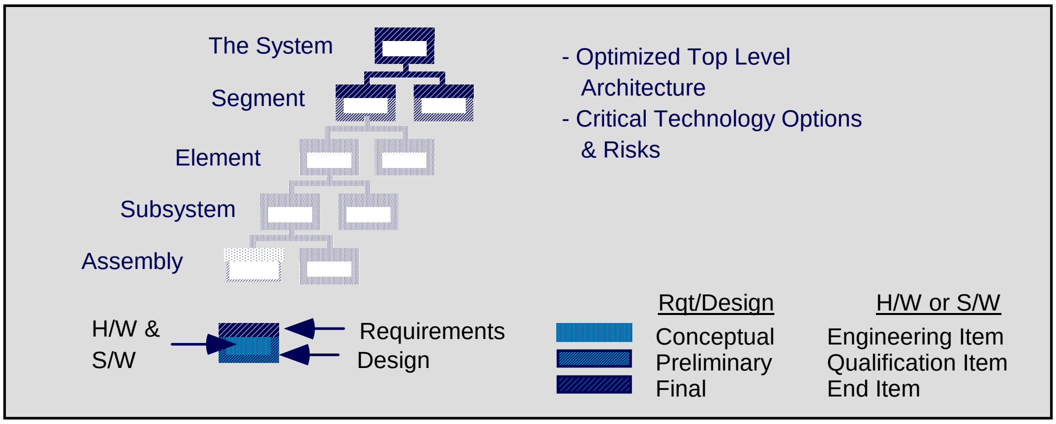

Figure 5.2.4-1. System Maturity at the End of Mission Definition.

5.2.5. Tailoring

Tailoring considerations include the complexity and technical risk of the System. For example, early technology development may be needed before the overall architecture can be addressed.

Table 5.2.4-1. Typical Mission Definition Products

Product System
-

Engineering Requisites
C Design-To Specification
P Disposal Requirements
P Environmental Specification
C Interface Requirements
F Mission Goals and Objectives
F Mission Needs
F Science Requirements
P System Specification
C Applicable Standards
P Human System Standards
P Assumptions, Guidelines, and Constraints
P Technology Development Requirements

Verification & Test
C Verification Requirements Matrix
C Verification Plans

Execution
C Design Disclosure
P Hardware/Software List
C Instrumentation Program and Command List
ß Integrated Schematics
C Prime Item Design Candidates
ß Product Breakdown Structure
P System Concept & Architecture
C Integration and Assembly Plan
C Manufacturing Plan
P Quality Assurance Plan
C Disposal Plans
F Functional Mission Concept
ß Operations Concept
C Launch Operations Plan
C Integrated Logistics Support Plan

Analyses/Evaluations
P Concept/Design Evaluation Criteria
ß Reference Missions
ß Cost/Effectiveness Analyses
ß Environmental Assessment / Impact Statement
ß Failure Modes and Effects Analysis

Analyses/Evaluations (cont'd)
• Feasibility Assessment
ß Functional Flow Analysis
ß Logistics Support Analysis
ß PD/NSC-25 Databook
ß Specialty Engineering Studies
• System Interface Studies
ß Life Cycle Cost Estimates
• Trade & Analysis Results
P Development Test Plans

Tools
ß Analysis Models
• Systems Engineering Tools
ß Test Facilities & Equipment

Management/Control
C Development Plans
C Payload to Carrier Integration Plan
P Technical Performance Measurement Plan
• Systems Engineering Management Plan
P System Safety Plan
F Technology Development Plan
ß Integrated Logistics Support Program Plan
ß Technical Performance Measures Reports
P Work Breakdown Structure (Product System)
C Work Breakdown Structure (Operational System)
ß Engineering Master Plan / Master Schedule
• Rolling Wave Plan
ß Configuration Management Plan
C Documentation Tree
C Drawing Tree/ Engineering Drawing List
ß Information Management Plan
P Specification Tree
ß Risk Analyses
• Risk Identification and Characterization
P Risk Management Plan
P Program/Project management Plans
P Statement of Work (SOW)

Other
• Presentation Material
• Lessons Learned

C=conceptual, P=preliminary, F=final, Δ=update ß=partial / top-level, •=complete, U=engineering item, Q=qualification item, E=end item

5.3. System Definition

5.3.1. Overview

System Definition establishes an optimized definition of the items to be acquired or developed. Technical risks are mitigated by developing critical technology or long lead items. Programmatics are refined to provide firm cost and schedule estimates. Management preparations are made for the preliminary design stage. This includes preparation of various engineering and specialty plans and inputs to support program control and acquisition. Table 5.3.1-1 summarizes System Definition.

Table 5.3.1-1. Summary of System Definition

Objective:	• Complete system architecture and requirements allocation • Demonstrate System can be built within constraints • Develop test and verification program • Establish end item acceptance criteria • Refine information necessary to complete program definition
Major Products:	• Preliminary Design-To Specifications • Interface Requirements • Technology Development Results • Engineering and Technical Management Plans • Firm Cost & Schedule Estimates • Verification Matrix • Disposal Plans • Product Quality Plan • Engineering Plans
Major Decisions:	• Is System/segment design understood well enough to begin acquisition? • What items will be acquired?
Program Phase	During earlier part of Phase B.
Control Gate:	System Definition Review
Features:	• Primary study role by government or contractors. • Focus starts to shift to top-level design and implementation activity at subsystem and critical component level. • Significant planning activities in preparation for procurement and detailed design and development. • Larger team for design and analysis • Dedicated teams or contracts for technology and proof of concept projects on high risk or long lead items

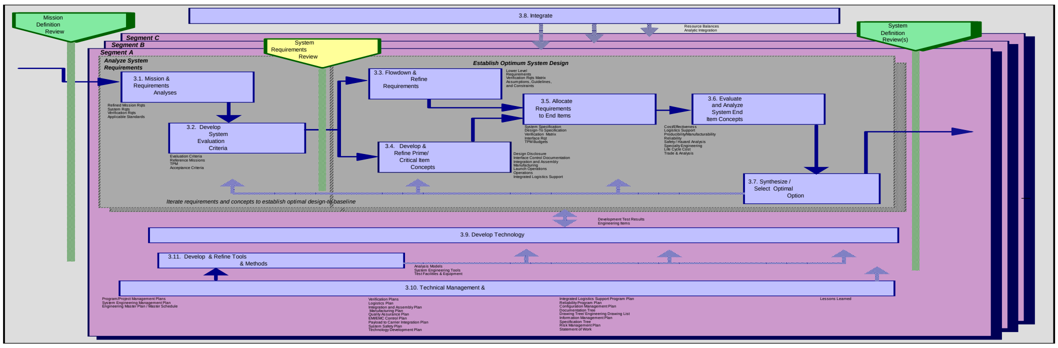

Figure 5.3.2-1. System Definition Activity Network.

5.3.2. Activities

Figure 5.3.2-1 depicts the activity network for the System Definition Stage. Design activities follow a process similar to the previous stages but focus on lower levels of the system hierarchy in order to identify the end-items. Thus the effort conducts several parallel definition activities at a segment or lower level. New activities include executing risk mitigation measures identified in Mission Definition and making preparation for Preliminary Design. To simplify the discussion, it is assumed that the end items are generally at the element level of the hierarchy. Depending on the system design, end items may be at various levels in the hierarchy.

<u>Analyze System Requirements</u>

3.1. Mission & Requirements Analyses: Mission requirements and concepts are refined as necessary to elicit more detailed data and understanding to support the more detailed considerations of this stage.

3.2. Develop System Evaluation Criteria: Metrics are refined and developed as necessary to support the focus on optimizing the element level of the system hierarchy. Criteria are identified for meeting System Definition objectives and for passing the control gate.

<u>Establish Optimal System Design</u>

3.3. Flowdown & Refine System Requirements: The effort flows down and refines requirements to develop preliminary functions specifications for end items. This includes analyses of implementation and utilization and addressing how requirements will be verified.

3.4. Develop & Design System Concepts: Designs are defined to sufficient depth to insure completeness and validity of requirements for the end items. The designs cover the upper tiers of System Hierarchy through end items and their major subsystems. Interfaces are refined and described. The effort also generates design related data that will be useful for later System level evaluations.

3.5. Allocate Requirements: Requirements are allocated to the components identified in the concept in a traceable and optimal manner. This includes trades, implementation and utilization analyses, and refinement of interfaces. Designs are updated and elaborated to reflect the allocations.

3.6. Evaluate and Analyze System Concepts: The effort analyzes and evaluates the results to ascertain acceptability and problem areas. Considerations include evaluation criteria, risk, and programmatics. The effort performs additional studies and analyses to understand and evaluate the System and its requirements. Additional requirements may emerge due to considerations such as safety, logistics, disposal, environment, or mission preparation.

3.7. Synthesize / Select Optimal Option: The insights provided by previous steps are used to identify improvements and problem areas that feedback into design or requirements changes. The effort abandons unpromising options, and identifies new ones. As necessary new baselines are identified.

General

3.8. Integrate: The results and efforts of the activities at the lower levels of the hierarchy are integrated so as to be compatible. Effects and issues at the System level are monitored and addressed.

3.9. Develop Technology: The effort performs specific projects to mitigate risks during detailed design and development. This includes technology development and advanced development activities that produce various engineering test articles.

3.10. Technical Management & Planning: The effort develops schedules and plans and processes. Baselines are identified and the configuration controlled. Formal and informal reviews and working forums are instituted to facilitate surfacing and resolving issues. Technical progress is measured. Various plans are developed in preparation for detailed design and development. Examples include the following:

- Systems Engineering Management Plan
- Information Management Plan
- Configuration Management Plan
- Technical Performance Measurement Plan
- Integrated Logistics Support Program Plan
- Reliability Program Plan
- Quality Assurance Plan
- Contamination Control Plan
- EMI/EMC Control Plan
- System Safety Plan
- Parts Control Plan

3.11. Develop & Refine Tools & Methods: As necessary, the effort identifies and develops the needed tools, methods, and skills. This may include acquiring tools to conduct or manage subsequent development.

5.3.3. Management & Control

5.3.3.1. General

The effort is supported by a number of teams that address more focused levels of the hierarchy in more detail. The skills of the system architect are critical. Technical management addresses both inter-team and intra-team concerns. These include the following.

- Team formation.
- Team communication.
- Appropriate level of detail, neither too general nor too specific.
- Balance flexibility and creativity with formality and process.
- Maintain traceability among goals, requirements, and concepts.
- Technical Performance Measurement
- Identify and release baseline and options

5.3.3.2. Reviews

The following interim reviews provide forums for exposing and discussing issues and approaches, and communicating decisions to team members.

- Peer reviews. These occur at the completion of each iteration or major drafts. They include outside experts.
- Requirements Review. The team may further analyze the mission and hold a review to demonstrate understanding of requirements. It is also often used to establish firm requirements. Typical requirements reviews are the System Requirements Review (SRR) and the Program Requirements Review (PRR).

The System Definition Review (SDR) is the control gate associated with System Definition. In conjunction with the SDR, The Non-Advocate Review (NAR) and the Program/Project Approval Review (PPAR) occur at the agency level. There may be multiple SDRs corresponding to different levels of the hierarchy (e.g., at the System and segment levels). The generic Life Cycle Model posits a template in which multiple reviews flow down to lower levels. Projects should tailor the sequencing of the reviews to meet their individual needs.

5.3.4. Products

Figure 5.3.1-1 summarizes the System's maturity at the end of System Definition. Table 5.3.4-1 summarizes typical System Definition products and their level of maturity. The System Specifications are approved and establish an approved functional baseline. An optimized set of end item requirements are defined and preliminary design-to specifications are prepared to establish a preliminary design-to baseline. Technology development activities produce various engineering articles. Engineering plans are prepared for the Preliminary and Final Design stages and to establish the activities required for planning, controlling and conducting a fully integrated engineering effort.

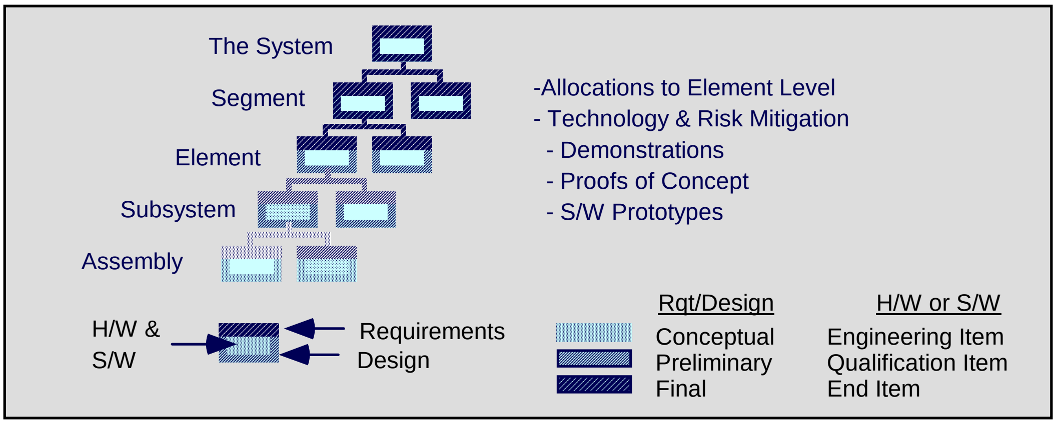

Figure 5.3.4-1. System Maturity at the End of System Definition.

By the SDR, the System level requirements have been fully allocated to the elements and segment levels. Element and segment specifications are completed and releasable. A preliminary functional decomposition of the element and segment levels has been done, with preliminary requirement allocation to subsystems, software modules and hardware components. The system architecture has been defined to the element and segment level with preliminary design concepts at the subsystem level. System architecture drawings are complete and releasable. Processes have been identified and put into place for design and requirement configuration control of released design and specification documentation. Design guidelines from the specialty engineering areas are available (reliability, contamination control, etc.). Technical performance measures have been identified with a preliminary profile and allocation completed.

5.3.5. Tailoring

Major tailoring considerations are the overall top-level system architecture and the technical risks established in Mission Definition. The top-level architecture drives the number and extent of lower-level definition processes. For example, if an existing launch system is to be used, the activities for that effort may identify what if any modifications are desirable. The nature and technological maturity of the end items are also an important tailoring consideration.

Table 5.3.4-1. Typical System Definition Products

Product System
U Engineering Items
ß Logistics Support Analysis Records

Engineering Requisites
P Acceptance Criteria
P Design-To Specification
P Disposal Requirements
F Environmental Specification
P Interface Requirements
Δ Mission Needs
F System Specification
P Vendor Hardware and Software Specification
P Environments Control Plan
P Applicable Standards
F Human System Standards
Δ Assumptions, Guidelines, and Constraints
F Technology Development Requirements

Verification & Test
P Verification Requirements Matrix
P Verification Plans

Execution
C Design Disclosure
F Hardware/Software List
P Instrumentation Program and Command List
ß Integrated Schematics
P Interface Control Documentation
ß Product Breakdown Structure
F System Concept & Architecture
C Integration and Assembly Plan
C Manufacturing Plan
P Quality Assurance Plan
ß Operations Concept
C Launch Operations Plan
C Operations Plan
P Spares Provisioning List
P Integrated Logistics Support Plan
P Parts Control Plan

Analyses/Evaluations
F Concept/Design Evaluation Criteria
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ß Reliability Assessment
ß Safety / Hazard Analysis
ß Specialty Engineering Studies
ß Life Cycle Cost Estimates
• Trade & Analysis Results
• Development Test Results
F Development Test Plans

Tools
ß Analysis Models
• Systems Engineering Tools
ß Test Facilities & Equipment

Management/Control
C Contamination Control Plan
P Development Plans
P EMI/EMC Control Plan
P Payload to Carrier Integration Plan
P Technical Performance Measurement Plan
• Systems Engineering Management Plan
F System Safety Plan
Δ Technology Development Plan
ß Integrated Logistics Support Program Plan
P Reliability Program Plan
ß Technical Performance Measures Reports
P Work Breakdown Structure (Product System)
P Work Breakdown Structure (Operational System)
• Engineering Master Plan / Master Schedule
• Rolling Wave Plan
• Configuration Management Plan
F Documentation Tree
P Drawing Tree/ Engineering Drawing List
• Information Management Plan
P Specification Tree
• Risk Analyses
• Risk Identification and Characterization
Δ Risk Management Plan
F Program/Project Management Plans
F Statement of Work (SOW)

Other
• Presentation Material
• Lessons Learned

C=conceptual, P=preliminary, F=final, Δ=update ß=partial / top-level, •=complete, U=engineering item, Q=qualification item, E=end item

5.4. System Preliminary Design

5.4.1. Overview

System Preliminary Design produces a stable, functionally complete design that meets the mission needs. The System is completely defined through the implementation level of design. Design dependent requirements and the interfaces among all entities are established. Engineering test articles may be developed and used to derive data for design. Throughout the effort, integration efforts maintain the unity of the System. Table 5.4.1-1 summarizes Preliminary Design.

