National Aeronautics and
Space Administration

MSFC-HDBK-3173
Revision B
EFFECTIVE DATE: October 16, 2012

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

EE11
MSFC TECHNICAL STANDARD

PROJECT MANAGEMENT AND SYSTEMS ENGINEERING HANDBOOK

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DOCUMENT HISTORY LOG

Status (Baseline/ Revision/ Canceled)	Document Revision	Effective Date	Description
Baseline		5/30/2001	Baseline Release
Revision	A	10/27/2003	Document has been edited and restructured. Section on Technology Development Projects has been added. Appendix D, Technical Performance Metrics, has been added. Review comments incorporated.
Revision	B	10/12/2012	Revision B released; document authorized through MPDMS. Document has been edited and restructured. Section 4, Project Management and Systems Engineering has been broken into two separate sections. Section 3, Project Management has been updated to reflect the current NASA Project Life-cycle and current MSFC practices. Section 3.1, Project Life-cycle, has been updated to comply with NPR 7120.5 and NPR 7120.8. Section 3.2, Project Organization, has been reduced in scope to include only those roles that are not specific to the current Center organization structure. Section 3.3, Project Management Functions, has been reduced in scope to eliminate data that exists in other Center documentation. Section 3.4, Project Reviews, has been revised to reflect the current Technical Reviews required by NASA documentation and reduced in scope to eliminate data that can be found in other Center documentation. Section 4, Systems Engineering, includes additional guidance on all 17 systems engineering processes. Appendices related to Requirements Development, and Technical Assessment and Analysis, Managing Reviews and Discrepancies, and Decision Analysis have been added. Appendix D, Technical Performance Metrics, has been deleted. Content from MSFC-HDBK-3599 has been integrated into the document.

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1. INTRODUCTION

1.1 Scope

This handbook describes the basic processes and provides general guidance for managing and implementing the life-cycle for all projects managed at Marshall Space Flight Center (MSFC) and executing the systems engineering processes employed at MSFC. Its intended use is for projects that provide aerospace products, technologies, data, and operational services (aeronautics, space, and ground). It also serves as an information source for projects such as non-flight infrastructure, Construction of Facilities (CofF), Small Business Innovation Research (SBIR), and for research and analysis projects. The guidance contained in this document, while not required, documents proven best practices and approaches to project management and systems engineering and is aligned with the NASA policies and guidance for Project Management and Systems Engineering.

While many of the management and systems engineering principles and practices described in this book apply to both programs and projects, the emphasis of the document is to describe the management and systems engineering processes necessary for project development; therefore, in general, the document refers only to project management and systems engineering. Readers interested in program management principles may apply this information to the program level.

While all process activities and general guidance are addressed, project managers, working with their systems engineers, may tailor and customize implementation to the specific needs of the project consistent with project size, complexity, criticality and risk. Tailoring and customizing are mechanism to encourage innovation and achieve products in an efficient manner while meeting the expectations of the customer. Tailoring results when a requirement is removed from a program/project/activity, whereas, customization results when a best practice or guidance is removed from the program/project/activity. Results of the tailoring will be documented in Program Commitment Agreements (PCAs), Program Plans, and Project Plans. All projects comply with applicable MSFC directives, requirements established by law, regulations, Executive Orders, and Agency directives.

1.2 Purpose

The purpose of this handbook is to describe the basic processes and to provide general guidance for managing and implementing projects at the MSFC. The handbook also defines the contemporary policies and practices employed at MSFC in the management of projects and execution of systems engineering processes.

This document is not intended to be a specification for future projects, but is to be used as guidance in both in the management of projects and in the development of plans for future projects. It will also serve as an orientation for newcomers and outsiders to the MSFC processes in the project management and systems engineering employed in the development of space systems.

2. REFERENCE DOCUMENTS

2.1 NASA Documents

Number	Title
NPR 7120.8	NASA Research and Technology Program and Project Management Requirements
NPR 7120.9	NASA Product Data and Life-Cycle Management (PDLM) for Flight Programs and Projects
NPR 1441.1	NASA Records Retention Schedules
NPR 7120.5	NASA Space Flight Program and Project Management Requirements
NPR 7123.1	NASA Systems Engineering Processes and Requirements
NASA/SP-2007-6105	NASA Special Publication: Systems Engineering Handbook
NASA/SP-2010-3403	NASA Special Publication: Schedule Management Handbook
NASA/SP-2010-3404	NASA Special Publication: Work Breakdown Structure (WBS) Handbook
NASA/SP-2009-569	Bayesian Inference for NASA Probabilistic Risk and Reliability Analysis
NASA-STD-8719.14	Limiting Orbital Debris
NASA Reference Publication 1358	NASA Reference Publication: System Engineering “Toolbox” for Design-Oriented Engineers
NSTS-21000-IDD-ISS	International Space Station Interface Definition Document
NSTS 21000-IDD-ISS	International Space Station Interface Definition Document, Revision A
SSP 42121	U.S. On-Orbit Segment Pressurized Mating Adapter – 1 to Russian Segment FGB Interface Control Document
SSP 41178-25	Software Interface Control Document, Internal Multiplexer De-Multiplexer to International Space Station Book 25, Node 2-2 Multiplexer De-Multiplexer Interface
SSP 30261:001	DC to DC Converter Unit External (DDCUE) Standard Interface Control Document (ICD)

SSP 30263:002	Remote Power Controller Module (ROCM) Standard Interface Control Document
CxP 70016	Constellation Program Requirements Engineering Management Plan

2.2 MSFC Documents

Number	Title
MPR 7123.1	MSFC Systems Engineering Processes and Requirements
MPR 1440.2	MSFC Records Management Program
MPR 6410.1	Handling, Storage, Packaging, Preservation, and Delivery (HSPPD)
MPR 7120.1	Space Flight Program/Project Planning
MPR 8040.1	Configuration Management, MSFC Programs/ Projects
MPR 8070.1	Administration of MSFC's Technical Standards
MSFC-HDBK-2221	Verification Handbook Volume I: Verification Process and Verification Handbook Volume II: Verification Documentation Examples
MSFC-STD-506	Standard Materials and Processes Control
MSFC-STD-555	MSFC Engineering Documentation Standard
MWI 6410.1	Packaging, Handling, and Moving Program Critical Hardware
MWI 6430.1	Lifting Equipment and Operations
MWI 7100.1	Proposal Review and Signoff Process
MWI 7120.6	Program, Project, and Institutional Risk Management
MSFC Form 2327	MSFC Engineering Change Request (ECR)

2.3 Other Documents

ANSI/GEIA-859	Data Management Standards
N/A	Defense Acquisition University, Systems Engineering Fundamentals
N/A	Defense Acquisition University, Test and Evaluation Management Guide
N/A	Fault Tree Handbook with Aerospace Applications
N/A	National Airspace System (NAS): Systems Engineering Manual

ANSI/AIAA/G-043-1992	Guide for Preparation of Operational Concept Documents
IEEE-STD-1362-1998	IEEE Guide for Information Technology - System Definition - Concept of Operations (ConOps) Document
INCOSE--TP-2005-001-03	INCOSE Systems Engineering Leading Indicators Guide, Version 2.0
INCOSE-TP-2010-005-02	INCOSE Systems Engineering Measurement Primer, Version 2.0
MIL-HDBK-520	Systems Requirements Document Guidance

3. PROJECT MANAGEMENT

Project management is the function of planning, overseeing, and directing the numerous activities to successfully achieve the requirements, goals, and objectives of NASA's customers. Two types of projects managed at MSFC are space flight system projects that may vary from a major stage of a launch vehicle to a small experiment to be housed on the International Space Station (ISS) and technology development projects that develop a particular technology or advance a particular technology to enable future capabilities. Although the scope, complexity, cost, development processes, and specific project management tasks for projects will vary, the basic structure of the project life-cycle for the various types of projects and the project management tasks are basically the same.