Table 5.4.1-1. Summary of System Preliminary Design

Objective:	• Establish a design solution that fully meets mission needs • Complete test and verification plans • Establish design dependent requirements and interfaces • Complete "implementation" level of design
Major Products:	• Final Design-To Specifications • Preliminary Build-To Specifications • Preliminary Interface Control Documents • Verification Plans • Qualification Item Plans • Engineering Test Data • Preliminary Training Materials • Operations Procedures
Major Decisions:	• What are the best designs and technologies for the end items? • What is the System configuration? • How will design and product be validated and verified? • What are the acceptance criteria?
Program Phase	During later parts of Phase B.
Control Gate:	• PDR - Preliminary Design Review
Features:	• Typically performed by prime contractors and subcontractors • Government role is primarily validating and monitoring contracted effort and preparing for operations. • Full time government and contractor program managers

5.4.2. Activities

Figure 5.4.2-1 gives an overview of the activities of Preliminary Design. The primary technical definition effort is at the level of end items and their constituents. The effort develops a suitable configuration that provides a stable environment for orderly development of full details. It is functionally complete in that it exposes the complete implementation level of design and meets all requirements. It is preliminary in that many lower level specifics at the realization level of design remain to be done.

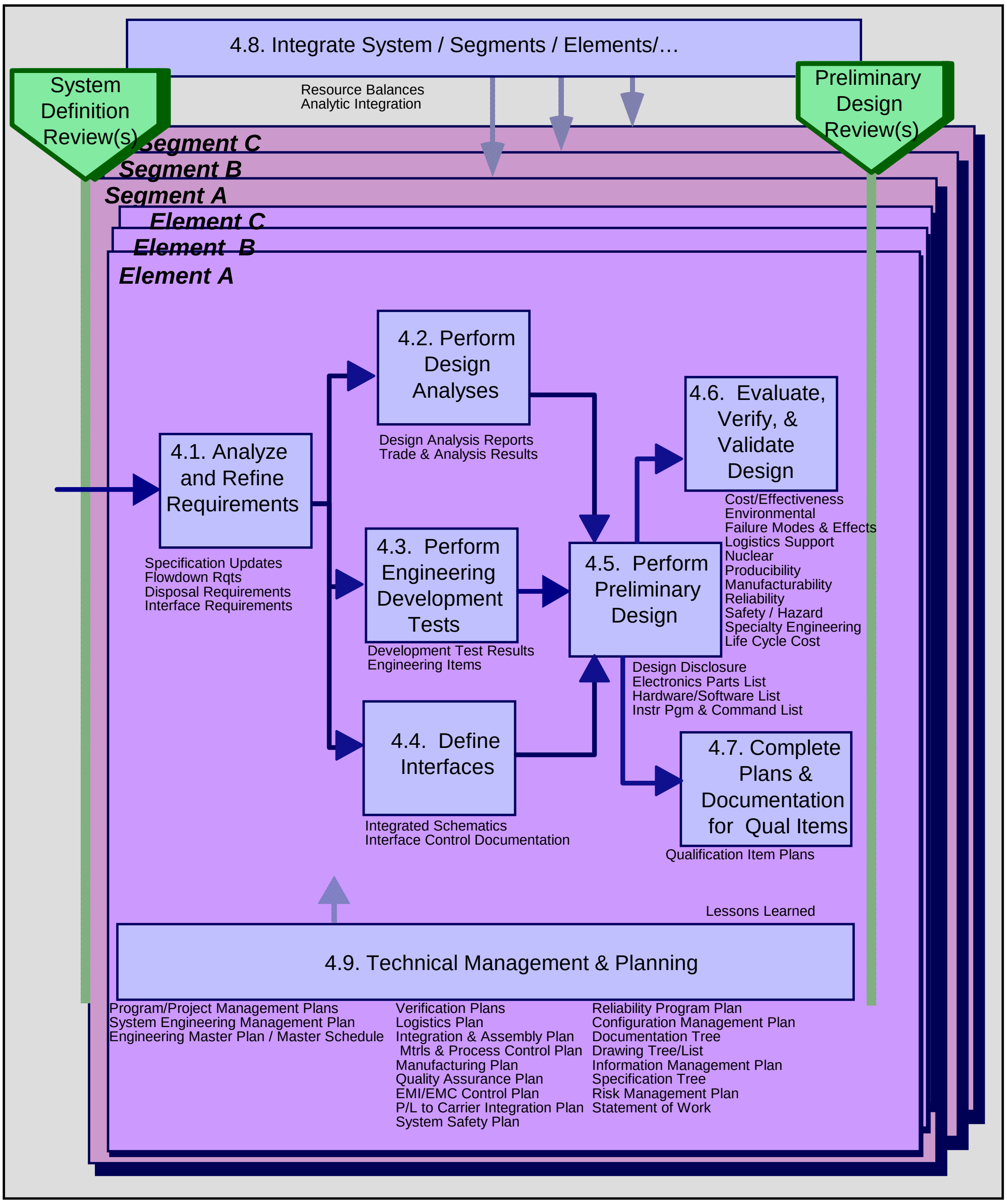

Figure 5.4.2-1. Preliminary Design Activity Network.

4.1. Analyze and Define Requirements: Mission and functional analyses are performed to derive lower level requirements and select parameter values. Parametrics expose thresholds and sensitivities and define a basis for selecting specific parameters. A systematic approach defines and characterizes interactions in a measurable form. Analyses develop supporting requirements to ensure proper operation and function of the entire System and to establish requirements on supporting elements.

4.2. Perform Design Analyses: Analyses and studies generate data for insight needed to derive design parameters or to evaluate options. Examples include thermal and structural analyses and simulations.

4.3. Perform Engineering Development Tests: Test articles and mockups are developed and used to generate data that are needed for design considerations such as environment, materials, performance, and lifetime.

4.4. Define Interfaces: Interfaces are defined and integrated to ensure the preliminary design will fit together and work. The preliminary interface definition is typically more functionally oriented.

4.5. Perform Preliminary Design: The effort creates and specifies a preliminary design that is a functionally complete implementation of the System. It includes a preliminary sizing of all functional components. The specification defines the item's functional and physical characteristics in the form of specifications, drawings, associated lists, interface control documents, and documents referenced therein.

4.6. Evaluate, Verify, and Integrate Design: The preliminary design is checked to demonstrate its merits and compliance with requirements. This include analyses such as a top-level Failure Modes and Effects Analysis. Global or system wide studies are also conducted.

4.7. Complete Plans and Documentation for Qualification Items. Items requiring certification to meet the operational environment are identified and the necessary test plans and documentation prepared.

4.8. Integrate: The efforts and results at lower levels of the hierarchy are monitored and integrated to assure the integrity of the overall System. This includes tracking interfaces, technical performance measures, allocations, etc.

4.9. Technical Management & Planning: Technical management facilitates an effective orderly execution via configuration control, technical reviews, and technical decisions. The effort prepares and maintains reports that give the status of properties consistent with the developing design. It prepares specific technical plans such as Electromagnetic Interference/Electromagnetic Compatibility (EMI/EMC) Test Plan.

5.4.3. Management & Control

5.4.3.1. General

Technical management must direct and integrate the activities at multiple levels of the system hierarchy. Support is typically provided by multiple organizations. The skills of the system architect and the top-level designer are critical.

Preliminary Design is typically conducted under contract. In this case the government’s role is primarily one of technical management and review.

5.4.3.2. Reviews

The Preliminary Design Review (PDR) is the associated control gate. Other reviews may include those discussed in Mission Definition and System Definition.

5.4.4. Products

Figure 5.4.4-1 summarizes the overall System maturity for Preliminary Design. Table 5.4.4-1 summarizes products and their level of maturity. Design-to specifications and build-to specifications are approved and establish approved design-to and preliminary build-to baselines respectively. Engineering test items and prototypes are produced. Various plans and lists guide and facilitate the technical effort. The results should indicate that the design selection was optimal. By PDR, results should provide enough information on the maturity and adequacy of the design to justify the building of qualification hardware to validate the design concept. It should be demonstrated that program plans are mature and thorough and adequate development processes are in place to reduce risk. Verification plans must fully cover the verification of all requirements. They should provide clear direction for the planned design validation activity following the review. The majority of major issues relating to adequacy of the design should be identified in processes leading to the design review prior to submittal of the data package. These items should be identified in the review along with resolution/risk mitigation plans. These issues should be identified prior to submittal of the data package as far as possible. If major issues emerge after data package submittal, they should be presented with the updated presentation material in the formal review. The design should be defined in sufficient detail to identify risk areas, to answer questions regarding previously defined risk areas, to identify long lead items, and to accurately reflect their impact on overall scheduling and critical paths.

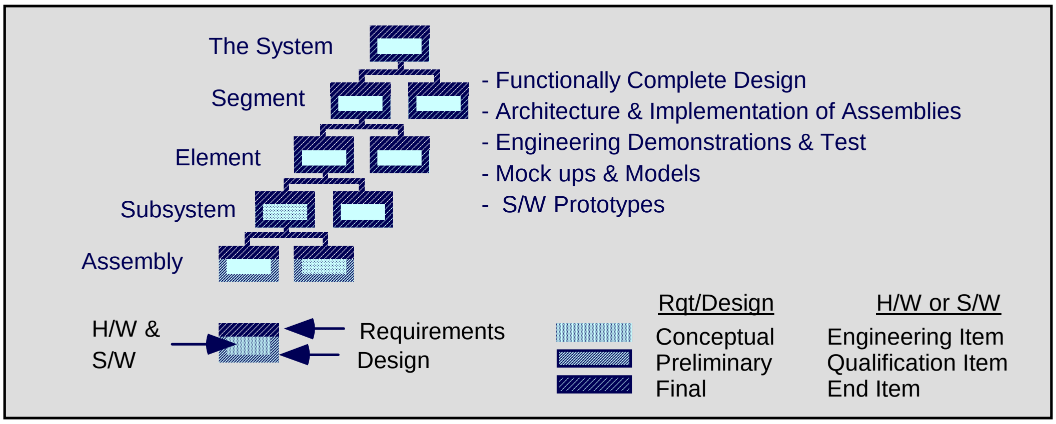

Figure 5.4.4-1. System Maturity for Preliminary Design.

5.4.5. Tailoring

Considerations in tailoring include the following.

- Schedule: It is generally not feasible to synchronize the development of different parts of the System. Schedules and costs will be unreasonable unless some parts proceed into manufacture while others are still in design.
- PDR template. There are typically PDRs corresponding to different levels of the hierarchy (e.g., the System, on down). The generic Life Cycle Model posits a template in which multiple reviews flow up to higher levels. Projects should tailor the sequencing of the reviews to meet their schedule and technical needs.

Table 5.4.4-1. Typical Preliminary Design Products

Product System
U Engineering Items
C Operations Data
ß Logistics Support Analysis Records
ß User's Manuals

Engineering Requisites
F Acceptance Criteria
P Build-To Specification
F Design-To Specification
F Disposal Requirements
F Interface Requirements
Δ Mission Needs
F Vendor Hardware and Software Specification
F Environments Control Plan
F Applicable Standards
Δ Assumptions, Guidelines, and Constraints

Verification & Test
ß Verification Requirements and Specifications
F Verification Requirements Matrix
F Qualification Item Plans
ß Verification Procedures & Data
F Verification Plans

Execution
P Design Disclosure
ß Electronics Parts List
Δ Hardware/Software List
P Instrumentation Program and Command List
ß Integrated Schematics
P Interface Control Documentation
ß Material and Processes Data
ß Parts Susceptible to Environmental Damage List
ß Product Breakdown Structure
P Computer Resource Integrated Support Document
P Integration and Assembly Plan
P Manufacturing Plan
P Materials and Processes Control Plan
F Quality Assurance Plan
P Disposal Plans
• Operations Concept
P Launch Operations Plan
C Operations Plan
P Transition to Operations Plan
ß EEE Parts Management Data
P Spares Provisioning List
P Integrated Logistics Support Plan
F Parts Control Plan
P Training Plan

Analyses/Evaluations
Δ Concept/Design Evaluation Criteria
• Reference Missions

Analyses/Evaluations (cont'd)
• Cost/Effectiveness Analyses
ß Design Analysis Reports
• Environmental Assessment / Impact Statement
ß Failure Modes and Effects Analysis
ß Functional Flow Analysis
ß Logistics Support Analysis
• PD/NSC-25 Databook
ß Producibility/Manufacturability Studies & Audits
• Reliability Assessment
• Safety / Hazard Analysis
• Specialty Engineering Studies
• Life Cycle Cost Estimates
• Trade & Analysis Results
• Development Test Results

Tools
• Analysis Models
• Systems Engineering Tools
ß Test Facilities & Equipment

Management/Control
P Acceptance Plans
F Contamination Control Plan
F Development Plans
F EEE Parts Management Plan
F EMI/EMC Control Plan
F Payload to Carrier Integration Plan
F Technical Performance Measurement Plan
• Systems Engineering Management Plan
Δ System Safety Plan
• Integrated Logistics Support Program Plan
F Producibility/Manufacturability Program Plan
F Reliability Program Plan
ß Technical Performance Measures Reports
F Work Breakdown Structure (Product System)
P Work Breakdown Structure (Operational System)
• Cost & Schedule Report
• Engineering Master Plan / Master Schedule
Δ Item Development Status Summary and Schedule
• Rolling Wave Plan
Δ Documentation Tree
F Drawing Tree/ Engineering Drawing List
• Information Management Plan
F Specification Tree
• Risk Analyses
• Risk Identification and Characterization
Δ Risk Management Plan
Δ Program/Project management Plans
F Statement of Work (SOW)

Other
• Presentation Material
• Lessons Learned

C=conceptual, P=preliminary, F=final, Δ=update ß=partial / top-level, •=complete, U=engineering item, Q=qualification item, E=end item

5.5. System Final Design

5.5.1. Overview

Final Design produces a stable, producible, and cost effective design that is ready to build, integrate, and test. Engineering test articles and qualification articles are constructed and tested. Detailed test and verification plans are prepared. Throughout the effort, integration efforts maintain the unity of the System. Table 5.5.1-1 summarizes Final Design.

Table 5.5.1-1. Summary of Final Design

Objective:	• Establish complete, validated detailed design • Complete all design specialty audits • Establish manufacturing processes and controls • Finalize & integrate system interfaces
Major Products:	• Final Design • Build-To Specifications • Interface Control Documents • Verification Specifications & Plans • Integration & Test Plans • Manufacturing Plans • Engineering Test Data • Preliminary Training Materials • Preliminary Operations Procedures
Major Decisions:	• What will be manufactured? • Will components and parts perform in projected environment? • What is detailed System configuration? • How will design and product be validated and verified? • What are acceptance criteria?
Program Phase	During Phase C.
Control Gate:	• CDR-Critical Design Review
Features:	• Typically performed by prime contractors and subcontractors • Government role is primarily monitoring and preparation for operations. • Full time government and contractor program managers

5.5.2. Activities

Figure 5.5.2-1 gives an overview of the activities of the Final Design stage. The effort establishes the design realizations of all details of the design. Detailed interfaces are defined and controlled. Qualification articles are built to establish that the design will function in the expected environment.

5.1. Define & Control Detailed I/F: The effort defines the specific, detailed interfaces between the parts of the System and the approaches to their test and verification. This involves the preparation and maintenance of ICDs. Designs are audited to insure matches.

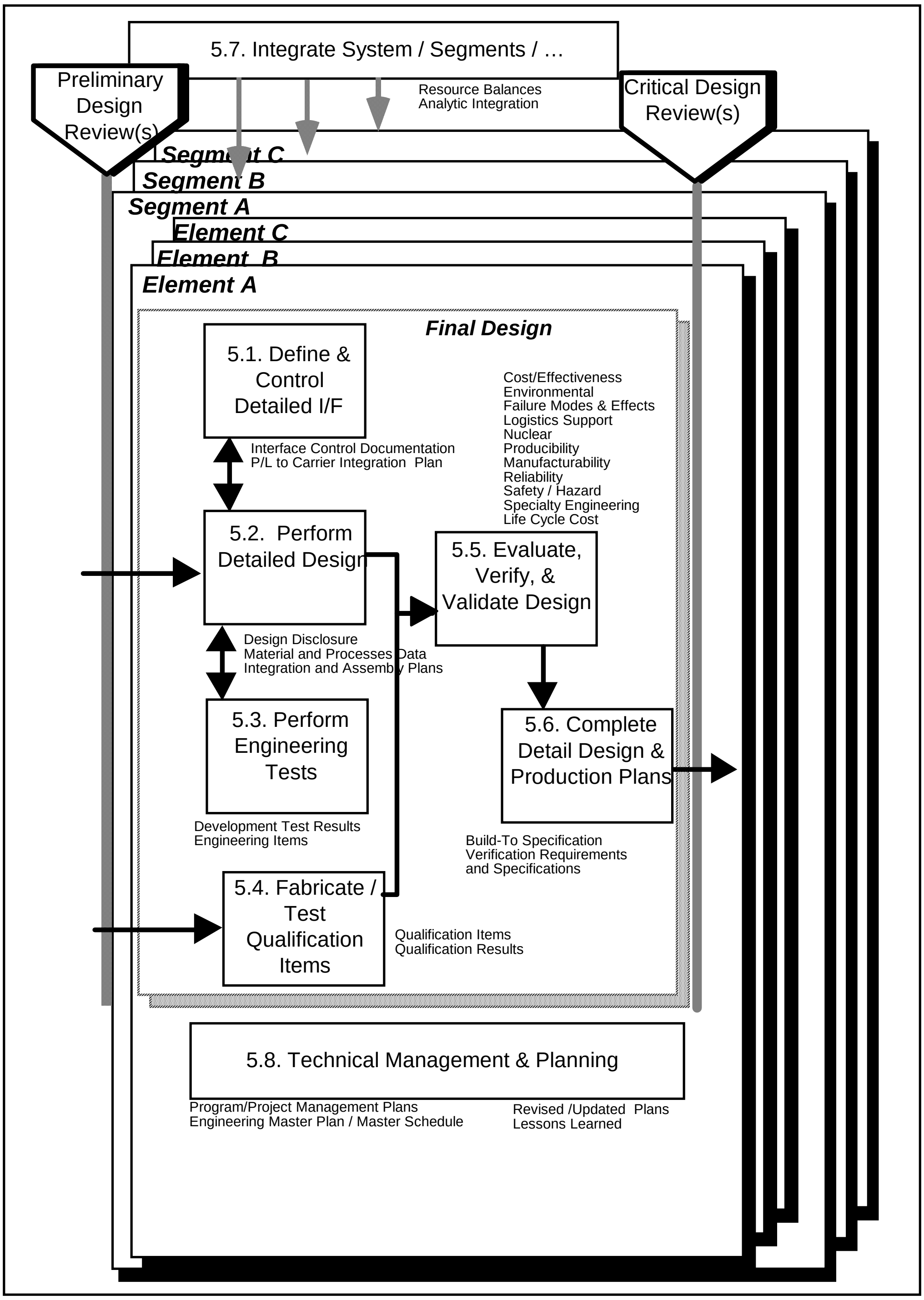

Figure 5.5.2-1. Final Design Activity Network.

5.2. Perform Detailed Design: The effort completes specification of all details of the design and their verification. It develops and prepares full drawing and specifications to detail needed for manufacture.

5.3. Perform Engineering Tests: Additional tests are performed as needed to support the detailed design effort. Necessary engineering units are constructed.

5.4. Fabricate / Test Qualification Items: Qualification articles are constructed and subjected to qualification testing.

5.5. Evaluate, Verify, & Integrate Design: The detailed design is checked to demonstrate its merits and compliance with requirements.

5.6. Complete Design and Production Plans: All details of the design are completed and plans for production are prepared.

5.7. Integration: The effort tracks parameters, budgets, and interfaces as final design progresses to ensure the design will fit together and work and to facilitate later physical integration.

5.8. Technical Management & Planning: Technical management facilitates an effective orderly execution via configuration control, technical reviews, technical decisions. The effort prepares and maintains reports that give the status of properties consistent with the developing design. It prepares specific technical plans such as Electromagnetic Interference/Electromagnetic Compatibility (EMI/EMC) Test Plan.

5.5.3. Management & Control

5.5.3.1. General

Technical management must direct and integrate the activities at multiple levels of the system hierarchy. Support is typically provided by multiple organizations. The skills of the designer and the integrator are critical.

Final Design is typically conducted under contract. In this case the government’s role is primarily one of technical management and review.

5.5.3.2. Reviews

The Critical Design Review (CDR) is the control gate associated with Final Design. The Critical Design Review is ideally held at the end of qualification testing for hardware products and when the design is complete for software products. It is held prior to the start of fabrication/production of end items and prior to the start of coding of deliverable software products. There are typically CDRs corresponding to different levels of the hierarchy (e.g., the System, on down). The generic Life Cycle Model posits a template in which multiple reviews flow up to higher levels. Projects should tailor the sequencing of the reviews to meet their individual needs.

5.5.4. Products

Table 5.5.4-1 summarizes the products produced and their level of maturity. Figure 5.5.4-1 summarizes the System maturity after Final Design. Design-To specifications and Build-To Specifications are approved and establish approved design-to and build-to baselines respectively. Engineering test items and qualification items are produced. The baseline design is established for production of end item hardware and software. Integration plans, acceptance test plans and manufacturing plans are in place and the program is ready to commit to setting up tooling, facilities and manpower to fabricate, integrate and test a product based on the build-to baseline.

Table 5.5.4-1. Typical Final Design Products

Product System
- U Engineering Items
- Q Qualification Items
- P Operations Data
- ß Spares
- • Logistics Support Analysis Records
- F Operational Limits & Constraints
- ß Technical Manuals and Data
- ß User's Manuals

Engineering Requisites
- F Acceptance Criteria
- F Build-To Specification
- F Vendor Specifications
- F Manufacturing Processes Requirements
- Δ Assumptions, Guidelines, and Constraints

Verification & Test
- • Qualification Results
- • Verification Requirements and Specifications
- ß Verification Requirements Compliance
- Δ Verification Requirements Matrix
- • Verification Procedures & Data
- Δ Verification Plans

Execution
- F Design Disclosure
- • Electronics Parts List
- F Instrumentation Program and Command List
- • Integrated Schematics
- F Interface Control Documentation
- • Material and Processes Data
- • Parts Susceptible to Environmental Damage List
- • Product Breakdown Structure
- ß Quality Assurance Results
- ß Software Programmers Manual
- P Computer Resource Integrated Support Document
- F Integration and Assembly Plan
- F Manufacturing Plan
- F Materials and Processes Control Plan
- F Disposal Plans
- P Operations Procedures
- F Launch Operations Plan
- P Operations Plan
- F Transition to Operations Plan
- U Training Facilities, Equipment, & Materials
- • EEE Parts Management Data
- • Inventory Control Software

Execution (cont'd)
- F Spares Provisioning List
- F Integrated Logistics Support Plan
- P Training Plan

Analyses/Evaluations
- Δ Concept/Design Evaluation Criteria
- • Cost/Effectiveness Analyses
- • Design Analysis Reports
- • Failure Modes and Effects Analysis
- • Functional Flow Analysis
- • Logistics Support Analysis
- • Producibility/Manufacturability Studies & Audits
- • Reliability Assessment
- • Safety / Hazard Analysis
- • Specialty Engineering Studies
- Δ Life Cycle Cost Estimates
- • Trade & Analysis Results
- • Development Test Results

Tools
- • Analysis Models
- • Systems Engineering Tools
- ß Test Facilities & Equipment

Management/Control
- F Acceptance Plans
- • Systems Engineering Management Plan
- Δ Integrated Logistics Support Program Plan
- • Technical Performance Measures Reports
- F Work Breakdown Structure (Product System)
- F Work Breakdown Structure (Operational System)
- • Cost & Schedule Report
- • Engineering Master Plan / Master Schedule
- • Item Development Status Summary and Schedule
- • Rolling Wave Plan
- • Design Changes Summary
- Δ Documentation Tree
- Δ Drawing Tree/ Engineering Drawing List
- • Information Management Plan
- • Risk Analyses
- • Risk Identification and Characterization
- Δ Risk Management Plan
- Δ Program/Project management Plans
- F Statement of Work (SOW)

Other
- • Lessons Learned
- • Presentation Material

C=conceptual, P=preliminary, F=final, Δ=update ß=partial / top-level, •=complete, U=engineering item, Q=qualification item, E=end item

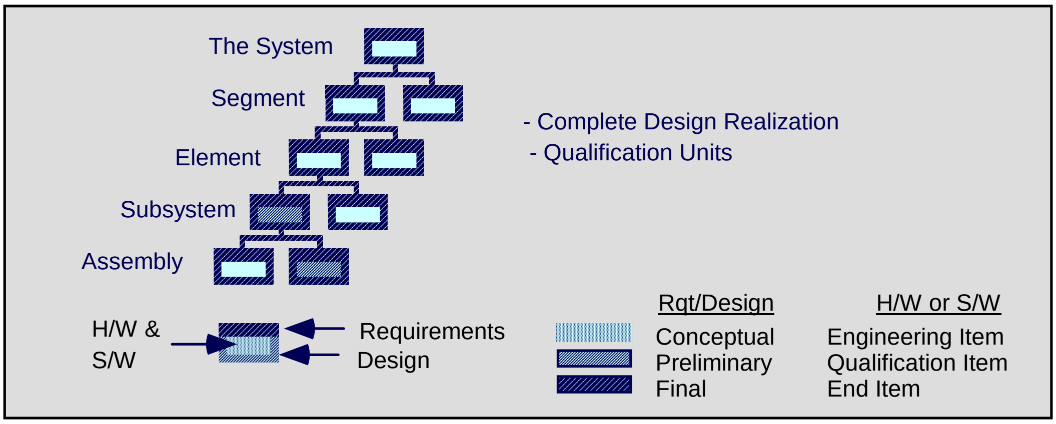

Figure 5.5.4-1. System Maturity for Final Design.

5.5.5. Tailoring

Considerations in tailoring include the following.

- Qualification philosophy: It is often not feasible to provide a complete qualification of the design because of schedule and cost constraints. Complete qualification is then often not completed until the first “protoflight” article is flown.
- Schedule: It is generally not feasible to synchronize the development of different parts of the System. Schedules and costs will be unreasonable unless some parts proceed into manufacture while others are still in design.
- CDR template. The sequence and scheduling of reviews should be tailored to schedule and technical issues.
- Separate Production Readiness Review (ProRR): The model presents the authorization to proceed to production as occurring at CDR. For some items it may be preferable to restructure this part of CDR into a separate control gate.

5.6. Fabrication and Integration

5.6.1. Overview

During Fabrication and Integration, the project manufactures, assembles, and tests the end items. Personnel gain experience from the actual end-items and support equipment. Table 5.6.1-1 summarizes Fabrication and Integration.

Table 5.6.1-1. Summary of Fabrication and Integration

Objective:	• Produce items that conform to specifications and acceptance criteria • Assemble and integrate the System • Validate and verify System • Develop capability to use System to perform mission • Prepare facilities for production, maintenance and operation
Major Output:	• Validated & Verified H/W and S/W • Support Equipment • As-Built Documentation • Training Materials • Operations Plans & Procedures • Verification & Acceptance Data • Disposal Procedures
Major Decisions:	• Do items exhibit suitable workmanship? • Is System properly integrated?
Program Phase	During earlier parts of Phase D.
Control Gate:	• SAR - System Acceptance Review
Features:	• Primary end item activity conducted by contractors. • Government typically monitors and reviews end item development. • Operations preparation

5.6.2. Activities

Figure 5.6.2-1 gives an overview of the activities of Fabrication and Integration. The System is assembled and tested in a bottom up manner. The flow depicted is an idealization relevant to an individual end-item. The incremental testing facilitates finding and fixing problems earlier to avoid rework.

<u>Prepare for Production</u>

6.1 Ready Production Facilities: The manufacturers secure the necessary materials, facilities, tooling, etc. Plans are in place for quality, safety, etc.

<u>Manufacture & Assemble</u>

6.2. Fabricate / Assemble End Item: Individual end items are constructed and assembled. Lower level testing is performed and documented.

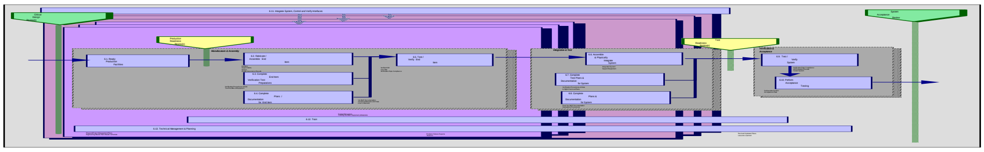
Figure 5.6.2-1. Fabrication and Integration Activity Network.

6.3. Complete End Item Verification Preparations: The project completes necessary preparation for verifying that the end item meets performance and workmanship requirements. This includes complete definition of test cases, procedures, and input data. Test equipment and facilities are constructed or modified as necessary.

6.4. Complete Plans / Documentation for End Item: The effort captures and documents information that users and testers will need. This includes such information as manuals and data for training and maintenance; as-built schematics; audit trails and item fabrication history. These support acceptance and certification and provide a data base to investigate anomalies or recertification.

6.5. Test / Verify End Item: The effort verifies that end items meet performance and workmanship requirements. The effort captures the data for later reference and for the acceptance package.

<u>Integrate & Test</u>

6.6. Assemble & Physically Integrate System: The project physically integrates the end items into the required configuration for system verification and acceptance testing. Considerations include proper installation and functioning. The effort is typically incremental.

6.7. Complete Test Plans & Documentation for System: The project completes necessary preparation for verifying that the integrated System meets performance and workmanship requirements. This includes complete definition of test cases, procedures, and input data. Test equipment and facilities are constructed or modified as necessary.

6.8. Complete Plans & Documentation for System: The effort captures and documents System level information that users and testers will need. Considerations are similar to those for the individual end items.

<u>Verify and Accept</u>

6.9. Test / Verification System: The effort demonstrates that the System has been properly configured and meets performance and workmanship requirements. This activity is typically incremental and in parallel with System assembly and physical integration.

6.10. Acceptance Testing: As necessary the System undergoes additional tests to assure the customer that it is ready for delivery. The specific tests or milestones reflect the formal conditions for acceptance previously agreed to with the customer.

General

6.11. Interface Control & Verification: The project maintains a continuing effort to ensure items are built and assembled consistently. This includes audits and tests of the construction and configuration of interfaces.