This section provides a description of the project development process from Concept Development to project Closeout. This section also discusses some of the common organizations and roles used in the project life-cycle and describes various project management functions. Significant variances between technology development projects and classical engineering development projects are also discussed.

Programs and projects follow the Technical Authority process per Integrated Management Systems Board (IMSB) per NPR7120.5. NASA established this system as part of its system of checks and balances to provide independent oversight of programs and projects in support of safety and mission success through the selection of specific individuals with delegated levels of authority. Technical Authority originates with the Administrator.

Project Management and Systems Engineering roles, responsibilities, and authority are tightly coupled throughout the project life-cycle. Figure 1 illustrates the relationship between the Project Manager (PM) and Systems Engineering (SE), showing areas of overlap. Safety and Mission Assurance including Risk Management, is another Complementary and overlapping domain of roles, responsibilities, authority and perspective.

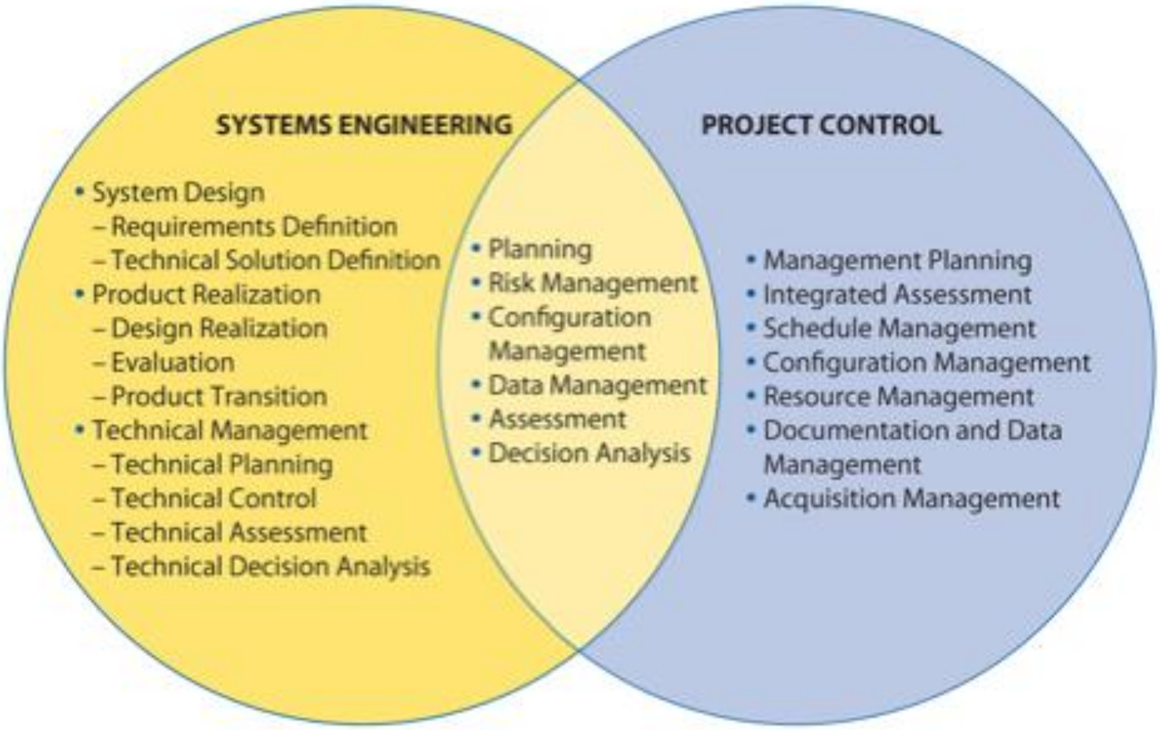


Figure 1. Systems Engineering is Collaborative with Project Management

3.1 ProgramLife-cycles

Within NASA, programs are categorized into four groups: Loosely coupled programs, tightly coupled programs, uncoupled programs, and single-project programs.

a. **Loosely coupled programs** are responsible for the management and leadership of projects for which there is organizational commonality but little programmatic and technical commonality. The Program life-cycle consists of the reviews (System Requirements Review (SRR), Acquisition Strategy Meeting (ASM), and System Definition Review (SDR)) and documents (Formulation Authorization Document (FAD), Program Plan and PCA) required to obtain approval for implementation to begin. From this point on, the program activities are limited to Program Implementation Reviews as required by the Decision Authority (DA). The Project continues with the implementation phases with the normal life-cycle reviews and their data products.

b. **Tightly coupled programs** contain projects that have a high degree of organizational, programmatic, and technical commonality. No single project within a tightly coupled program is capable of implementing the complete mission. Such programs typically have greater integration functions at the program level, such as risk management, reserve management, and requirements management.

c. **Uncoupled programs** are implemented under a broad scientific theme and/or a common program implementation concept, such as providing frequent flight opportunities for cost-capped projects selected through AOs or NASA Research Announcements (NRAs). Each project is independent of the other projects within the program. Same as above for loosely coupled projects.

d. **Single-project programs** are considered synonymous to tightly coupled projects and programs for the purposes of this handbook. In addition to duties as a program manager, a single-project program manager or the manager of a tightly coupled program needs to manage like a project manager, although at a much higher level.

For tightly coupled and single-project programs, the program manager has a significant role and influence over the management and execution of the project(s). In the case of a tightly coupled program, major project decisions frequently require the approval of the program manager. Decisions to change elements, such as reduce scope or extend schedule, for one project may affect all other projects within that program. The project manager provides frequent briefings and regular progress status to the program and certain project risks may be integrated into a list of top program risks. Any change in program requirements has a direct impact on certain project requirements. The program manager may hold some or even all of the reserves.
For loosely coupled or uncoupled programs, the program office may simply provide a management infrastructure and serve as a funding source to the projects. Program requirements are high level. Most, if not all, reserves are maintained by the project.

See MPR 7120.1 for life-cycles and products required for each of these life-cycles.

3.1.1 Space Flight System Development Projects

This section describes the processes followed by projects that are basically engineering development projects that generally utilize existing technology. Although many of these projects at the MSFC also require some advancement in technology to achieve their objectives, the process described in the following paragraphs is generally followed. Paragraph 3.1.2 describes the general process for technology development projects. Some projects may require a combination of the two types described. The following sub-paragraphs provide a description of the project's development processes including project Formulation (including planning), Evaluation, Approval, and Implementation.

3.1.1.1 Formulation Phase

The formulation phase consists of two (2) phases:

Phase A: Key Decision Point (KDP) A to KDP B: This phase is associated with Program/System Requirements Review (P/SRR) and Program /System Definition Review (P/SDR) and its objective is to evaluate whether the project functional and performance requirements are properly formulated and correlated with the Agency and Mission Directorate strategic objectives and to assess the credibility of the project's estimated budget and schedule.

Phase B: KDP B to KDP C: This phase is associated with P/SDR to Preliminary Design Review (PDR) and its objective is to evaluate the proposed project requirements/ architecture and allocation of requirements to initial projects and to assess the adequacy of project pre-Formulation efforts and to determine whether the maturity of the project's definition and associated plans are sufficient to begin implementation.

3.1.1.1.1 Pre-Phase A: Concept Studies prior to KDP A

The PM obtains an approved FAD or is provided a general mission concept with science objectives in the case of a pending competitive AO. While a preliminary mission needs may have been generated during pre-formulation studies, the more thorough studies of the early formulation confirms the mission needs, defines mission concepts, and establishes mission feasibility. The mission need determination is the first step in a multi-faceted preliminary concept definition activity. This is the step that may be first performed by or sponsored by NASA Headquarters or Center level (or industry, university, etc.) and is the precursor to concept development. The mission need determination is that part of early mission planning that identifies a national need or gap (i.e., scientific knowledge, access to space) that could be met with some kind of NASA sponsored activity. These needs are captured in a User or Mission Needs Statement.