6.12. Develop Operations Capabilities: The project develops the capability to use the hardware and software to perform the mission. Training efforts are conducted to ensure personnel have skills to build, test, operate, and maintain the System. The effort includes developing training materials such as simulators, equipment, manuals, and courses. Plans and procedures are developed. Organizations are developed for operations and for support and logistics.

6.13. Technical Management & Planning: Technical management defines schedules and maintains proper control of the process.

5.6.3. Management & Control

5.6.3.1. General

Manufacturing, verification, and operational organizations are involved in this stage. The government typically functions in a technical management role in the manufacturing activities. The operations role varies. The skills of the builder and the tester are critical.

5.6.3.2. Reviews

The following interim reviews provide forums for exposing and discussing issues and approaches, and communicating decisions to team members.

- Design Certification Review: This ascertains that the design meets requirements.
- Production Readiness Review: This ascertains that preparations are mature enough to begin manufacturing.
- Test Readiness Reviews: This ascertains that an item and test preparations are mature enough to begin testing.

The System Acceptance Review (SAR) is the control gate associated with Fabrication and Integration. The completion of SAR also authorizes the installation of the accepted hardware and software at the site(s).

5.6.4. Products & Maturity

Table 5.6.4-1 summarizes the key products of Fabrication and Integration. Figure 5.6.4-1 summarizes the System maturity at the end of Fabrication and Integration. In addition to the items that are fabricated, test results and documentation are generated. Updates are made to design and training documentation to reflect corrections and changes. At the time of SAR, the deliverable elements of end items are complete and the System is ready for launch and/or deployment. Operational software should be ready and capable of supporting the vehicle during and after the launch. Space vehicles should be complete and ready to be shipped to the launch base. Other deliverable hardware (such as GSE or specialized equipment to support the mission control or data processing elements on the ground) should be complete and ready to ship to the site where they will be used. As much functional checkout as possible was done to ensure an item's operational readiness without

Table 5.6.4-1. Typical Fabrication and Integration Products

Product System
- E Hardware/Software End Items
- P Operations Data
- • Spares
- E Support Items
- Δ Operational Limits & Constraints
- • Technical Manuals and Data
- • User's Manuals

Engineering Requisites
- Δ Acceptance Criteria
- ß Operational Readiness Criteria

Verification & Test
- • Acceptance Data
- • Verification & Validation Evaluation Results
- Δ Verification Requirements and Specifications
- • Verification Requirements Compliance
- • Verification Procedures & Data
- • In-flight Checkout Plans

Execution
- Δ Design Disclosure
- Δ Instrumentation Program and Command List
- Δ Interface Control Documentation
- • Quality Assurance Results
- • Software Programmers Manual
- F Computer Resource Integrated Support Document
- Δ Integration and Assembly Plan
- F Operations Procedures
- F Operations Plan

Execution (cont'd)
- Δ Transition to Operations Plan
- E Training Facilities, Equipment, & Materials
- F Training Plan

Analyses/Evaluations
- Δ Design Analysis Reports
- • Failure Modes and Effects Analysis
- Δ Logistics Support Analysis
- • Producibility/Manufacturability Studies & Audits
- • Reliability Assessment
- • Safety / Hazard Analysis

Tools
- • Analysis Models
- • Test Facilities & Equipment

Management/Control
- Δ Acceptance Plans
- • Problem / Failure Reports
- • Technical Performance Measures Reports
- • Engineering Master Plan / Master Schedule
- • Rolling Wave Plan
- F Waivers
- • Information Management Plan
- • Risk Analyses
- • Risk Identification and Characterization
- Δ Risk Management Plan

Other
- • Lessons Learned
- • Presentation Material

C=conceptual, P=preliminary, F=final, Δ=update ß=partial / top-level, •=complete, U=engineering item, Q=qualification item, E=end item

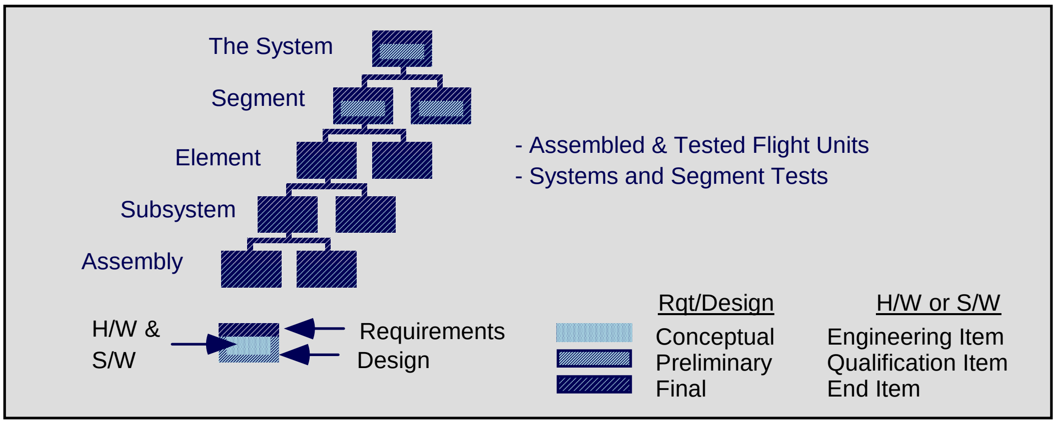

Figure 5.6.4-1. System Maturity at the End of Fabrication and Integration.

removing it from the "factory" where it was built. Actual integration with other products produced under separate contracts may occur later (e.g., launch vehicle and spacecraft integration). However, some integration work should have been done with the use of software and hardware simulators.

5.6.5. Tailoring

Tailoring considerations include the approach to testing and verification. The need for formal production and test readiness reviews should be considered.

5.7. Preparation for Deployment

5.7.1. Overview

During Preparation for Deployment, the System is configured and prepared for the first mission. Typical activities involve completion of operational plans and procedures, training, launch integration, and so on. The Flight Readiness Review control gate marks operational readiness to support the mission. Table 5.7.1-1 summarizes Preparation for Deployment.

Table 5.7.1-1 Summary of Preparation for Deployment

Objective:	• Configure System for launch / deploy • Establish readiness to launch / deploy
Major Products:	• System Configured for Launch • Trained Personnel • Readiness Data • Operations Data • Updated/Verified Operations Plans • Final Support Plans
Major Decisions:	• Is System ready to launch?
Program Phase	During Phase D.
Control Gate:	FRR - Flight Readiness Review
Features:	• Government and contractor involvement. • Contractor supports checkout of systems

5.7.2. Activities

Figure 5.7.2-1 gives an overview of the activities of Preparation for Deployment. The model assumes the situation where a single launch is needed to demonstrate operational capability. Other situations include multiple launches and incremental development of operational capabilities. In such cases, the effort would cycle through these activities as needed.

7.1. Deliver / Install System: The developer transports the verified System items in their prelaunch configuration to the launch site. The items are configured for launch and integrated with other systems that support the mission.

7.2. Configure H/W for Launch: Hardware items are configured for launch and integrated with other systems that support the mission. Activities may include readiness tests, loading with consumables, configuration with operational data.

7.3. Configure S/W for Launch: Software items are configured for launch and integrated with other systems that support the mission. Activities may include preparation, loading, and verification of data parameters and software patches.

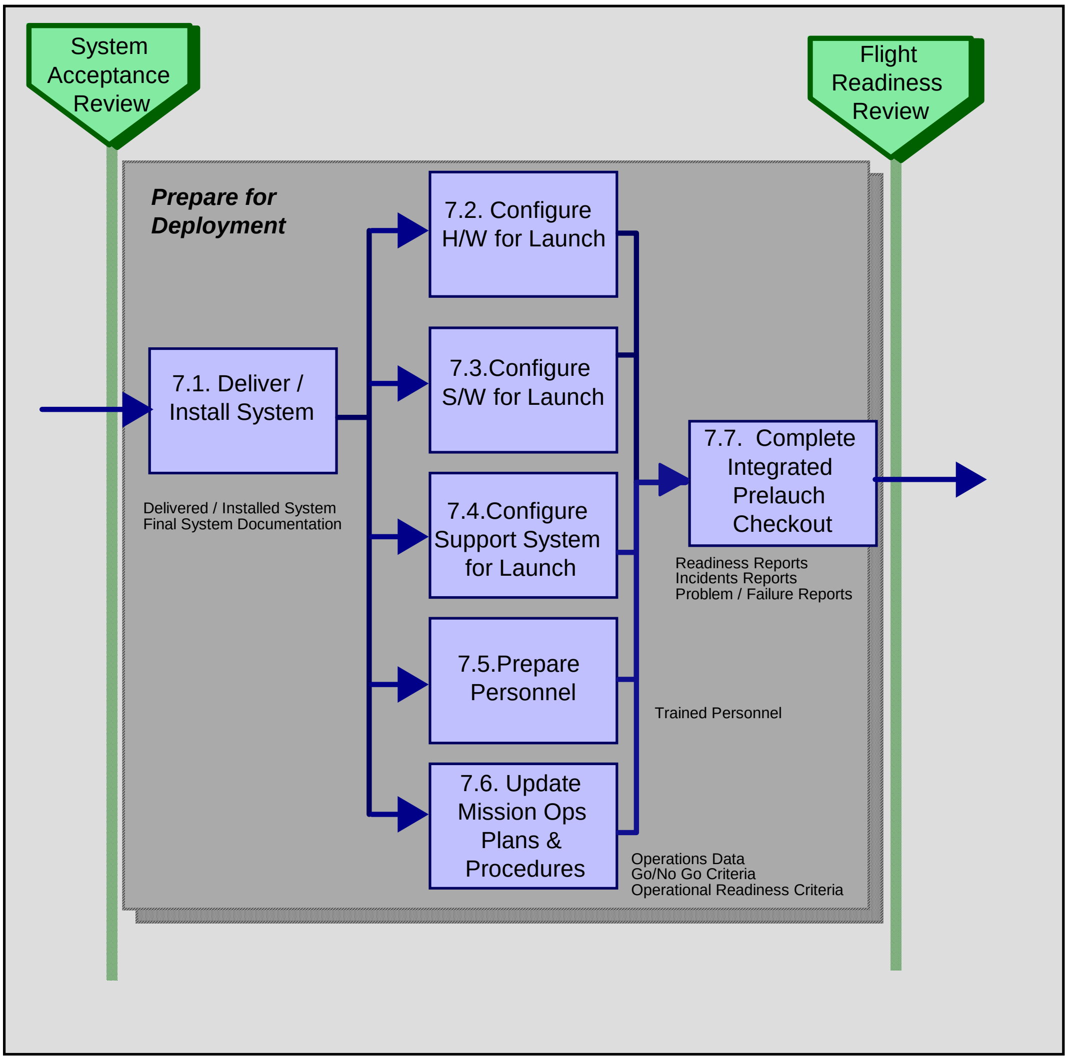

Figure 5.7.2-1. Preparation for Deployment Activity Network.

7.4. Configure Support System for Launch: Supporting infrastructure (communication, weather, range safety, etc.) is readied and tested. Support items are configured for launch or operations and integrated with other systems that support the mission.

7.5. Prepare Personnel: The project develops personnel with the proficiency to conduct the mission. Courses and simulations help personnel to develop and maintain the relevant knowledge and skills.

7.6. Update Mission Plans and Procedures: The operational organization develops and documents data and procedures as to how the mission will be conducted and how the System will be operated. This includes procedures, rules, and relevant data for configuring and operating the System under normal and contingency conditions.

7.7. Complete Integrated Prelaunch Checkout: Final preparations are made for launch. This may include various end-to-end tests of integrated items.

5.7.3. Management & Control

5.7.3.1. General

Both development and operational organizations are involved in Preparation for Deployment. The development organizations support start up and operational certification as well as the relevant troubleshooting. Development roles transition to product improvement. The skills of the launch integrator are critical.

5.7.3.2. Reviews

The Flight Readiness Review (FRR) is the control gate associated with Preparation for Deployment.

5.7.4. Products

Table 5.7.4-1 summarizes the key products of Preparation for Deployment. Figure 5.7.1-1 summarizes the System maturity at the end of Preparation for Deployment. The major product is an operationally certified System. This includes properly deployed and functioning equipment, trained personnel, and operational data and procedures. At the time of FRR, all software, hardware and procedures are complete and all verification data is sufficient to give complete confidence that the System is ready to begin operations. Ample demonstrations of the interplay between the hardware, software and launch elements have been done to assure that the procedures are adequate in addressing these interfaces and do not include operations outside the limitations and constraints of the System.

Table 5.7.4-1. Typical Preparation for Deployment Products

Product System
- E Hardware/Software End Items
- F Operations Data
- • Spares
- E Support Items
- Δ User's Manuals
- • Trained Personnel

Engineering Requisites
- • Operational Readiness Criteria

Verification & Test
- Δ Verification Requirements and Specifications
- • Verification Requirements Compliance
- • Verification Procedures & Data
- • Launch Facility Checkout Results

Execution
- F Go/No Go Criteria
- Δ Operations Procedures
- Δ Launch Operations Plan
- Δ Operations Plan

Analyses/Evaluations
- Δ Environmental Assessment / Impact Statement

Tools
- \-

Management/Control
- F Certification of Flight/Launch Readiness
- • Closure Reports
- • Incidents Reports
- • Problem / Failure Reports
- • Readiness Reports
- • Engineering Master Plan / Master Schedule
- • Rolling Wave Plan
- • Product Change Report
- • Information Management Plan
- • Risk Identification and Characterization

Other
- • Lessons Learned
- • Presentation Material

C=conceptual, P=preliminary, F=final, Δ=update ß=partial / top-level, •=complete,

U=engineering item, Q=qualification item, E=end item

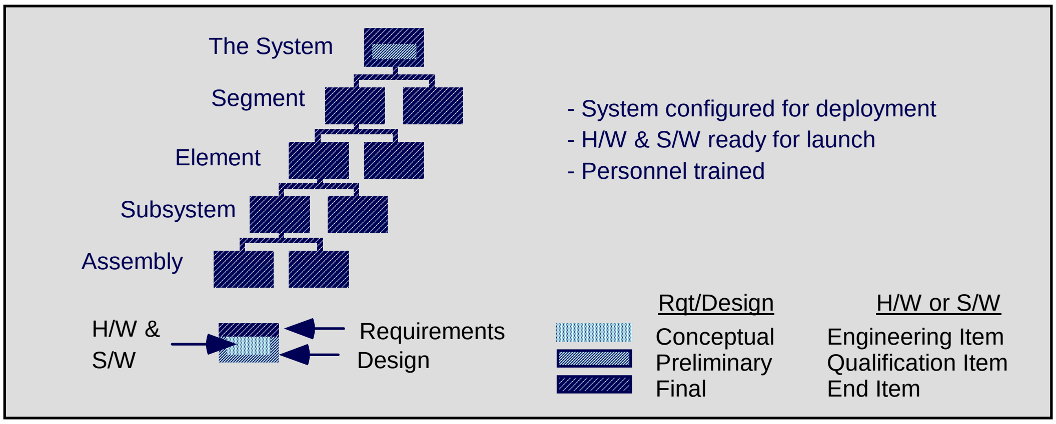

Figure 5.7.4-1. System Maturity at the End of Preparation for Deployment.

5.7.5. Tailoring

Tailoring involves definition of the specific activities that must be performed to prepare for deployment. Some systems (e.g., launch vehicles) will require multiple or continuing launches. In such cases, this stage may be interpreted as the initial launch or deployment. Relevant activities would then be repeated as needed in the operations stage.

5.8. Deployment and Operational Verification

5.8.1. Overview

During the Deployment and Operational Verification Stage, the System is configured and prepared for the first operational mission. Operational capability is reached as operational characteristics are demonstrated and personnel gain actual experience in use of the System. Specifics depend significantly on the particular System and its mission. Typical activities involve completion of operational plans and procedures, training, launch, in-flight tests, and so on. The Operational Readiness Review control gate marks operational readiness to support the mission. Table 5.8.1-1 summarizes Deployment and Operational Verification.