The PM negotiates and secures a team to work the Pre-Phase A effort, with the understanding that this team may not be the team in place to proceed into the Implementation phases. This team may include partnerships and be fully defined by the end of Pre-Phase A, with crisp roles and responsibilities defined. Once the user or mission needs are established, a concept definition activity is begun to explore candidate concepts that may meet the documented mission needs. These concepts could have come from a pre-formulation study or from other sources within or external to NASA. The majority of concepts that are studied at MSFC are assigned by NASA

Headquarters and funded accordingly. MSFC can also submit proposals for an AO as outlined in MWI 7100.1, Proposal Review and Signoff Process. Competition and creativity are encouraged to ensure that a wide variety of options are identified and examined. The goal of a concept definition activity is to determine the concept(s) that will satisfy the mission and science requirements. Modeling and computer analysis are generally used to assess the best concepts. Where possible, a utility analysis is conducted to determine the value of a project. This requires a best estimate of the Life Cycle Cost (LCC) of the project and benefits versus existing alternatives. The PM secures time and resources from the customer (Mission Directorate (MD), program manager, or MSFC Institution) to perform adequate Pre-Phase A planning.

At this stage of the process the utility analysis may be more qualitative than quantitative because of the uncertainties in the knowledge base. The following criteria are considered during this study, as appropriate: the program needs are met, the scientific knowledge acquired, and potential technology spin-offs and applications are identified. Project planning is accomplished during early formulation and includes establishing project control for oversight and reporting, which integrates the cost, schedule, and technical performance of the project. This process is repeated and updated as more in depth knowledge is obtained. As concepts and project planning becomes more defined, a preliminary Work Breakdown Structure (WBS) and WBS dictionary are developed to serve as the basis for project technical planning, scheduling, cost estimating and budgeting, contract scope definition, documentation product development, and status reporting and assessment. In the case of a competitive solicitation, the PM works with the Procurement Office to ensure that the proposed contract agreements and structure are included and defined in the Proposal for the entire project life-cycle. In two step selections that involve a second down-select after a Phase A period, the contract structures for a Phase A period and for the remainder of the life-cycle are defined in the proposal, as they can be different.

The PM assures that the team performs appropriate concept trades and studies evolving the design against the initial requirements or the preliminary science objectives, to include Design Reference Mission (DRM) analysis feasibility studies, technology needs analysis, and study of alternatives. The Mission Concept will eventually be captured and presented at the Mission Concept Review (MCR), or documented as part of the proposal for competitive solicitations at the end of this Pre-Phase A effort.

Development of a set of Technical Performance Metrics (TPMs) during the early planning activities provides a mechanism for tracking and maintaining successful project performance. Establishment of the TPMs includes meaningful milestones with a connection to a project-oriented WBS that quantitatively measures progress of the project. The TPMs are updated as the process continues through formulation and into implementation to include appropriate metrics for project control of the additional activities.

Ensuring safety is primary for all projects, and doing so begins in the early formulation phase. The following is a brief summary description of principal system safety tasks and outputs during the early formulation phase:

a. Perform preliminary top-level hazard analyses and safety assessment of each project approach. Hazard analyses:

1) Identifies hazards and evaluate the method by which the hazards may be eliminated or controlled for each concept;
2) Evaluates each proposed approach or concept and provide recommendations for the selection of one or more approaches or concepts. Rationale for solution is clearly stated; and
3) Serves as a baseline for hazard analyses later in the formulation phase.

b. Develop safety criteria and requirements for inclusion in design concept(s). Once the criteria and requirements have been established they are documented in the Preliminary Systems Requirements Document. These criteria and requirements are continually evaluated throughout the life of the project.

Another activity initiated during this phase is the development of a project risk management summary, containing as a minimum, a composite listing of project development areas that have a high potential of causing project schedule delays, cost increases, and/or technical performance short comings, as well as safety risks, hazards, and associated control actions.

Appropriate concept trades and studies are performed to evolve the design against the initial requirements or the preliminary science objectives, to include Design Reference Mission (DRM) analysis feasibility studies, technology needs analysis, and study of alternatives. The Mission Concept is eventually captured and presented at the Mission Concept Review (MCR), or documented as part of the proposal for competitive solicitations at the end of this Pre-Phase A effort.

The PM assists either the program manager or the principal investigator (PI) in drafting the top level Project Requirements held at Headquarters (HQ) or the program, as appropriate, and iterating with the concept trades and studies as the mission design matures. This includes the stratification of Primary and Secondary, or Baseline and Floor objectives/requirements as the local vernacular dictates.

The top WBS and a rough WBS Dictionary sufficient to document the project cost are drafted and defined. If Cost Account Managers are used, they are specified and their scope defined by the end of Pre-Phase B.

Budget analysis and cost estimating functions are often confused and incorrectly used interchangeably. Both are key to project refinement and cost formulation and are phased against the top-level WBS elements. Budget analysis includes the development of a phased budget, tracking actuals and explaining variances and working with procurement in laying out the contract phasing and procurement task durations. An understanding of general workflow, critical path, facilities, and long lead items are crucial. Cost estimating is independently performed by MSFC's Office of Strategic Analysis and Communications Office based on the general design concept to and cost basis. Cost estimating methods include parametric cost estimates, top-down, bottoms-up, or Rough Order of Magnitude (ROM) estimates.

At the end of Pre-Phase A, this Cost formulation includes a Basis of Estimate and is phased per top-level WBS, and includes Unallocated Future Expenses (UFEs) (generally 25 – 30%). No known work is booked under UFEs at the end of Pre-Phase A. This estimate includes funded Schedule Reserve, consistent with best practices (Science Mission Directorate (SMD): one month/year from start of Implementation to Integration and Test (I&T), two months/year for I&T, and one week/month for activities at the launch site.) The best method for determining the amount of life-cycle schedule reserve needed is via a Joint (budget and schedule) Confidence Level (JCL) analysis per NPR 7120.5; however, whatever method is used (e.g. - SMD), the total reserve time is added to the end of the schedule so that it can be utilized at any point throughout the project life-cycle.

The PM develops an understanding of facility and infrastructure needs to support the project, including test facilities, propulsion testing, flight and ground communications, and calibration and contamination needs.

A top-level Schedule will be developed, capturing all of the top-level project milestones, the duration of the various project phases; the basic facility needs to support the project and the general work flow through the facilities.

A Technology Assessment will be performed, including the Technology Readiness Levels (TRL) associated with all major items of equipment. As part of this assessment, every item entered in the Master Equipment List is evaluated.

During this phase, it is ensured that risk is evaluated as part of the design maturation, concentrating on the unique risks associated with the mission and spacecraft concepts. The5x5 classification methodology is quick and easy to identify and mitigate risks to further examine/study/test during Phase A. The best level is that which helps influence the concept maturation process throughout this phase.

The PM plans and executes an MCR, or participates in the development of a proposal to be submitted to the customer solicitation at the end of this phase. All elements mentioned within this section are to be included. For MCR, the Mission Concept (and its technical design) is evaluated against the mission need and objectives to verify relevance and completeness for the cost envelope defined or projected.

All products required for KDP A are to be completed and consistent with NPR 7120.5, Table 4-3 and reviewed by the governing PMC prior to KDP A. A Phase A Plan is developed to govern the activity to be accomplished during the Phase A portion of the project. For competitive solicitations, this can sometimes be performed between the time at which the proposal is submitted and the selection to proceed into Phase A.