Table 5.8.1-1. Summary of Deployment and Operational Verification.

Objective:	• Launch / deploy System • Establish operational envelope of System • Establish System logistics
Major Products:	• Operational System • Trained Personnel • As-Deployed Documentation • Operations Data • Updated Training Materials • Verified Operations Plans • Final Support Plans
Major Decisions:	• Is System ready to perform mission?
Program Phase	During later parts of Phase D.
Control Gate:	ORR - Operational Readiness Review
Features:	• Operator and developer involvement. • Developer supports checkout of systems

5.8.2. Activities

Figure 5.8.2-1 gives an overview of the activities of Deployment and Operational Verification. The model assumes the situation where a single launch is needed to demonstrate operational capability. Other situations include multiple launches and incremental development of operational capabilities. In such cases, the effort would cycle through these activities as needed.

8.1. Launch / Deploy System: The System is launched into space and transferred to its destination.

8.2 Configure for Checkout and Operations: Reconfiguration and initial check out are performed and the System achieves initial operating status.

8.3. Demonstrate Operational Capability: The project demonstrates the operational capability of the System to perform its mission. The effort checks out the characteristics and functions of the deployed System. Demonstrated operating envelopes are identified. Anomalies are identified and resolved. The capability of operations personnel to operate the System is demonstrated.

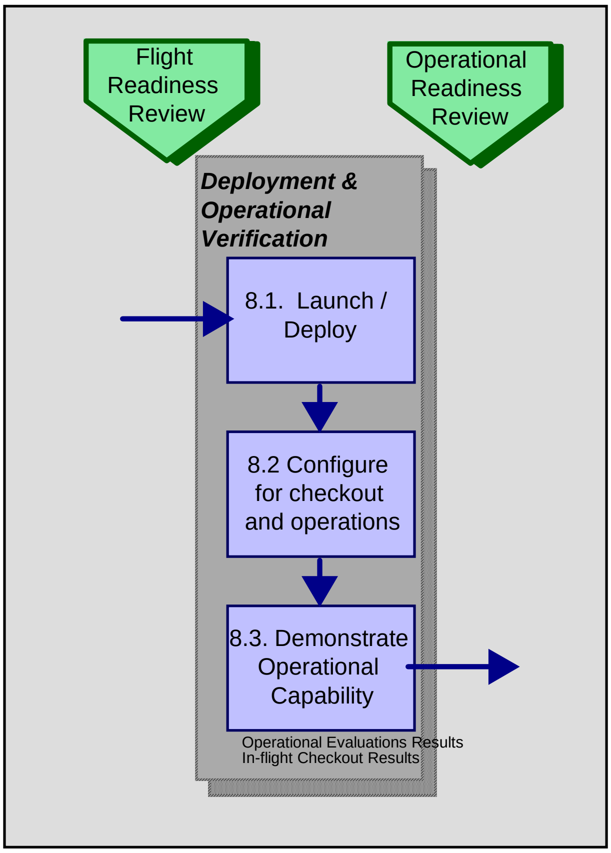

Figure 5.8.2-1. Deployment and Operational Verification Activity Network.

5.8.3. Management & Control

5.8.3.1. General

Both development and operational organizations are involved in Deployment and Operational Verification. The development organizations support start up and operational certification as well as the relevant troubleshooting. Development roles transition to product improvement. The skills of the initial operator are critical.

5.8.3.2. Reviews

The Operational Readiness Review (ORR) is the control gate associated with Deployment and Operational Verification.

5.8.4. Products

Table 5.8.4-1 summarizes the key products of Deployment and Operational Verification. Figure 5.8.1-1 summarizes the System maturity at the end of Deployment and Operational Verification. The major product is an operationally certified System. This includes properly deployed and functioning equipment, trained personnel, and operational data and procedures. Lessons learned from test and/or launch operations regarding operational

Table 5.8.4-1. Typical Deployment and Operational Verification Products

Product System
- F Operations Data
- • Spares
- Δ Operational Limits & Constraints
- Δ Technical Manuals and Data
- Δ User's Manuals
- • Trained Personnel

Engineering Requisites
- ß Product improvement requirements

Verification & Test
- • Verification Requirements Compliance
- • Verification Procedures & Data
- ß Operational Evaluations Results
- • In-flight Checkout Results

Execution
- Δ Operations Procedures
- Δ Operations Plan
- Δ Transition to Operations Plan
- Δ Integrated Logistics Support Plan

Analyses/Evaluations
-

Tools
Analysis Models

Management/Control
- • Problem / Failure Reports
- • Readiness Reports
- • Engineering Master Plan / Master Schedule
- • Rolling Wave Plan
- • Configuration changes
- • Information Management Plan
- • Risk Identification and Characterization

Other
- • Lessons Learned
- • Presentation Material

C=conceptual, P=preliminary, F=final, Δ=update ß=partial / top-level, •=complete,
U=engineering item, Q=qualification item, E=end item

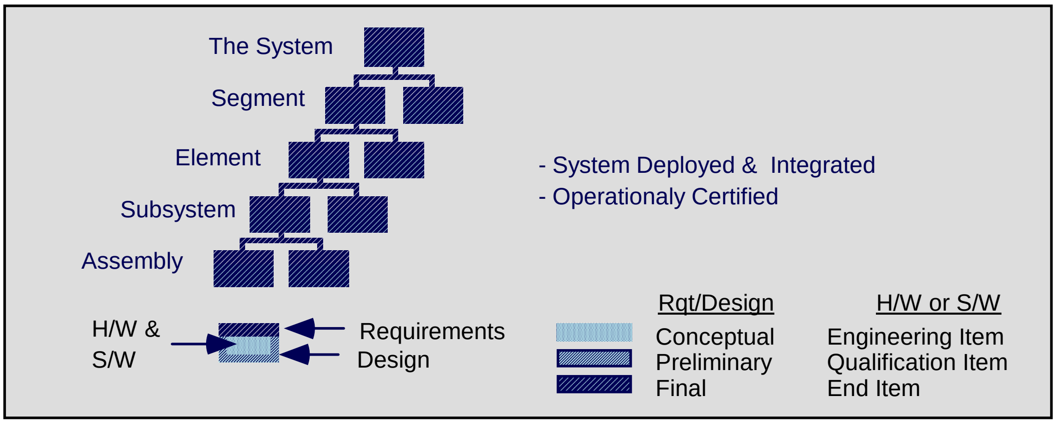

Figure 5.8.4-1. System Maturity at the End of Deployment and Operational Verification.

characteristics of the System have been incorporated into the procedures and manuals. All necessary operational support plans and procedures are in place including anomaly resolution procedures, contingency procedures, nominal operation procedures, maintenance plans and procedures, logistics plans and procedures, etc.

5.8.5. Tailoring

Tailoring considerations include the following.

- Qualification testing: In many cases, it is impractical or unfeasible to perform a complete qualification of the design until the first flight. The first flight article may serve for qualification tests.
- Multiple articles: Deployment and operational verification would be replicated for later items in the System. If later articles are replacements or additions, their deployment and operation may be captured as a part of operations. Note that both the amount and types of tests for a first item may be significantly different from those for later items.
- Operational increments: A new or enhanced capability may be defined for the System.

5.9. Mission Operations

5.9.1. Overview

The Mission Operations stage entails the use and support of the System to accomplish mission objectives. Specifics depend significantly on the System, its mission, and its evolution. Systems using expendable or repeated items exhibit multiple production. For complex systems, the System may evolve by stages that mark levels of capability. Each of these increments may require activities that repeat the previous stages to some extent to develop the new capabilities. Lessons learned are captured. Table 5.9.1-1 summarizes Mission Operations.

Table 5.9.1-1. Summary of Mission Operations

Objective:	• Perform Mission • Sustain System • Improve/augment System
Major Products:	• Mission Products/Services • Sequential Production • Trained Personnel • Disposed / Decommissioned Items • Operations / Support Plans • Operations Data and Trends
Major Decisions:	• What is System Operational Status? • Proceed with sequential production / evolution?
Program Phase	During Phase E.
Control Gate:	• None
Features	• Varies with user organizations and missions. • Typical role of systems engineering is change control.

5.9.2. Activities

The nature of mission operations depends on the specifics of the mission, System, and the products and services involved. Figure 5.9.2-1 summarizes typical activities.

9.1. Configure for Operations: Items are configured for mission operations. This may include transition of personnel from developers to operators.

9.2. Conduct Mission: The System is used to produce products or services that support the mission objectives.

9.3. Train Personnel: Training provides personnel with skills needed to operate the System effectively and efficiently. Training considerations include changes in mission or System, personnel changes, augmented or enhanced skills, and new operations or procedures.

9.4. Maintain System: Scheduled and unscheduled actions are taken to avoid and rectify problems. These may include readjusting or recalibrating System characteristics (e.g., orbit trim, recalibrate) or correcting anomalies/problems (e.g., switch components, software patches, etc.).

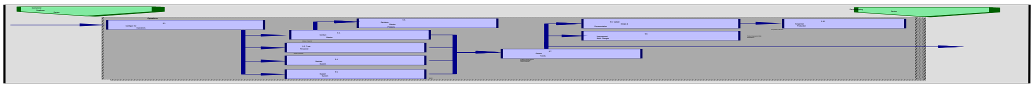

Figure 5.9.2-1. Mission Operations Activity Network.

9.5. Support System: Logistical support maintains System effectiveness. This includes resupply of consumables or expendables, replacements and spares, and maintenance of technical data.

9.6. Distribute Mission Products: Data, samples, and so on are provided to the end users.

9.7. Assess Trends: The state and evolution of the System, its constituents, and its environment are monitored. This supports the ability to recognize potential opportunities and problems.

9.8. Update Design & Documentation: Changes in design or configuration are made to correct problems or enhance capability. Changes may reflect preplanned product improvements or experience with earlier flight items.

9.9. Improvement, Block Changes: Significant changes may be made to the System. They may reflect enhancement to existing constituents of the System or evolution to new operational capabilities. The changes may involve significant retrofit and development depending on the System. The changes undergo their own life cycle.

9.10. Sequential Production: Additional items are produced as needed. The new items may replace expendables or may augment operational capability with additional units. Production involves fabrication, workmanship tests, delivery, and so on.

5.9.3. Management & Control

5.9.3.1. General

Operational management and control varies with user organizations and missions. Typical roles of systems engineering are change control. The skills of the operator and the supporter are critical.

5.9.3.2. Reviews

The Decommissioning Review is the control gate associated with transition from Mission Operations. Other reviews depend on the specific System and mission.

5.9.4. Products

The products of Mission Operations vary with the mission and operational organization. Table 5.9.4-1 summarizes products of interest to the evolution of the System. These involve System upgrades, product improvements, operational data and anomalies, and disposal.

Table 5.9.4-1. Typical Operations Products

Product System • Mission Products Δ Trained Personnel • Spares	**Analyses/Evaluations** Depends on System
Engineering Requisites Δ Disposal Requirements • Product improvement requirements	**Tools** Depends on System
Verification & Test • Verification Requirements Compliance • Operational Evaluations Results	**Management/Control** • Problem / Failure Reports • Readiness Reports • Engineering Master Plan / Master Schedule • Rolling Wave Plan • Information Management Plan
Execution F Decommissioning Schedule Δ Disposal Plans • Personnel Transition Plans	**Other** • Lessons Learned
C=conceptual, P=preliminary, F=final, Δ=update ß=partial / top-level, •=complete,	U=engineering item, Q=qualification item, E=end item

5.9.5. Tailoring

Tailoring considerations include operational lifetime, reuse, planned improvements, and so on.

5.10. Disposal

5.10.1. Overview

The Disposal Stage entails the final disposition of the System. Specifics depend significantly on the System, its mission, and its evolution. Systems using expendable or repeated items exhibit multiple production. For complex systems, the System may evolve by stages that mark levels of capability. Each of these increments may require activities that repeat the previous stages to some extent to develop the new capabilities. Table 5.10.1-1 summarizes Disposal.

Table 5.10.1-1. Summary of Disposal

Objective:	• Decommission/dispose of System
Major Products:	• Disposed / Decommissioned Items • Lessons Learned
Major Decisions:	
Program Phase	During Phase E.
Control Gate:	• None
Features	• Varies with mission.

5.10.2. Activities

The nature of Disposal depends on the specifics of the mission, System, and the products and services involved. Figure 5.10.2-1 summarizes typical operational activities.

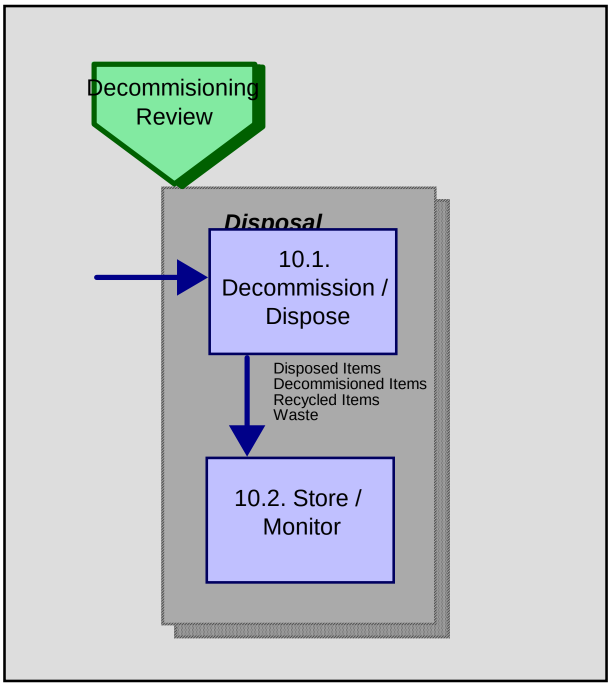

Figure 5.10.2-1. Disposal Activity Network.

10.1 Decommission / Dispose: Constituents that are no longer needed are removed from service. As necessary, items are turned off, made safe, moved to disposal area, destroyed or stored. Items in space may be deorbited or place in a safe orbit. Decommission and disposal can be an ongoing part of operating the System.

10.2 Store/Monitor: Stored items are maintained as needed. If necessary, the disposed item or its remnants are monitored.

5.10.3. Management & Control

Operational management and control varies with user organizations and missions.

5.10.4. Products

The products of Operations vary with the mission and operational organization. Table 5.10.4-1 summarizes products of interest to disposal.

Table 5.10.4-1. Typical Disposal Products

Product System
- • Disposed / Decommissioned items

Engineering Requisites
- Δ Disposal Requirements

Verification & Test
Depends on System

Execution
- • Personnel Transition Plans
- F Decommissioning Schedule
- Δ Disposal Plans

Analyses/Evaluations
Depends on System

Tools
Depends on System

Management/Control
- • Engineering Master Plan / Master Schedule
- • Rolling Wave Plan
- • Information Management Plan

Other
- • Lessons Learned

C=conceptual, P=preliminary, F=final, Δ=update ß=partial / top-level, •=complete,

U=engineering item, Q=qualification item, E=end item

5.10.5. Tailoring

In practice, items may be disposed during other stages of the System's life cycle. For example, an upper stage would be disposed during the deployment of a spacecraft. The life cycle for the item should be tailored to its actual use.

6. Reviews

6.1. Review Execution

This section provides a general outline for conducting a control gate review. It identifies various participants, their roles, and the flow of activity. Particular attention is given to the process for processing Review Item Discrepancies (RIDs).

6.1.1. General

A control gate review is an extended process rather than a single formal critique meeting. The review process may span days to months depending on the stage of the project, the complexity of the System, and the readiness at the time of the control gate review.