3.1.1.1.2 KDP A to KDP B: Phase A - Concept and Technology Development

This phase begins with the Project FAD that formalizes a project initiation. The FAD is concisely written direction by the Mission Directorate Associate Administrator(s) (MDAA) authorizing resources for formulation with a scope of work for formulation activities (which may include technology development and other non-study activities), any cost targets or constraints, and schedules. The FAD can be used for the authorization of a project to be consistent with the Program Plan, developed during program formulation. In response to the FAD, the project develops a Formulation Agreement.

The PM defines the time and resources required to perform adequate Phase A planning, and secures appropriate commitments from the customer (MD, program manager, or MSFC Institution) that these resources are available. One top-level document that defines the basic scope, resources, and contents of programs (and sub-tier projects) is the Program PCA, which is developed during program formulation. The PCA is an agreement between the Administrator and the MDAA that documents the Agency's commitment to execute the program requirements within established constraints. The PCA includes: (1) a comprehensive definition of the program or project concept and Project performance objectives, and (2) agreements, approaches, and plans for meeting the technical, budget, schedule, risk management, commercialization, acquisition, and related management system requirements (see MPR 7120.1, MSFC

Engineering and Project Management Requirements). The PCA is the starting point for all project activity and sets the stage for projects to emerge and exist to fulfill the needs of the program. The Program Plan provides program inputs to project formulation including, program requirements allocated to the project and budget direction/constraints. Structuring, streamlining, and focusing the definition phase of any project will reduce the total lead-time and cost between concept and flight. Both the Program PCA and Program Plan will be submitted for approval as part of the program approval process. These are Program developed documents that help inform the Project Plan.

The NASA acquisition planning process is separated into three significant and discrete events: Acquisition Strategic Planning (ASP), the ASM, and the Procurement Strategy Meeting (PSM) (see NFS 1807.170). The ASP and the ASM occur during the program and project approval and requirements development processes. The ASP is used to approve programs and significant projects for execution. The ASM is program or project specific, more detailed than the ASP, and is conducted in accordance with NPR 7120.5. The PSM is project or contract specific, and is developed by the project manager, supported by the contracting officer (CO), and approved as prescribed in the NFS. The key is for the project to document: proposed milestones for in-house work and procurements, including completing any Contract Statements of Work (SOW) and Requests for Proposal (RFP); identify long-lead procurements to be initiated, and provide associated rationale; identify anticipated partnerships (other government agencies, U.S. and foreign partners), if any, including roles and contributed items and plans for getting commitments for contributions and finalizing open inter-agency agreements, domestic partnerships, and foreign contributions.

The PM selects the project team, including key support personnel with a diversity of background and skills to keep him/her continuously informed about programmatic, contract and technical issues, whose opinions are respected and who are willing to speak up when they see issues. Agreements and roles/responsibilities are finalized for major project entities and allocate to each of these that portion of project resources required to accomplish the assigned Phase A tasks. Project internal control boards/change boards are and review boards are established to provide mechanisms for project control. The PM (or delegated representative) chairs these boards and ensures that the Technical Authorities (TAs) are represented on the boards (and PI/Science as appropriate) to provide independent assessments; however, decision authority resides with the PM (or with the PI for SMD missions). For PI-led missions, the PM takes an active role to expeditiously bring major decisions and issues to resolution even if the PM is not the decision authority.

The PM assists the program manager, the MDAA and the NASA HQ Office of External Relations (OER) to mature all inter-Agency and international agreements and finalize desired roles and responsibilities, focusing on having all agreements signed and in place prior to the Phase B Non-Advocate Review (NAR). They assist either the program manager or the PI in maturing the top-level project objectives and requirements held at HQ or the program as appropriate. This includes completion of the stratification of Primary and Secondary, or Baseline and Floor objectives/requirements as the local vernacular dictates. These program requirements and objectives are flowed down into the development, by the project team, of project level requirements, where minimum or threshold objectives are identified. Coupled with the project objectives and requirements held above the project, the top-level project requirements are matured (in conjunction with the PI for SMD Missions). The Pre-Phase A conceptual designs, trades and mission studies are iterated against the maturing requirements to provide the additional engineering detail needed to produce viable mission architecture. The PM assures that cost refinement activities, including identification of UFEs and consistent with design maturation and the WBS, are being effectively performed, and that a level of confidence estimate and appropriate budget management processes are in place.

During this phase, it is ensured that risk is evaluated consistent with the maturation of system and subsystem design, the increasing stability of requirements and the greater fidelity of the mission design concept. This activity includes the top-level identification and mitigation strategy developed in Pre-Phase A and is at a level that assures a positive influence on the concept maturation process. The Technology Assessment from Pre-Phase A continues, completing the studies and prototyping low TRL concepts. The PM studies and takes positive steps to buy-down those significant design risks (i.e., perform the appropriate risk mitigation steps) identified in the risk maturation process.

The project team develops a preliminary Operations Concept, iterated against the maturing requirements and mission architecture, including ground and flight communication paths, as well as a preliminary Integrated Master Schedule (IMS) that shows the project critical path and the timing of critical resources, such as facilities, and the need dates for major procurement deliverables.

3.1.1.1.2.1 Project Plan

One of the key documents that captures and establishes the baseline for the project implementation activities is the Project Plan. The PM directs the development of a preliminary one, consistent with NPR 7120.5, Appendix F. The Project Plan references any stand-alone Control Plans (Safety and Mission Assurance (S&MA), Risk Management, Systems Engineering Management Plan (SEMP), Software Management, Configuration Management (CM)/ Data Management (DM), Security, Export Control, Safety, Engineering Process Outsourcing (EPO), etc.) and all subordinate plans. The Project Plan begins development during the early formulation phase and matures with the continuation of the project formulation. A Project Plan is the basic planning document that documents the products of the formulation process and describes the overall plan for implementation of a project. Project Plans are unique to each project and the format and level of detail may vary with the size, complexity, sensitivity, and other particular characteristics of the project. Project Plans for conventional flight hardware development projects will show the projected requirements development, design, reviews, fabrication, verification, launch plans, schedules, costs, and other criteria. Project Plans are prepared in accordance with MPR 7120.1. MPR 7120.1 is the Center's documented approach to Project management Tailoring of the project's requirements will be identified in the Project Plan. The Project Plan will serve as the basic agreement for the project between the Project Manager, the Center managing the project, and the program management. This plan is required at the Project SRR/Mission Definition Review (MDR).

3.1.1.1.2.2 Systems Engineering Management Plan (SEMP)

A Preliminary Program SEMP is developed for the P/SRR, and the Project SEMP is developed for the MCR, with the baseline due at SRR. The SEMP provides a single, integrated technical planning document which addresses the systems engineering management and implementation for systems and subsystems for in-house and contracted programs/projects/activities as well the common technical processes. The SEMP and the project plan are coordinated to ensure compatibility with the allocated resources/enabling products (cost, schedule, personnel, and facilities), milestones and deliverables. The SEMP is used to identify and evaluate the required technical teams' performances. The SEMP is also used in the technical risk assessment and deriving the progress measurement criteria.

3.1.1.1.2.3 Other Plans/Reports/Assessments (CADRe, SRR, Make or Buy, Orbital Debris, Export Control, and Long Lead Items)

For Category 1 and 2 projects, the PM ensures that a CADRe (parts A, B, and C), based on the project's technical baseline mission concept is developed and is available 60 days prior to KDP B.

The PM also directs the development of the SRR Plan, consistent with NPR 7123.1, Appendix G.1

The PM ensures the S&MA Plan is available at P/SRR and P/SDR. Other plans are required at the P/SRR and the P/SDR including the S&MA Plan. These are available on the full Life-Cycle Wall Chart.