Projects should structure and sequence activities and meetings so that the review process is manageable and understandable to participants. Projects should consider the complexity and structure of the System and tailor the review process to allow consistent scope and focus for individual review meetings and review teams. The overall process must address how the project will elevate and resolve lower level issues as appropriate. A basic strategy for structuring a review of the System has individual reviews corresponding to the relevant entities in the System. Each individual review is in the context of the entity and focuses on the pertinent issues and perspectives. This limits those who must be involved. The basic template is to review an entity after the review of its immediate subordinates in the system hierarchy. This allows for surfacing only issues that can not be properly handled at lower levels. Depending on complexity, the formal status of these entity reviews range from agenda items to separate meetings. Figure 6.1.1-1 illustrates this strategy applied to a typical robotic mission.

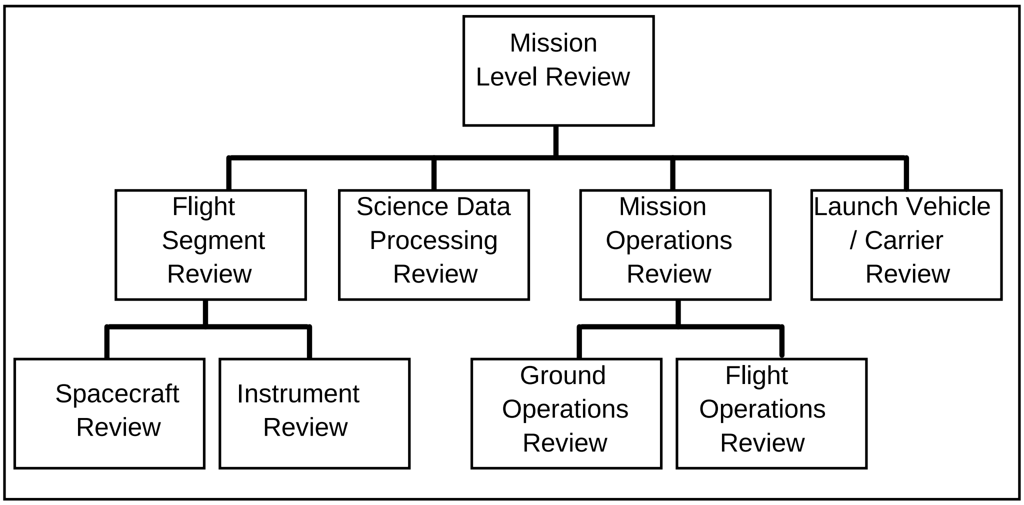

Figure 6.1.1-1. Review Structure Example.

6.1.2. Organization

As discussed below, the personnel that support a review typically can be viewed as comprising four teams: Execution, Internal Review, Independent Review, and RID. The review process involves personnel both internal and external to the project. The internal participants are those who are linked to the project and its management. They serve to keep in mind the internal project interests and perspectives, to identify and resolve discrepancies and inconsistencies, and to surface issues early. Independent participants have no direct interest in project. They serve to provide additional, non-biased perspectives, to identify deficiencies not seen by those closely involved in the project, and to bring additional experience to the review.

6.1.2.1. Execution Team

The Execution Team generates the review material and provides detailed information to the reviewers. These personnel also provide solutions to issues and discrepancies and respond to RIDs and action items. Membership consists of a coordinator and appropriate engineering personnel.

6.1.2.2. Internal Review Team

The Internal Review Team provides an overall project perspective. Its members check consistency, quality, adherence to standards and constraints, and system balance and fit. They also review data packages before release to independent reviewers and attend dry runs. Together with the independent review team, they provide recommendations to the execution team and project management in the form of assessments and RIDs. Membership represents the following:

- Project management
- Chief engineer
- Managers and leads for areas that interface with review item
- Intended operational perspective
- Senior management
- Specialty engineers

6.1.2.3. Independent Review Team

The Independent Review Team provides an evaluation independent of the project. They should provide broad and deep technical expertise as well as additional experience and perspectives. They review the technical content with an eye toward potential design deficiencies, hidden risks, and likelihood of success. Like the internal review team, they provide recommendations to the execution team and project management in the form of assessments and RIDs. Membership includes the following:

- Chairman
- Project office liaison

- Senior management and lead design engineers from outside the project
- Experienced operational personnel
- Senior technical experts, academic experts, outside contractors and consultants

6.1.2.4. RID Review Team

The RID Review Team organizes and prioritizes RIDs and generates recommendations for RID disposition to project management. A subgroup of the RID team serves as a RID screening team that filters RIDs with respect to compliance to groundrules and completeness. The screening team also groups, organizes and combines related RIDs. Members of the RID team come from the following:

- Independent review team
- Execution team
- Program office
- Safety, Reliability, and Quality Assurance Organization(s)

6.1.3. Activity Flow

This section describes the activities in a control gate and the roles of the various teams. Networks are provided for both the overall control gate process and the process for reviewing and disposing of RIDs.

6.1.3.1. Control Gate Review Process

Figure 6.1.3.1-1 depicts a template for the general flow of activities for a control gate review. Projects should tailor this template to reflect their complexity and structure. Prior to starting review activities, management and the review coordinator should evaluate readiness for review. This should consider readiness criteria and maturity of applicable products. Management and the review coordinator then form and organize the teams. The plans for the review are then completed and agreed to by the teams. This includes establishing the schedule and the agenda for the main review meeting, defining the contents of the data package, and setting the scope and ground rules. The execution team prepares material for review. This involves informal reviews with members of the internal review team that result in feedback to the execution team and refinements to the data package.

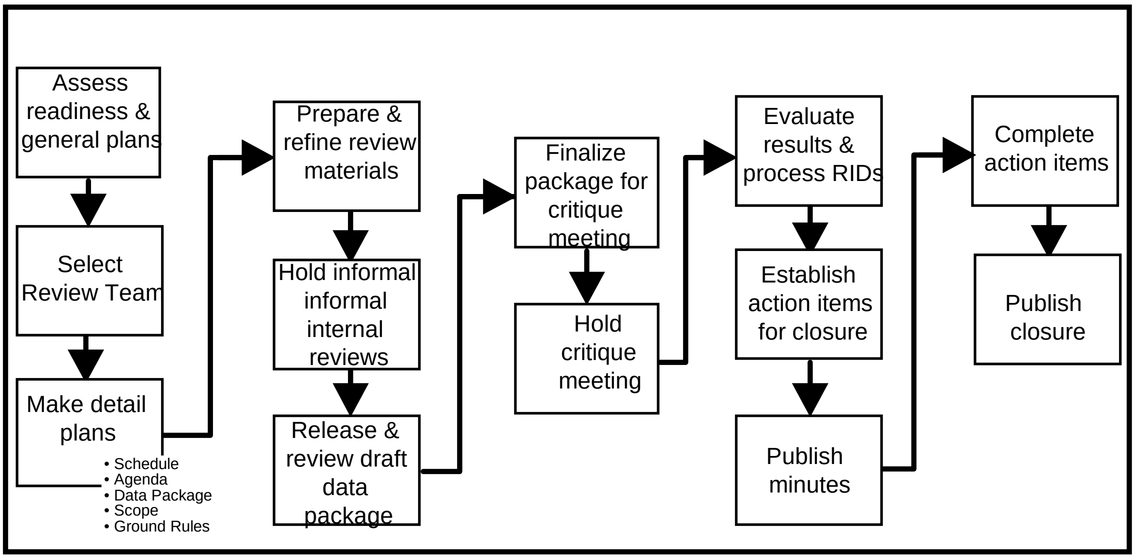

Figure 6.1.3.1-1. Typical Control Gate Review process.

With approval of the internal review team, the review coordinator releases the draft data package to the full review team. The execution team incorporates resulting comments and answers necessary questions. The execution team finalizes the data package for the formal main review meeting(s). The project holds the main review or critique meeting(s). This is a formal meeting (or meetings) attended by the customer, independent review team, and key project personnel. The reviewers assess the results of the review and generate the necessary Review Item Discrepancies (RIDs). This assessment includes an evaluation of whether completion criteria have been met. The RID review team processes the RIDs and submits recommendations to project management. The review coordinator publishes minutes including updated charts, data package, and list of action items. The project completes action items before closing the review, including those arising from RIDs. To establish formal closure, project management, customers, and other relevant parties may sign a letter noting the results of all action items.

Projects should tailor the review process so that it is manageable and productive. Thus a project may perform most of the RID processing before the formal critique meetings so that only truly substantive issues need be addressed.

6.1.3.2. RID Process

A template for a typical RID process is summarized in figure 6.1.3.2-1. Projects should tailor this template to reflect their complexity and structure. Reviewers generate RIDs and typically submit them to the RID team within a week after the main review meeting(s). The RID screening team applies criteria to screen the RIDs and to combine redundant or similar RIDs. This may involve coordination with the submitters. The full RID review team reviews the consolidated RIDs and provides feedback and coordination to Project Management. Program Management approves a list of action items and establishes conditions for official closure. Project Management also approves the final close-out of the RIDs. Throughout the RID process, the project maintains traceability among requirements, RIDs, analyses, and so forth.

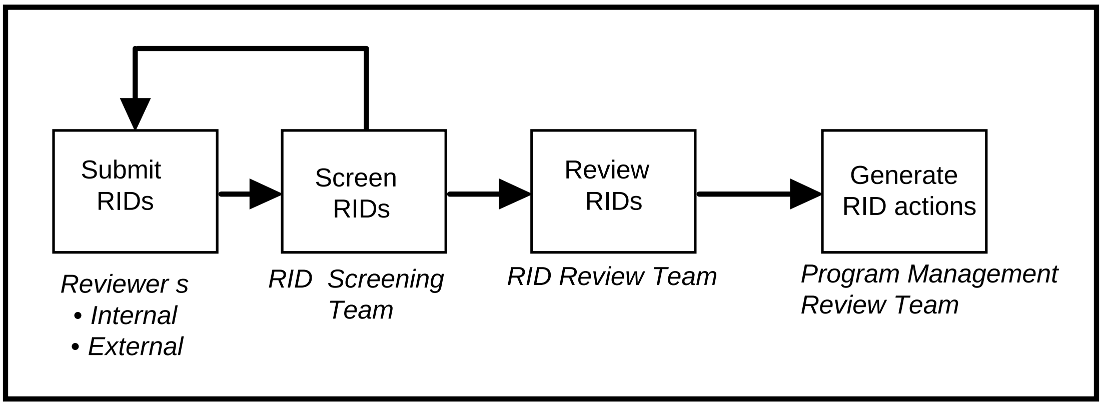

Figure 6.1.3.2-1. Typical RID disposition process.

Early in the review process, the project should establish groundrules and screening criteria that are agreed to by the various teams and project management. Groundrules may limit the channels from whom RIDs will be accepted. Typical screening criteria include the following:

- Must apply only to activities on which the review focuses; e.g., no major design improvements at CDR.
- Must be within scope of item being reviewed; e.g., cannot RID the ground facility software at a spacecraft review or a part at an element review.
- Must have technical or programmatic impact; e.g., typographical errors should be submitted as comments for information only, not as RIDs.
- Must exhibit proper traceability and rationale; e.g., no orphan requirements.

6.2. Major Control Gates

This section contains information as to the purpose, objectives, success criteria, and results of the individual control gates. This information is intended to provide project guidance for the actual review definition, and to illustrate the progressive maturation of the review activities (and products as described in Appendix A) throughout the project life cycle.

6.2.1. Mission Concept Review

6.2.1.1. Purpose

The Mission Concept Review (MCR) is an internal review that usually occurs at the field center near the completion of a mission feasibility study. The purpose of the MCR is to understand and affirm the mission need, and examine the proposed mission's objectives and the concept for meeting those objectives.

6.2.1.2. Objectives

The objectives of the review are to:

1) demonstrate that mission objectives are complete and understandable.
2) demonstrate that the mission concepts demonstrate technical and programmatic feasibility of meeting the mission objectives.
3) confirm that the customer's mission need is clear and achievable.
4) ensure that prioritized evaluation criteria are provided for subsequent mission analysis.

6.2.1.3. Criteria for Successful Completion

The following items compose a checklist to aid in determining readiness of MCR product preparation. The checklist aids in the preparation of specific review item entry and completion criteria but does not take their place.

1) Are the mission objectives clearly defined and stated? unambiguous? internally consistent?
2) Will satisfaction of the preliminary set of requirements provide a system which will meet mission objectives?
3) Is the mission feasible? Has there been a solution identified which is technically feasible? Is the rough cost estimate within an acceptable cost range?
4) Have the concept evaluation criteria to be used in candidate system evaluation been identified and prioritized?
5) Has the need for the mission been clearly identified?
6) Are the cost and schedule estimates credible?
7) Was a technology search done to identify existing assets or products that could satisfy the mission or parts of the mission?

6.2.1.4. Results of Review

A successful MCR supports the determination that the proposed mission meets the customer need, and has sufficient quality and merit to support a field center management decision to propose further study to the cognizant PAA as a candidate Phase A effort.

6.2.2. Mission Definition Review

6.2.2.1. Purpose

The Mission Definition Review (MDR) occurs near the completion of the mission definition stage. The purpose of the MDR is to examine the functional and performance requirements defined for the System and the preliminary program plan, and assure that the requirements and the selected top-level design will satisfy the mission.

6.2.2.2. Objectives

The objectives of the review are to:

1) establish that the allocation of the functional System requirements is optimal for mission satisfaction with respect to requirements trades and evaluation criteria which were internally established at MCR (and possibly re-confirmed at MRR).
2) validate that System requirements meet mission objectives.
3) identify technology risks and the plans to mitigate those risks.
4) present refined cost, schedule and personnel resource estimates.

6.2.2.3. Criteria for Successful Completion

The following items compose a checklist to aid in determining readiness of MDR product preparation. The checklist aids in the preparation of specific review item entry and completion criteria but does not take their place.

1) Do the defined System requirements meet the mission objectives expressed at the start of the program?
2) Are the System level requirements complete, consistent and verifiable? Have preliminary allocations been made to the element level?
3) Have the requirement trades converged on an optimal set of System requirements? Do the trades address program cost and schedule constraints as well as mission technical needs? Do the trades cover a broad spectrum of options? Have the trades identified for this set of activities been completed? Have the remaining trades been identified to select the final system design?
4) Are the upper levels of the System completely defined? Are all the segments defined?
5) Are the decisions made as a result of the trades consistent with the evaluation criteria established at the MCR?
6) Has an optimal final design (to element level) converged with limited candidate options?
7) Have technology risks been identified and have mitigation plans been developed?

6.2.2.4. Results of Review

A successful MDR supports the decision to further develop the design and technology for a System to accomplish the mission. The results further reinforce the mission merit and provide a basis for the system acquisition strategy.

6.2.3. System Definition Review

6.2.3.1. Purpose

The System Definition Review (SDR) occurs near the completion of the system definition stage and represents the culmination of effort in analysis and allocation of the system requirements. The purpose of the SDR is to examine the proposed system architecture and the flowdown to all functional elements of the System.

6.2.3.2. Objectives

The objectives of the SDR are to:

1) demonstrate that the architecture is acceptable, that requirements allocation is complete, and that a System that fulfills the mission objectives can be built within the constraints posed.
2) ensure that plans for the testing and verification program are identified and the verification philosophy is defined.
3) establish end item acceptance criteria.
4) ensure that adequate detailed information exists to support initiation of further development or acquisition efforts.

6.2.3.3. Criteria for Successful Completion

The following items compose a checklist to aid in determining readiness of SDR product preparation. This checklist aids in the preparation of specific review item entry and completion criteria but does not take their place.

1) Will the top-level system design selected meet the system requirements, satisfy the mission objectives, and address operational needs?
2) Can the top-level system design selected be built within cost constraints and in a timely manner? Are the cost and schedule estimates valid in view of the system requirements and selected architecture?
3) Have all the System level requirements been allocated to one or more elements?
4) Have the major design issues for the elements and subsystems been identified? Have major risk areas been identified with mitigation plans?
5) Have plans to control the development and design process been completed?
6) Is a development test plan in place to provide data for making informed design decisions?
7) Is the minimum end item product performance documented in the acceptance criteria?

8) Is there sufficient information to support proposal efforts? A complete validated set of requirements? Sufficient System definition? Valid cost and schedule estimates?

6.2.3.4. Results of Review

As a result of successful completion of the SDR, the System and its operation are well enough understood to warrant design and acquisition of the end items. Approved specifications for the System, its segments, and preliminary specifications for the design of appropriate functional elements may be released; and the configuration management plan is established to control design and requirement changes. Plans to control and integrate the expanded technical process are in place.

6.2.4. Preliminary Design Review

6.2.4.1. Purpose

The Preliminary Design Review (PDR) occurs after completing a full functional implementation, and its purpose is to:

1) demonstrate that the preliminary design meets all System requirements with acceptable risk.
2) show that the correct design option has been selected, interfaces identified, and verification methodologies have been satisfactorily described.
3) provide prerequisites for proceeding with detailed design.

6.2.4.2. Objectives

The objectives of the PDR are to:

1) ensure that all System requirements have been allocated, the requirements are complete and the flowdown is adequate to verify System performance.
2) Show that the proposed design solution is expected to meet the functional and performance requirements.
3) show that the design is verifiable and does not pose major problems which may cause schedule delays and cost overruns.
4) show sufficient evidence in the proposed design approach to proceed further with the next step of the detailed design phase.

6.2.4.3. Criteria for Successful Completion

The following items compose a checklist to aid in determining readiness of PDR product preparation. This checklist aids in the preparation of specific review item entry and completion criteria but does not take their place.

1) Have all the System and segment requirements been allocated down to the end item level?
2) Are all end item design-to specifications complete and ready for formal approval and release?
3) Can the proposed design be expected to meet all the requirements?
4) Does the proposed design satisfy requirements critical to human safety and mission success?
5) Do the human factors considerations of the proposed design support the intended end users' ability to operate the product and perform the mission effectively?
6) Have the manufacturing, operations, utilization, test, and various specialty engineering organizations reviewed the design? Are proposed concepts producible, reliable and logistically cost effective for the life-cycle?
7) Are the appropriate specialty engineering, design specifications and program plans sufficiently complete to provide the design engineer the guidance, constraints and System requirements to execute the design?
8) Is there sufficient confidence that the design concept is sound, that long-lead items that might threaten schedule compliance are minimal, and that required resources are available to proceed further?

6.2.4.4. Results of Review

As a result of successful completion of the review, engineering drawings, End Item Design-To Specifications, preliminary interface control documents and software specifications will be approved. Preliminary design drawings will be released, and implementation of the design qualification activities will begin with the objective of providing full verification of the Design-To Baseline.

6.2.5. Critical Design Review

6.2.5.1. Purpose

The Critical Design Review (CDR) is held near the completion of full design realization, and its purpose is to:

1) disclose the complete System design in full detail, and ascertain that technical problems and design anomalies have been resolved without compromising System performance, reliability and safety.
2) ensure that the design maturity justifies the program decision to initiate manufacturing, verification and integration of the mission hardware and software.

6.2.5.2. Objectives

The objectives of the CDR are to:

1) ensure that a Build-To Baseline contains detailed System, subsystem to hardware component or software module level specifications adequate to assure satisfactory function and performance of the manufactured product.
2) ensure that the design has been satisfactorily audited by manufacturing, test, operations, utilization and various specialty engineering organizations. The audit issues and recommendations are answered and action items are closed.
3) ensure that the manufacturing processes and controls are sufficient to produce the design with minimum cost and schedule risk.
4) establish that planned Quality Assurance activities will establish perceptive test and screening processes for producing a quality product.
5) verify that the detailed design fulfills the specifications established at PDR.

6.2.5.3. Criteria for Successful Completion

The following items compose a checklist to aid in determining readiness of CDR product preparation. This checklist aids in the preparation of specific review item entry and completion criteria but does not take their place.

1) Is the design complete? Are drawings ready to begin manufacturing? Is software product definition sufficiently mature to start coding?
2) Is the Build-To Baseline sufficiently traceable to assure that no orphan requirements exist?
3) Do the design qualification results from software prototyping, engineering item tests, simulation and analysis support the conclusion that the product will meet requirements?
4) Are all internal interfaces completely defined; external interfaces current?
5) Do the integrated safety analyses show that no outstanding hazards exist which cannot be controlled or are within acceptable risk if waivers are required?
6) Are the manufacturing plans in place? Are they reasonable with respect to schedule, risk control and quality assurance?
7) Are there adequate quality checks in the manufacturing process?
8) Do the integrated logistics analyses identify and support adequate spares provisioning for the program life cycle?
9) Are the acceptance and life test plans complete? Do the test cases correlate with the acceptance criteria established at the SDR? Will the tests demonstrate product capability to achieve the mission?
10) Are System integration and verification plans complete?
11) Have design audits been completed to ensure compatibility with other interfacing parts of the System?

6.2.5.4. Results of Review

As a result of successful completion of the review, the Build-To Baseline, manufacturing and test plans are approved; and approved drawings are released and authorized for fabrication of mission hardware. It also authorizes coding of deliverable software according to the Build-To Baseline and coding standards presented in the review.

6.2.6. System Acceptance Review

6.2.6.1. Purpose

The System Acceptance Review (SAR) is held near the completion of the system fabrication and integration stage, and its purpose is to:

1) examine the end items, documentation, test data and analyses that support verification.
2) ensure that the items have sufficient technical maturity to authorize their shipment and installation to the launch site or the operational ground facilities.

6.2.6.2. Objectives

The objectives of the SAR are to:

1) establish that the end item is ready to be delivered and accepted under DD-250.
2) ensure that the end item meets acceptance criteria which were established at SDR.
3) establish that the end item meets requirements and will function properly in the expected operational environments as reflected in the test data, demonstrations and analyses.
4) establish an understanding of the capabilities and operational constraints of the “as built” product, and that the documentation delivered with the product is complete and current.

6.2.6.3. Criteria for Successful Completion

The following items compose a checklist to aid in determining readiness of SAR product preparation. This checklist aids in the preparation of specific review item entry and completion criteria but does not take their place.

1) Are tests and analyses complete? Do they indicate that the product will function properly in the expected operational environment?
2) Does the product meet the criteria described in the acceptance plans?
3) Is the product ready to be delivered? Flight items to the launch facility? Non-flight items to the operational sites for installation?
4) Is the product documentation complete and accurate?

5) Is it clear what is being bought?

6.2.6.4. Results of Review

As a result of successful completion of the review, the System elements are accepted by the government, authorization is given to ship the hardware to the launch and/or operational facilities, and to install software and hardware for operational use.

6.2.7. Flight Readiness Review

6.2.7.1. Purpose

The Flight Readiness Review (FRR) is held after the System has been configured for launch, and its purpose is to:

1) examine demonstrations, tests, analyses and audits which determine the systems' readiness for safe and successful launch and subsequent flight operations.
2) ensure that all flight and ground hardware, software, personnel and procedures are operationally ready and compatible.

6.2.7.2. Objectives

The objectives of the FRR are to:

1) receive certification from each segment that launch and flight operations can safely proceed with acceptable risk.
2) confirm that the System and support elements are properly configured and ready for launch.
3) establish that the interfaces between the segments are compatible and function as expected.
4) establish that the System state supports a launch "GO" decision based on GO/NO GO criteria.

6.2.7.3. Criteria for Successful Completion

The following items compose a checklist to aid in determining readiness of FRR product preparation. This checklist aids in the preparation of specific review item entry and completion criteria but does not take their place.

1) Is the launch vehicle ready for launch?
2) Is the space vehicle hardware ready for safe launch and subsequent flight? with a high probability for achieving mission success?
3) Are all flight and ground software elements ready to support launch and flight operations?

4) Are all segment interfaces checked out and found to be functional?
5) Have all open items and waivers been examined and found to be acceptable?
6) Are the launch and recovery environmental factors within constraints?

6.2.7.4. Results of Review

As a result of successful FRR completion, agreement between all segment representatives assures that technical and procedural maturity exists for System launch and flight authorization, and in some cases initiation of System operations.

6.2.8. Operational Readiness Review

6.2.8.1. Purpose

The Operational Readiness Review (ORR) occurs when the System and its operational and support equipment and personnel are ready to undertake the mission, and its purpose is to:

1) examine the actual System characteristics and the procedures used in its operation.
2) ensure that all flight and ground hardware, software, personnel, procedures, and user documentation reflect the deployed state of the product accurately.

6.2.8.2. Objectives

The objectives of the ORR are to:

1) establish that the System is ready to transition into an operational mode through examination of available ground and flight test results, analyses and operational demonstrations.
2) confirm that the System is operationally and logistically supported in a satisfactory manner considering all modes of operation and support (normal, contingency and unplanned).
3) establish that operational documentation is complete and represents the System configuration and its planned modes of operation.
4) establish that the training function is in place and has demonstrated capability to support all aspects of System maintenance, preparation, operation and recovery.

6.2.8.3. Criteria for Successful Completion

The following items compose a checklist to aid in determining readiness of ORR product preparation. This checklist aids in the preparation of specific review item entry and completion criteria but does not take their place.

1) Are the System hardware, software, personnel and procedures in place to support operation?
2) Have all anomalies detected during prelaunch, launch and orbital (and recovery) flight been resolved, documented, and incorporated into existing operational support data?
3) Are the changes necessary to transition the System from flight test to operational configuration ready to be made?
4) Are all waivers closed?
5) Are the resources in place, or financially planned and approved to support the System during its operational lifetime?

6.2.8.4. Results of Review

As a result of successful ORR completion, the System is ready to assume normal operations, and any potential hazards due to launch or flight operations have been resolved through use of redundant design or through changes in operational procedures.

6.2.9. Decommissioning Review

6.2.9.1. Purpose

The Decommissioning Review (DR) occurs when major items within the System are no longer needed to complete the mission, and its purpose is to:

1) confirm that the reasons for decommissioning are valid and appropriate.
2) examine the current System status and plans for disposal.

6.2.9.2. Objectives

The objectives of the DR are to:

1) establish that the state of the mission and/or the System requires decommissioning/disposal. Possibilities include no further mission need, broken/degraded System elements, or phase out of existing System assets due to a pending upgrade.
2) demonstrate that the plans for decommissioning, disposal and any transition are correct, current and appropriate for current environmental constraints and System upgrades (if any).
3) establish that resources are in place to support disposal plans.
4) ensure that archival plans have been completed for essential mission/project data.

6.2.9.3. Criteria for Successful Completion

The following items compose a checklist to aid in determining readiness of DR product preparation. This checklist aids in the preparation of specific review item entry and completion criteria but does not take their place.

1) Are reasons for decommissioning/disposal well documented?
2) Has any revision to the disposal plan been identified? completed? compliant with local, state and federal environmental regulations?
3) Does the disposal plan address the disposition of existing hardware, software, and facilities?
4) Have data archival plans been defined?
5) Is a personnel transition plan in place? issues resolved?

6.2.9.4. Results of Review

A successful DR completion assures that the decommissioning and disposal of System items are appropriate and effective.

6.3. Interim Reviews

Interim Reviews are driven by programmatic and/or agency milestones which are not necessarily supported by the major reviews. They often entail multiple processes to provide important information for major reviews, programmatic decisions, and agency commitments. Program tailoring will dictate the need for and scheduling of these reviews.

6.3.1. Overview

This section summarizes major types of interim reviews. Section 6.3.2 gives further guidance on common interim reviews.

6.3.1.1. Requirements Reviews

Prior to the CDR, the mission and System requirements must be thoroughly analyzed, allocated and validated to assure that the program can effectively understand and satisfy the mission need. Specifically, these interim requirements reviews will confirm whether:

1) the proposed mission supports a specific agency program deficiency.
2) in-house or industry-initiated efforts should be employed in the program realization.
3) the proposed requirements meet objectives
4) the requirements will lead to a reasonable solution
5) the conceived architectural approach is both realizable and affordable.

These issues, as well as requirements ambiguities, are resolved, or resolution actions are assigned. In summary the interim requirements reviews alleviate the risk of excess design and analysis burdens too far into the life cycle.

6.3.1.2. Safety Reviews

As an element of the system life cycle and its associated safety program, safety reviews are conducted to insure compliance with NHB 1700.1B, "NASA Safety Policy and Requirements Document". Review(s) will be approved by the Program/Project Manager at the recommendation of the System Safety Manager(SSM), and their purpose, objectives and general schedule will be contained in appropriate safety management plans. The safety reviews will address possible hazards associated with system assembly, test, operation and support. Special consideration is given to possible operational and environmental hazards related to the use of nuclear and other toxic materials.

6.3.1.3. Software Reviews

Software reviews are scheduled by the program/project manager for the purpose of ensuring that software specifications and associated products are well understood by both program and user elements. Throughout the development cycle, the pedigree, maturity, limitations and schedules of delivered preproduction items, as well as the Computer Software Configuration Items (CSCI) are of critical importance to the engineering, operations and test communities.

6.3.1.4. Readiness Reviews

Readiness reviews are conducted prior to commencement of major events which commit and expose critical program resources to risk. These reviews define the risk environment and address the resource elements' capability to satisfactorily operate in that environment.

6.3.2. Mission Requirements Review(s) (MRR)

6.3.2.1. Purpose

The MRR occurs (as required) following the maturation of the mission requirements in the Mission Definition stage. Its purpose is to examine and substantiate requirements analysis products and assess their readiness for external review.

6.3.2.2. Objectives

The objectives of the review are to:

1) confirm that the mission concept satisfies the agency user needs.
2) confirm that the mission requirements support identification of external and long-lead support requirements (DoD, International, CofF resource).

3) determine the adequacy of the analysis products to support development of the Preliminary Phase B Approval Package.

6.3.2.3. Criteria for Successful Completion

The following items compose a checklist to aid in determining readiness of MRR product preparation.

1) Are the top-level mission requirements sufficiently defined to describe objectives in measurable parameters? Are assumptions and constraints defined and quantified?
2) Is the mission and operations concept adequate for support of preliminary program documentation development? Engineering Master Plan / Schedule, long-lead planning approach for the Project Definition Plan, technology assessment, initial Phase B/C/D resource requirements, acquisition strategy development?
3) Are Evaluation Criteria sufficiently defined to provide quantified conditions of satisfaction for Mission Definition? Measures of Effectiveness, Constraints, Design Goals?
4) Are specific requirements identified which are determined to be high risk/cost drivers, and options described to relieve or mitigate the problems?

6.3.2.4. Results of Review

Successful completion of the MRR provides program confidence to submit information for Preliminary Non-advocate Review and subsequent submission of the Mission Need Statement for agency approval.

6.3.3. System Requirements Review (SRR)

6.3.3.1. Purpose

The SRR occurs (as required) following the formation of the project/engineering team and evaluates their thorough understanding of the mission requirements as well as requirements at the System level. The purpose of the review is to demonstrate understanding of the requirements.

6.3.3.2. Objectives

The objectives of the review are to:

1) confirm that the requirements at the System level meet the mission objectives.
2) confirm that the specifications of the System are sufficient to meet the project objectives.

6.3.3.3. Criteria for Successful Completion

The following items compose a checklist to aid in determining readiness of SRR product preparation.

1) Are the allocations contained in the System Specifications sufficient to meet mission/program/project objectives? consistent with the customer's mission need?
2) Are the Evaluation Criteria established? realistic?
3) Are Measures of Effectiveness established? realistic?
4) Are cost estimates established? realistic?
5) Has a system verification approach been identified?
6) Are appropriate plans being initiated to support projected system development milestones?
7) Have the technology development issues been identified with approaches to solution?

6.3.3.4. Results of Review

Successful completion of the SRR freezes program/project requirements and leads to a formal decision by the cognizant PAA to proceed with proposal request preparations for Project Implementation.