The PM directs the activities associated with the conduct of the SRR, in accordance with the SRR plan, including the production of minutes and actions to be tracked to closure. As part of the requirements vetting process, it is important to focus not only on the requirements but also on the verification method for those requirements, to be discussed at the same time. Linking requirements development with verification methods will avoid potential cost-bearing problems later in the project life-cycle. All gate products required for KDP B, consistent with NPR 7120.5, Table 4-3, are initiated.

Necessary analyses are performed to establish a viable Make or Buy Plan, and that the ASM addresses these strategies and that the project complies with the decisions of the PSM approved acquisition plan. The PM refines the top WBS and preliminary WBS Dictionary developed in Pre-Phase A to include project products and elements below Level 2, consistent with the maturation of the project requirements and mission design, and ensures that detail is sufficient to document the project cost and cost phasing throughout the project life cycle.

Consistent with project maturation, sufficient analyses is performed to develop and maintain current the project cost phasing per year, consistent with the refined WBS, below Level 2.

In developing the initial project baseline for Phase A, the PM leads the project team in initiating a formal decomposition of mission performance requirements from the highest levels of control, flowing these down to project-level design and performance requirements to a complete set of system and sub-system design specifications for both flight and ground elements. The technical requirements are sufficiently detailed to establish firm schedules and cost estimates for the project. These will be finalized in Phase B. This effort includes a trace from the top levels downward to ensure that all of the top-level requirements are properly traced to lower level requirements. As part of the functional decomposition, the PM ensures that preliminary mission/vehicle software requirements are developed and are compatible with the maturing mission design.

The PM ensures the S&MA Plan is available at P/SRR and P/SDR. Although the initial version is not required until prior to PDR, a draft Orbital Debris Assessment Report is developed, consistent with guidelines provided in NASA-STD-8719.14, to demonstrate that the project is planning to limit generation of orbital debris while on orbit, depleting onboard energy sources after completion of the mission, limiting orbital lifetime after mission completion (or maneuvering to a disposal orbit), and limiting the human casualty risk from space system components surviving reentry as a result of post-mission disposal.

The PM also seeks early support from the MSFC Export Control Administrator in conducting a preliminary Export Control assessment. Assistance is also secured from the Agency OER for help with interagency and international agreements, and for support in review and management of any data that may fall under export control or SBU requirements.

Preparations for Phase B are made by identifying long-lead procurements that will also need to be initiated early. The project team ensures that plans for all KDP B gate reviews, including SDR, MDR and Preliminary Non-Advocate Review (PNAR), are developed, reviewed, and approved. The team obtains a Planetary Protection Certification from NASA HQ, if applicable, and develops a Nuclear Safety Launch Approval Plan, if applicable. The project team conducts the equivalent of an SDR, MDR and PNAR. It is suggested that this can be most efficiently accomplished with an integrated review, but this is not strictly required.

The PM ensures that all gate products required for KDP B, consistent with NPR 7120.5, Table 4-3, have been completed, and that the governing Project Management Council (PMC) review prior to KDP B is supported, and that all plans necessary for initiation of Phase B activities are in place prior to the completion of the KDP B gate, which controls transition into Phase B. Finally, the PM works with the Procurement Office to ensure that any significant pending solicitation for contracted work (i.e., a Source Evaluation Board (SEB)) is planned and documented in a commensurate plan, and that plan is reviewed and baselined prior to use in Phase B.

3.1.1.1.3 KDP B to KDP C: Phase B - Preliminary Design and Technology Completion

Missions selected through the AO process may be requested to conduct an SRR, but that review is not required, since the Concept Study Report and Technical, Management, and Cost (TMC) evaluation conducted by SOMA at Langley replaces the need for the SRR and the Authority to Proceed (ATP) from the DA. Otherwise, upon completion of the SRR (or SDR if the two reviews are combined), the PM will secure ATP into Preliminary Design from the DA. Phase B verifies that concepts being considered will meet top-level project requirements, meet budget and schedule constraints, and that these concepts are feasible. All feasible concepts are studied, and trade studies are performed to determine the viable concepts for the project application considering objectives, and budget and schedule requirements. This phase refines the viable concepts and verifies that the concepts will meet project requirements, budget, and schedule. After all alternative concepts have been analyzed, a primary concept is chosen for further development and project planning. Also during this phase, mission analyses are performed and mission concepts and operations are formulated. Requirements for support systems and availability of existing infrastructure to support the project are determined to capture total system implementation requirements.

Throughout this phase, the concepts and requirements that were developed and risks that were identified during Phase A are iteratively reviewed and analyzed. Through trade studies, the concepts' capabilities are compared to the requirements. Those concepts that satisfy the requirements are identified and refined. Concepts that do not meet performance and other requirements are analyzed for possible elimination. Following the examination of those that do not perform well, assessments are made to determine the feasibility of improving performance and meeting requirements. Concepts that have to change too much or would experience severe budgetary and/or schedule impacts are deleted from the concept definition and analysis cycle. Verification of design concepts through the performance of detailed analyses and tests utilizing mockup and/or subscale hardware can be extrapolated to provide confidence in a particular approach.

These trade studies, through the use of tailored evaluation criteria that are used as concept discriminators, provide a more detailed look at the architectural concepts. These concepts may consist of certain satellites and/or instruments, space flight vehicles, or technology demonstrators. The trade studies also result in a narrowing of the field of candidates for a more detailed level of design. Trades performed during this time consider such things as performance, cost, schedule, lifetime, and safety. The evaluation criteria used to assess alternative concepts are developed to a finer level of detail than for earlier system trades. Trade study results are input to the risk management summary updates.

Cost estimates are refined as further detailed requirements are identified during the formulation phase. The cost estimating process is still dependent on parametric analysis though grassroots engineering estimates and contractor bids begin to add fidelity to the estimate. The Office of Strategic Analysis and Communications (OSAC) works closely with the project formulation team to evaluate costing methodology and continuously compares government cost estimates with those of the study contractors, if contracted. If a large discrepancy occurs, the assumptions and schedule inputs of the study contractor are examined. If this examination yields valid assumptions and schedules, the NASA estimates are reconciled. The cost estimation process goes through continuous iterations during the study to reflect the refinement resulting from trade studies. For every project there are unknowns that may affect cost. A project management reserve is included in the cost estimation process to cover these unknowns.

This phase continues through the determination of all viable concepts for project application and the refinement of project requirements. The outputs of this phase are refinements to the inputs to the phase. Also by this phase, certain long-range programmatic aspects are considered (if not already). Some of these may be technical, but have impact upon overall project requirements, planning, and costs. An example of this is the Radio Frequency (RF) spectrum requirements and licenses that are approved by the National Telecommunications and Information Administration (NTIA). The NTIA Conceptual review (Stage 1 of 4) is due after initial planning has been completed (reference *Manual of Regulations & Procedures for Federal Radio Frequency Management*). Another example is the decision to utilize (or not) the International System of Units (Metric).

During this phase, schedules are further refined. An IMScovers the full life-cycle development integrating the early and mid-formulation phases to overall project schedules to lower levels of the WBS to include subsystem development, project management, manufacturing, verification, logistics planning, operations planning and other technical areas. The IMS is resource loaded. In addition, other schedules are developed that include implementation procurement strategies, cost phasing and project staffing requirements. The overall project schedules show the phasing of all major activities through launch and the follow-on operations.