6.3.4. System Safety Review

6.3.4.1. Purpose

System Safety Review(s) (SSR) occur in multiple phases of the life cycle. The purpose of these reviews is to:

1) provide early identification of safety hazards.
2) insure that measures to eliminate, reduce or control the risk associated with the hazard are identified and executed in a timely, cost efficient manner.

6.3.4.2. Objectives

The objectives of the reviews are to:

1) identify those items considered as critical from a safety viewpoint.
2) assess alternatives and recommendations to mitigate or eliminate risks and hazards.
3) insure that mitigation/elimination methods can be verified.

6.3.4.3. Criteria for Successful Completion

The following items comprise a checklist to aid in determining readiness of SSR product preparation.

1) Have the risks been identified? quantified?
2) Have design/procedural options been analyzed? quantified as to risk reduction?
3) Have verification methods been identified for candidate options?

6.3.4.4. Result of Review

A successful SSR results in the identification of hazards and their causes in the proposed design and operational modes, and specific means of eliminating, reducing or controlling the hazards.

The methods of safety verification will also be identified prior to PDR. At CDR, a safety baseline is developed.

6.3.5. Software Specification Review

6.3.5.1. Purpose

The Software Specification Review(SoSR) occurs shortly after the start of preliminary design. The purpose of the SoSR is to ensure that the software specification set is sufficiently mature to support preliminary design efforts.

6.3.5.2. Objectives

The review objectives are to:

1) verify that all software requirements from the system specification have been allocated to CSCIs and documented in the appropriate software specifications.
2) verify that a complete set of functional, performance, interface and qualification requirements for each CSCI has been developed.
3) ensure that the software requirement set is both complete and understandable.

6.3.5.3. Criteria for Successful Completion

The following items comprise a checklist to aid in determining the readiness of SoSR product preparation.

1) Are functional CSCI descriptions complete and clear?
2) Are the software requirements traceable to the system specification?
3) Are CSCI performance requirements complete and unambiguous? execution time? storage?

4) Is control and data flow between CSCIs defined?
5) Are all S/W-S/W and S/W-H/W interfaces defined?
6) Are the mission requirements of the System and associated operational and support environments defined? Are milestone schedules as well as special delivery requirements negotiated and complete?
7) Are the CSCI specifications complete? design and programming constraints? standards? quality assurance? testability? delivery preparation?

6.3.5.4. Results of Review

Successful completion of the SoSR results in release of the software specifications and the start of preliminary design activities based upon the specification development requirements and guidelines.

6.3.6. Test Readiness Review

6.3.6.1. Purpose

The Test Readiness Review (TRR) is held prior to the start of formal testing. The review is applicable to initiation of formal testing for an element of the System as well as integrated test efforts between segments; e.g., ground and flight segments. The purpose of the TRR is to insure that the test article hardware/software, test facility, ground support personnel and test procedures are ready for testing, data acquisition, reduction and control.

6.3.6.2. Objectives

The objectives of the review are to:

1) confirm that in-place plans provide for test execution which meets test objectives
2) confirm that sufficient program resources are allocated to the test effort.
3) examine detailed test procedures for completeness and safety during test operations.
4) determine that critical test personnel are test-and safety-certified.
5) confirm that all test support software are adequate, pertinent and verified.

6.3.6.3. Criteria for Successful Completion

The following items comprise a checklist to aid in determining the readiness of TRR product preparation.

1) Have the test cases been reviewed and analyzed for expected results? results consistent with test plans and objectives?

2) Have the test procedures been "dry run"? Do they indicate satisfactory operation?
3) Have test personnel received training in test operations and safety procedures? certified?
4) Are program resources available to adequately support the planned tests as well as contingencies, including failed hardware replacement?
5) Has the test support software been demonstrated to handle test configuration assignments, data acquisition, reduction, control and results archival?

6.3.6.4. Results of Review

A successful TRR signifies that program, test, engineering, and safety management have certified that preparations are complete; and that commitment of resources is authorized for formal test initiation.

6.3.7. Production Readiness Review

6.3.7.1. Purpose

The Production Readiness Review (ProRR) occurs after design certification and prior to the start of manufacturing. The purpose of the ProRR is to ensure that production plans, facilities, and personnel are in place and ready to begin production.

6.3.7.2. Objectives

The objectives of the review are to:

1) ascertain that all significant production engineering problems encountered during development are resolved.
2) insure that the design documentation is adequate to support manufacturing.
3) insure that manufacturing plans and preparation are adequate to begin production.
4) establish that adequate resources have been allocated to support end item manufacture.

6.3.7.3. Criteria for Successful Completion

The following items comprise a checklist to aid in determining the readiness of ProRR product preparation.

1) Is the design certified? incomplete design elements identified? Risks and mitigation efforts defined?
2) Has the bill of materials been reviewed? critical parts identified? delivery schedules verified? alternative sources identified? adequate spare planned and budgeted?

3) Are the facilities and tools sufficient for end item manufacture? special tools and test equipment specified in proper quantities? personnel/CAM software qualified and certified?
4) Is production engineering and planning mature for cost-effective manufacturing? compliant with OSHA, environmental and energy conservation regulations?
5) Are manufacturing processes and methods consistent with quality requirements?

6.3.7.4. Results of Review

A successful ProRR results in certification of production readiness by Engineering, Manufacturing, Program, Safety, Reliability and Quality Assurance management. All open issues are resolved with closure actions and schedules.

6.3.8. Design Certification Review

6.3.8.1. Purpose

The Design Certification Review (DCR) is held following test completion at the component and subsystem level and prior to start of manufacturing for that item. The purpose of the DCR is ensure that the testing demonstrated design compliance with performance requirements.

6.3.8.2. Objectives

The objectives of the review are to:

1) confirm that the test results met performance requirements, and that test plans and procedures were executed correctly in the specified environments.
2) certify that traceability between test article and production article is correct, including name, identification number, and current listing of all waivers.
3) Identify any incremental tests required or conducted due to design or requirement changes made since test initiation, and resolve issues regarding their scheduling and approval.

6.3.8.3. Criteria for Successful Completion

The following items comprise a checklist to aid in determining the readiness of DCR product preparation.

1) Are the pedigrees of the test articles directly traceable to the production units?
2) Is the Test Plan used for this article current and approved?
3) Do the test procedures and environments used comply with those specified in the plan?

4) Are there any changes in the test article configuration or design resulting from the as-run tests? Do they require design or specification changes? retests? Have design and specification documents been audited?

5) Do the test results satisfy performance requirements?

6) Do the test, design and specification documentation correlate? Are any review issues regarding certification closed?

6.3.8.4. Results of Review

As a result of a successful DCR the end item design is approved for production.

Appendix A - Product Dictionary

This appendix provides guidance on the contents and maturity of technical products at the various control gates. For each product, the following information is provided:

- generic name of the product as used in this document
- location in the product structure (codes are summarized in Table 4.8.1-1)
- relation to end products and process (types are summarized in Table 4.8.1-2)
- product maturity at each control gate (codes are summarized in Table 4.8.3-1)
- details on product contents or scope at each control gate

The products are listed alphabetically according to title.

The listing is not intended to suggest a specific packaging or formats of the products. Indeed, many of them may occur as different sections of the same document. Particular formats would be provided by relevant Data Requirement Descriptions (DRDs). For example, a Mission Feasibility study might package all it products in three basic documents: a management plan, an engineering master plan/schedule, and a final report.

Appendix B - Glossary

This glossary identifies the key terms used in this document to describe the systems engineering processes for programs and projects. This glossary focuses on general terms rather than specific documents or products. It restricts discussion of documents only to general classes. Names of documents and their presence and maturity at various reviews are contained in the data dictionary in Appendix A.

Agency Reviews: reviews that involve participation by upper management and NASA Headquarters.

Architecture Aspect: describes the top-level form or structure of a system or entity. This includes top-level function, functional areas, and their interactions. Architecture is often represented in functional block diagrams.

As-Built Baseline: describes the actual configuration of the products that were produced. Also called a Production Baseline.

As-Deployed Baseline: describes the actual configuration of the System as deployed and operated. Also called an Operational Baseline.

Assembly: functional unit viewed as entity for analysis, manufacturing, maintenance, etc. Example: A power generator.

Baseline: used in a generic sense to mean a reference point from which to identify and to control change. Baselines may thus have varying degrees of firmness. Baselines vary as to what they address. Technical baselines address the configuration of system products. In addition to technical baselines, there are business baselines that address matters such as funding, staffing, and schedule. A technical baseline is embodied in the specifications and in other system documentation. Typical technical baselines are Functional, Design-To, Build-To, and As-Built.

Build-To Baseline: specifies the configuration of the products to be produced. Established with the approval of the Build-To Specification. Also called a Production Baseline.

Build-To Specification: describes an item in sufficient detail to enable procurement or fabrication. May be functional or fabrication and may correspond to any item below the System/segment level. Functional specifications describe all characteristics (performance, quality, interface, etc.) of the item that are essential for its intended use. Fabrication specifications provide detailed direction on the proper construction of the item (parts, assembly, performance, test/inspection, etc.). Establishes a build-to baseline. Also called Product Specification, Type C Specification, Configuration Item Specification.

Certification: a process for establishing that an item, as built, will fit and function within the spacecraft for which it is intended.

Complete: indicates that the product is finished to the extent planned.

Completion Criteria: a set of guidelines for evaluating successful closure of the review associated with a stage's control gate. They determine whether the quality and quantity of work is sufficient to progress to the next stage.

Concept: early, top-level plans that identify basic goals and principles. May also be called Philosophy.

Conceptual: refers to products at the lowest level of maturity. They are typically early estimates or drafts in which significant revision is expected.

Control Gate: a major review process that marks progress in technical maturity and risk reduction. In the sense used in this document, a control gate is a process rather than a single formal meeting or review.

Design-To Baseline: allocates performance and design requirements to particular sub items. Established with the approval of the Design-To Specification. Also called an Allocated Baseline.

Design-To Specification: a development specification that states the requirements for the design or engineering development of a product. Typically prepared for prime or critical items. Primary focus is on the allocated performance. Includes pertinent direction to designers regarding characteristics and features. Establishes a design-to baseline. Also called Development Specification, Type B Specification, Performance Requirements Document, Contract End Item Design Specification.

Element Level: complete integrated set of subsystems capable of an operational role. Typically constructed as a physically separate entity. Example: Weather Satellite.

End Item: products used to support the mission. When multiple items are built, production articles are the product baseline. These may differ from the articles used for the initial flights and demonstration of operational capability. Other names include flight articles, flight units, configuration items, prime items, contract end items, hardware configuration items (HWCI), computer software configuration items (CSCI).

Engineering Item: development articles that are used to generate information important to designing the final item. They use non-flight parts and workmanship standards. Their uses include technology demonstrations, proof of concept, and design data generation. May include bread-boards or mock-ups.

Entry Criteria: a set of guidelines detailing the recommended maturity level for the program and for individual products to justify readiness to enter a specific stage's control gate. They determine the readiness of the project to hold a review.

Final: refers to products with the highest level of maturity. These have had significant review and are deemed stable. There are typically under formal configuration control.

Formulation/Implementation: (from NHB 7120.5) a division of a project's life cycle into two key types of activities. Formulation is the initial development period of a program, when the focus is on what is to be done and what is to be procured. Implementation is the later detailed development, production, and operation of a project's hardware, software, and facilities. The transition from formulation to implementation occurs at the Phase B - Phase C boundary.

Functional Baseline: states the technical performance of an item. Established with the approval of the System Specification

Goals: desirable characteristics or conditions. Typically somewhat qualitative.

Implementation Aspects: describes the theoretical embodiment of a system architecture in functional units and processes. It identifies subsystems, technology, operating principles, interfaces, etc. Schematic block diagrams typically represent implementation.

Major Reviews: key reviews that mark significant decisions or milestones in the technical development. These include control gates but are not necessarily restricted to them.

Mission Needs Statement: a high level document that defines the mission requirements.

Mission: the utilization of assets to accomplish some specific milestones or to provide some specific service.

Objectives: desirable characteristics or conditions. May be quantitative and verifiable.

Operational System: those deployed entities that perform the mission.

Part: smallest functional entity that can not be disassembled without damage. Example: A solar cell.

Partial: product will undergo significant expansion or refinement. Typically applied to analyses that address only part of the design.

Physical System Hierarchy: the levels in the Product Breakdown Structure.

Plan: Intermediate planning items that formulate how an activity will be accomplished. Typically identify organization, responsibility, general flow, and key events.

Preliminary: refers to products with a significant level of maturity. They exhibit significant engineering effort and are expected to undergo only modest revision as to details.

Procedures: detailed step by step planning materials.

Program Controls: products pertain to the general administrative and project management. These include engineering master schedules and cost reports.

Program Plan : indicates a specific approach to develop a comprehensive plan (e.g., a Reliability Program Plan).

Program/Project Life Cycle Model: an idealized partitioning (segmenting) of a project's life cycle into distinct, sequential activity periods that are separated by major control gates or technical reviews. The model identifies the key activities and the criteria for progressing from one stage to the next. These are frequently process models that entail three basic functions: 1) identify major stages of a project, 2) identify the activities of the stages, and 3) establish transition criteria for progressing between stages.

Project Phase: segments of a project's life cycle from a management or procurement standpoint. These are the usual Phase A through Phase E, each of which is defined in, for example, NASA NHB 7120.5.

Qualification Item: development articles used to demonstrate that the proposed design will function properly in the required environment under the required conditions. They are generally not intended for flight.

Qualification: a process for establishing that a design or material will perform satisfactorily in the environment in which the System is to be operated (e.g. low Earth orbit). Also called design certification, material certification.

Ratify: certify that a process was adequate and that the results and recommendations are justified.

Realization Aspects: describes the actual physical embodiment of an entity. It identifies explicit components, parts, physical layout, tolerances, etc. Detail drawings typically document realizations.

Requirements: used to connote a formal, verifiable statement of function, performance, or characteristic.

Segment Level: grouping of elements that are closely related. These elements often interface physically. A segment often corresponds to a top-level function of the System. Example: Data Collection Segment.

Specification: a document that contains requirements, implementation concepts, and operations concepts for all or part of a system. Specifications are also sometimes referred to as requirements documents, but in addition to requirements, a complete specification also includes descriptions of candidate hardware, software, and facilities and a discussion of how the System will be operated.

Subassembly Level: two or more units joined together to form a stockable unit capable of disassembly. Example: A solar panel.

Subsystem Level: grouping of components that provide a major function or related functions. Example: Power generation and distribution.

System Specification: defines the functional, performance, and interface requirements for the System or segments. Includes a top-level description of the architecture and operations. Establishes a functional baseline. Also called Type A Specification, System/Segment Specification.

System: in general, some collection of entities. *Product system* refers to the totality of hardware, software, personnel, and so on associated with the actual accomplishment of a mission. This system is distinct for the *producing system* associated with a development project.

Technical Management: products that focus on the definition and control of a technical process that defines a complete, balanced attainment of the mission needs and objectives. These include products that define the process and tools to be used, the plans for monitoring and controlling the process, and plans to ensure suitable integration of engineering specialties.

Technical Product: products pertain to the actual definition and fulfillment of mission needs. These include engineering plans, requirements/specifications, concepts / designs/data/drawings, criteria, test data, technology, operations plans, training material, and hardware and software. Here, the term product is used in a general sense to indicate some specific data or item rather than a complete document or separate deliverable.

Technical Stage: segments of a project's life cycle from a technical working level standpoint. Each stage has a unique focus or technical thrust (although there may be significant overlap), and a transition to a different type of activity is made as the project passes through a control gate between one stage and the next.

The System: the totality of hardware, software, personnel, and so on needed to perform the designated function or mission. Example: Earth Monitoring System.

Update: a new release of a previously approved product.

Validation: a process for establishing that an entity will meet (or can meet) mission needs or objectives.

Verification: a process for establishing that an entity meets specifications.

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