Preliminary quality planning and generation of a preliminary Quality Plan, preliminary Hazard Analysis, Fault Tree Analysis (FTA), and functional Failure Mode and Effects Analysis (FMEA) are accomplished during the mid-formulation phase. Quality planning activity results are also input to the risk management summary updates. In addition, long lead items may be initiated during this phase as required. The Quality Plan can be included as part of the overall S&MA Plan or may be a standalone document. The following is a brief summary description of principal system safety tasks and outputs:

a. Develop a project system safety assessment in which the proposed system safety effort in formulation is integrated with other formulation program elements. Prepare a preliminary hazard and safety assessment for each proposed approach in order that comparative studies may be utilized in the final concept. These assessments will be used as a baseline for performing detailed hazard assessments during the Implementation phase. The preliminary hazard assessments consider mission profile and environments, abort and rescue/escape, critical time periods for each subsystem, system/subsystem interfaces, man-machine interfaces, and caution and warning system. The identified hazards are evaluated with recommended corrective actions issued in the form of design criteria, design requirements, or operational constraints.

b. Prepare and submit a comparative assessment providing safety rationale for recommending one concept or approach over the others.

c. Define specific safety requirements and criteria to be included in Implementation Process requirements.

d. Expand the project risk management summary commensurate with the hazard analyses. Residual risks and rationale for acceptance are identified and documented in accordance with MWI 7120.6, *Program, Project and Institutional Risk Management.*

e. Perform Preliminary FMEA and FTA. A FTA is a tool that is used to perform the hazard analysis. A project may choose to use a different tool such as a cause tree analysis.

f. Perform a Software Assurance Classification and Software Safety-Criticality Assessment

Personal involvement in the staffing process is maximized in this phase to ensure the team is properly staffed, especially with experienced people in key positions. In addition to experienced team members, the PM includes less experienced members to mentor them in the teaming environment to ensure proper experience is passed along to subsequent programs/projects. If the project acquisition strategy is such that a contractor is to be brought on board via competitive selection at this time, then the appropriate level of contractor support is secured as follows. Note that there is no set project phase whereby the contractor must be brought on-board. It is determined based upon the specific parameters for a given mission and the environment that sets the make-buy plan.

The PM, in conjunction with the Procurement Office, establishes the SEB and selects a Board Chair consistent with the SEB Plan established prior to PDR. It is suggested that the Contracting Officer's Technical Representative (COTR) be selected at this point, so that the COTR is fully engaged in the source selection activity. Depending upon the particular mission-specific environment, it can either be the PM or a designee from the project office. The PM, COTR, and the project team develop the SOW, Data Requirements List (DRL) and Data Procurement Document (DPD) and all other products associated with the RFP. During this development activity, it is ensured that the review teams are established for proposal evaluation.

The PM, COTR, and the project team, working with the CO release the RFP and allow adequate time for contractor proposal development and submittal. The PM, and/or the COTR, work with the CO to oversee the proposal evaluation process, utilizing the established teams, and assure that all legal and ethical standards applicable to the evaluation process are observed. Upon completion of the proposal evaluation process, the project's findings and recommendations are provided to the SEB/Source Evaluation Committee (SEC) for final determination and selection. Upon completion of the selection process, the PM (and/or the COTR designee) participate in and support the CO in the contract award process.

Since the proposal itself is not binding, the PM, COTR, and the project team work with the CO to formalize contract content and scope such that both the Government and the Contractor are bound by the negotiated commitments. This is done after selection of a contractor and award of the contract to formally transfer government expectations to the contractor. The contract structure selected gives the PM the most flexibility to execute timely and affordable changes. Upon completion of negotiated binding scope with the selected contractor(s), the preliminary cost projections of Phase A are reassessed and re-baselined consistent with the negotiated commitments. The project team then maintains the cost-to-go profile as the design matures. Following the re-baseline of cost projections, which take into account Center infrastructure and matrixed support, the PM finalizes working arrangements and personnel commitments for Phase C/D with all supporting organizations, especially those remote from the Center. This becomes an annual exercise associated with the Project Operating Plan (POP) cycles.

The PM establishes clear communications, both on a formal and an informal level, with Agency infrastructure participants, including the launch vehicle provider, pre-launch operations at Kennedy Space Center (KSC) or other payload carriers, and begins and matures the formalization process to establish clear interface requirements with these support organizations via Interface Requirements Documents (IRDs). They work with the program office to initiate communications, logistics and rapport with all members of the SRB in accordance with SRB conduct guidelines, and if the project contains a distinct payload separate from a carrier or spacecraft, the oversees the development of interface requirements that are clear and consistent, via an IRD.

The PM also establishes clear communications, both on a formal and an informal level, with the Communications and/or Ground Networks provider, generally residing at another Center(s), and begins and matures the formalization process to establish clear interface requirements with these support organizations via IRDs. The PM, before the mid-point of Phase B, initiates the project's Safety Review Process with the next higher level of integration, or with the spacecraft/payload carrier organization. The PM provides a safety package, which identifies, as well as assesses, potential hazards to be eliminated and/or controlled prior to launch.

The process outlined in the Project Plan matures and gains approval by supporting Center organizations to provide timely and appropriate information to Center management and supporting organizations via reports and reviews. This definition includes any directorate periodic reporting, even if it is not in the Project Plan.

The PM consistent with the responsibilities of the Chief Engineer reviews and updates the draft SEMP developed in Phase A and establishes the board and panel structures and associated work processes. They oversee the development of a Software Requirements Review Plan, consistent with the guidelines established in the Project Plan, in preparation for the software requirements review process. The maturation process of needed technologies defined in Phase A continues in accordance with the Technology Development Plan which describes how the project assesses its technology development requirements and evaluates the feasibility, availability, readiness, cost, risk and benefit of the new technologies.

After successful SRR with a mature set of requirements incorporating comments/Review Item Discrepancies (RIDs), the PM obtains an update to the baseline program requirements on the project and ensures that the project requirements are baselined as soon as practical after the SRR (and SDR for any changes.) Each requirement has a method of verification associated with it, along with an owner and a discipline expert for top-level requirements responsible for following the design implementation and later the verification of that requirement.

During Phase B, the PM continues to ensure that risk is evaluated consistently with the maturation of system and subsystem design, the increasing stability of requirements and the greater fidelity of the mission design concept. This activity includes the formal execution of the Risk Management process whereby robust risk identification and mitigation strategy is rigorously performed. Consistent with the performance of the Risk Management process, a listing of cost threats is created, linked to identified and unknown risks, and maintained as the risks are managed. Note that threats can also be programmatic, and are added to the threat list even if a project elects to limit these types of risks in the risk database.

The PM initiates any long-lead procurements identified in Phase A, in accordance with the Acquisition Plan. While there is some risk in starting hardware acquisition in advance of the design reviews, sometimes there is no option but to begin procurement early. For significant procurements like propulsion systems, the PM gives consideration to structure some flexibility in the procurement as a hedge against changes due to lack of overall project maturity at this point.

The PM and project team, including the appropriate level of Systems Engineering support, functionally decompose the top-level requirements and develop the needed lower-level requirements, assign ownership of these requirements, and assure that appropriate verification methodologies are established. The PM directs the activities associated with the conduct of the Software Requirements Review, in accordance with the Project Plan, and ensured that all supporting documentation reflecting the maturity of the project are complete and available to the review team. Key to this success is a thorough analysis (or modeling) of all performance requirements and their "assignment" to software as implementing agent. It is also important to have sufficient maturity of needs from the flight operations, ground systems, launch processing, and systems test aspects of the project.

The PM establishes and maintains a configuration control process that identifies the configuration of any product at various points in time, systematically controls changes to the configuration of the product, maintains the integrity and traceability of the configuration of the product throughout its life, and preserves records of the product through disposition. The Configuration Control Program needs to be in place and functioning at PDR, with the final level of design control at Critical Design Review (CDR). The PM ensures that the Integrated Baseline is maintained under this configuration management process with traceability to the KDP C approved baseline.

The PM refines the WBS and Dictionary developed in Pre-Phase A and matured in Phase A so that a WBS can be baselined, at the appropriate level, consistent with the maturation of the project requirements and mission design.

Assuming that the Software Requirements Review was completed successfully with a mature set of requirements (after comment/RID incorporation), the PM ensures that the Mission/Vehicle software requirements are baselined, and that the requirements verification program encompasses the software requirements, identifying the methodology of verification.

The PM and project team initiate and maintain an iterative cycle of design analyses that are time-unique and time-consistent (the whole project works with one set of analysis assumptions, load sets, environments, etc. until that Decision Analysis Cycle (DAC) is complete). The DACs continue as the project operation and mission concepts, acquisition strategy and analysis of alternatives mature and as requirements are verified.

During Phase B, it is ensured that the Pre-Phase A and Phase A trades are iterated against the evolving design maturity. The maturation of systems and subsystems, the stability of requirements and the greater fidelity of the mission design concept are incorporated into the trade study activities to produce viable mission architecture.

The PM refines and baselines the mission operations concept following the baselining of requirements, establishment of a resource-loaded WBS, and baselining of the mission/vehicle software requirements. Since this document drives many things not the least of which is flight and ground software, it is important to keep this document consistent with the evolving design, including the DACs.

The PM and project team, including the appropriate level of Systems Engineering support, initiate a draft Verification Plan to identify the methodology and scheduling for verification of all requirements. The plan, developed with the contractor, provides a complete description of requirements to be verified by non-test processes and provides rationale as to why testing is not to be conducted.

The PM directs the development of all I&T Procedures for the System Integration Review (SIR) in Phase C. These procedures are to be consistent with the Requirements Verification Plan, the ongoing Requirements Verification process, and the I&T program.

The PM directs the refining of the cost baseline on an annual basis consistent with the Planning, Programming, Budgeting and Execution (PPBE) process at the Agency level.

The PM leads various elements of the project team to refine, baseline, and execute those formal plans that guide project progress through key milestones. The plans include the Project Plan, CM/DM Plan, Security Plan, Export Control Plan, S&MA Plan, including a preliminary Pre-Launch Safety Package and the preliminary Range Safety requirements and Risk Management Plan, and De-scope Options.

The PM and the project team mature, resource loads, and baselines the master schedule that shows the project critical path and the timing of critical resources, such as facilities, and the need dates for major procurement deliverables. The Master Schedule also shows funded schedule reserve, which is not the same as schedule slack or “float”.

The PM directs the development of a listing of critical metrics to be reviewed within the project and with the customer and MSFC Management as appropriate on a periodic, consistent basis to provide a measurement of project progress against critical milestones.

The PM, the COTR, and the CO establish a process whereby contract changes are properly reviewed prior to enactment, while providing a capability for safe, but expedient changes when circumstances dictate. This includes sufficient resources within the project office, Procurement, and Engineering to process the changes. As well, the PM budgets for the appropriate change processing durations in all of the appropriate project planning.

The PM ensures that the draft Orbital Debris Assessment Report developed in Phase A is refined and released as a preliminary version. As with the draft, the preliminary assessment is consistent with guidelines provided to demonstrate that the project is planning to limit generation of orbital debris while on orbit, depleting onboard energy sources after completion of the mission, limiting orbital lifetime after mission completion (or maneuvering to a disposal orbit), and limiting the human casualty risk from space system components surviving reentry as a result of post-mission disposal.

The PM directs the refinement of critical test efforts and planning with enough fidelity to determine more accurate project costs, and to maintain/iterate this effort as the project matures and as other events that might affect the testing occur. For unique and critical tests, the PM identifies a test lead at this point to follow each critical test, as applicable to the unique project parameters.

The PM directs the development of the PDR Plan, consistent with NPR 7123.1, Appendix G.7 and ensures that all products required for KDP C are completed consistent with NPR 7120.5, Table 4-3. The PM also directs the development of plans for the Standing Review Board (SRB) and the Integrated Baseline Review (IBR) to be conducted after contract award. In most cases, it makes practical sense to combine these reviews into a single review for logistical simplicity and overall project efficiency. Finally, larger projects split PDRs into subsystem or element pieces, and further to component pieces to more easily digest such a design review prior to a larger project-level PDR. The goal of a PDR is to have the initial design complete by PDR so that expert inside and outside parties can review the total design and provide feedback to the project.

The PM takes appropriate action to freeze the project baseline for the conduct of the PDR, SRB and IBR to provide consistency in these reviews. Failure to lock down the baseline prior to a review can result in significant added work and a failure of the review due to the inconsistencies that naturally surface in the review if the design were not frozen and consistent.

The PM, in accordance with the Technology Development Plan, completes the assessment of the project’s technology development requirements, completes the evaluation of feasibility, availability, readiness, cost, risk and benefit of the new technologies, and completes the technology maturation needed to support the project by the end of Phase B. This is a critical milestone prior to commitment to Implementation, and the project shows confidence that all hardware is producible consistent with the appropriate level of TRL maturity.

If required by Agency, Center or Environmental Protection Agency (EPA) direction, the PM performs an appropriate environmental assessment(s).

The PM directs the development of all gate products required for KDP C, consistent with NPR 7120.5, Table 4-3, in preparation for the PDR and ensures that the governing PMC review prior to KDP C is supported. Gate products include JCL estimates, baselined System Level Requirements, Preliminary Design Report, Mission Operations Concept, Technology Readiness Assessment Report, a preliminary Orbital Debris Assessment, plus an Integrated Baseline (cost and schedule) and a Business Case Analysis for Infrastructure. The KDP C review is critical because it is the “go, no-go” review and the impacts of the baselines, including risk, result from PDR decisions. The KPD C review of the technical and programmatic baseline and associated JCL that exists after PDR and is the basis for the KDP C decision. UFE is the funding for reserves and over-runs that also result from the JCL analysis, and that the JCL requires a resource-loaded schedule as a basis of the estimate analysis. It is also important to note that IBR(s) are driven from contract ATP dates, not the PDR schedule.

The PM directs the development of a preliminary Science Data Management Plan if the project yields science.

The PM directs the activities associated with the conduct of the PDR, the SRB and the IBR, in accordance with the PDR Plan and the Project Plan and under the requirements of NPR 7123.1, and ensures that all gate products required for KDP C, consistent with NPR 7120.5, Table 4-3, are complete and available to the review teams.

The PM utilizes the findings of the PDR, SRB and IBR, as appropriate, to establish the cost and schedule baseline for the Earned Value Management (EVM) process. For small projects under the EVM threshold, this milestone sets the cost and schedule baseline for the Implementation Phase, and the project is held accountable for this baseline.

Prior to completion of Phase B, the PM ensures the project’s Safety Review(s) with the next higher level of integration, or with the launch site support organization and with the spacecraft/payload carrier organization, are conducted. The PM provides a safety package per the project’s S&MA requirements which includes an updated assessment of all potential hazards.

For Category 1 and 2 projects, the PM ensures that a CADRe, based on the PDR technical baseline mission concept is developed and is available 60 days prior to KDP C.

The PM baselines IRDs with the spacecraft and its other payloads, if applicable, as an output of the PDR process (including comment/RID incorporation).

Consistent with the gate product requirements for KDP C and the PDR, the PM takes appropriate action to freeze all top-level requirements such that they do not change from this point forward except for any design deficiency found after this point. All “To Be Determined (TBDs)” have been eliminated, and no new requirements for new scope are entertained.

The PM baselines IRDs with Agency infrastructure participants providing support to the project, including the launch vehicle provider and pre-launch operations at KSC or other payload carriers, as an output of the PDR process (including comment/RID incorporation).

With interface requirements baselined, the PM initiates development of Interface Control Documents (ICDs), as needed, with the spacecraft and its other payloads, if applicable. They initiate development of ICDs, as needed, with external Agency/Industry participants supporting the project, including the launch vehicle provider and pre-launch operations at KSC or other payload carriers.

3.1.1.2 Project Approval

The objective of the approval process is to determine whether a project is ready to proceed from formulation activities to the implementation activities. If it is determined that a project is not ready to proceed into implementation, approval for a project to continue in the formulation process may be provided. Approval for a project to continue in the formulation process in which iterative formulation is required, or approval of changes to the Project Plan based on budgetary or technical considerations, may also be provided. The NASA recognizes the need for a certain degree of a project’s technical and programmatic maturity prior to approval into implementation. MPR 7120.1 requires the conduct of Independent Assessments (IAs), and as mentioned above, the IAs support the MSFC Center Management Council (CMC) and Engineering Management Council (EMC) approval process. The findings from the independent review team and the project's presentation containing their response to the review team findings are included in the approval process presentation material. The MSFC CMC provides guidance and direction based on the material presented. Projects schedule a CMC meeting, and the review team and project team will present their material along with any MSFC EMC recommendations. This results in an approved Project Plan and ATP into implementation, or additional formulation activity instructions. For projects under the requirements of NPR 7120.5, the Governing Project Management Council (GPMC) at NASA Headquarters is the DA, and the CMC meeting is merely for informational or recommendation purposes.

Prior to proceeding into implementation, project requirements are continually refined, project planning continues, final make or buy decisions are made, and for contracted projects, funding agreements and types of contracts are finalized.

Items to be considered prior to implementation include types of agreements in which MSFC may engage with foreign nations, academia, industry (including commercial space companies), or other government organizations for the conduct of space or non-space flight projects. The features of these agreements may vary to include ventures in which management and fiscal responsibilities are shared, or situations in which MSFC provides services on a reimbursable basis. (During the early planning stage, added emphasis is placed on a clear and mutual understanding of program definition, authorities, responsibilities, interfaces, and funding requirements. Center resource commitments are to be well planned, coordinated, and approved. Also, a mutual understanding on the extent to which NASA/MSFC management and design specifications and procedures are being applied is needed.

3.1.1.3 Project Implementation

As the project proceeds into implementation, the activity focuses on further refinement and approval of a set of baseline system requirements. Once the system requirements are base-lined, the design activity is initiated, and plans are refined for final development, fabrication, test and operations. The TPMs are updated to include appropriate metrics for the activities during the implementation process. The project implementation process may be divided into phases: the final design and fabrication phase, the system assembly, integrated test, launch and checkout phase, the operations and sustainment phase, and the closeout phase. These phases are defined by the activities being performed during each phase and are described in the following paragraphs.

3.1.1.3.1 KDP C to KDP D: Phase C - Final Design and Fabrication

Design and development is the process of converting design and performance requirements and concepts into a set of Computer-Aided Design (CAD) drawings that are manufacturable, and eventually into a collection of subsystem components and required software that are integrated into a functional system. The MPR 7120.1, *MSFC Engineering and Program/Project Management Requirements,* provides the MSFC policy and procedures to be followed in controlling the design during implementation, specifically in Chapter 6, “Design to Cost,” and Chapter 13, “Systems Engineering and Integration.” In addition, MPR 7123.1, MSFC Systems Engineering Processes and Requirements, provides the MSFC policy for implementing the 17 systems engineering processes. The early period of design and development is devoted to the fostering of a mutual understanding with the contractor or in-house team of requirements and plans, technical and schedule risks, cost estimates, and other matters.

Depending on the complexity of the project, the project plan may require more detailed plan(s) to define and schedule the design and development activities. For contracted projects, the initial version of this plan is typically submitted by the contractor with the proposal. This plan can be useful in the development of a mutual understanding of the total design and development process. Prior to the completion of contract negotiations, all project requirements and plans are as complete and detailed as possible. Also early in the design and development phase, prior to the PDR, manufacturing and materials and processes control plans are prepared. To help assure producibility, it is important that personnel with manufacturing skills are involved in the design effort. The Materials & Processes Selection, Implementation, and Control Plan delineate the manner in which the contractor meets the requirements imposed by MSFC-STD-506, *Standard Materials and Processes Control*. The Manufacturing and Assembly Plan specifies the tooling, facilities, schedule, critical processes, and the scheme for subsystem and final system assembly.

The design of a flight system evolves as system architectures are defined in more depth and refined by system analyses and trade studies. Design and development progress is tracked by a well-defined series of reviews. During this process much of the project resources (time and dollars) are expended, many of the problems surface, and, to a large degree, eventual success or failure of the project is determined. It is during design and development that many techniques and tools discussed elsewhere in this handbook are implemented. This design evolution begins in the late formulation phase with the baseline of systems requirements and initiation of preliminary design through the development of CAD models. This design activity includes the process of functional analysis and requirements allocation, the accomplishment of trade studies and optimization, system synthesis, and configuration definition in the form of top-level specifications. Software requirements refinement begins in formulation and extends to late in the implementation phase for the final builds. Software requirements may be impacted by any changes in system requirements. Software development is separate but closely related to the system development. Once the system functions are allocated to hardware and to software, the software implementation process begins. As the preliminary design continues into the early implementation phase, the emphasis of the design analyses and trade studies shifts from the requirements definition to proving that the design meets the requirements. The preliminary design process allows the CAD models used for analyses to be defined more realistically. This process is iterative as CAD models are constantly improved. The outputs of the analyses that use these CAD models are applied in the refinement of the design. Throughout the design and development phase, project risk assessments are evaluated and any new risks identified are documented and incorporated into the risk management process.

Detail design begins after assessment of the preliminary design and approval of the design approach. Design margins are allocated for each system and subsystem. During the detail design process, systems engineering analyzes system allocations (e.g., mass properties, electrical power) to ensure compliance with system requirements and design margins are maintained.

As the design evolves, the subsystems, boxes and components are examined through analyses and trade studies to determine the effects on the total system. The design becomes more refined as analyses, utilizing CAD models that incorporate the refined designs, verify the performance of the system as designed. Detailed mathematical analysis models determine if the system, as designed, meets the systems requirements. Tests of critical technology are conducted to verify the design and model’s accuracy. Through this iterative process the CAD models become more refined and confidence is gained that the results from the analyses are accurate. System design drawings, schematics, and interconnect diagrams are maintained current with design refinement to aid the analysis process. All equipment and hardware items are specified. The CAD models and engineering drawings for component fabrication and acquisition are completed as designs are refined.

A prototype of a flight system or a subsystem may be developed if feasible and cost effective to build one-of-a-kind full scale hardware to check performance, human engineering, fit and installation, and the physical operating range of moving elements. The prototype hardware can be used to verify the flight software if sufficient hardware is developed.

The PM ensures that contamination control planning, if required for the project payload or if the system contains optics, is complete and that a Containment Control Plan is in place and is being followed at the start of the manufacturing and assembly phase.

The production of an end item which meets project requirements and mission objectives is a milestone in the overall systems engineering process. Production planning and production capabilities are factored into the system design from the beginning of the project if the activities are to be cost effective. Consideration is given to production functions such as materials and materials usage, processes, process control, integration and assembly initiation, testing, preservation, packaging, storage, shipping, and disposition of unused materials. Early and continuous consideration is given to these production functions in trade studies, cost analysis, risk management, schedules, and other products of the systems engineering process.

As design is completed and CAD models and drawings are released, fabrication of piece parts of the project begins. Earlier make or buy analysis has been accomplished, and decisions on whether fabrication will be performed in-house or by the project contractor have previously been made. Concurrent engineering has ensured that the drawings have properly identified the materials, processes, and quality sensitivity of the items to be produced, and that fabrication facilities have properly ordered the materials and scheduled the fabrications. During this period, the responsible design engineer follows the fabrication progress and assists the fabricator when any production questions and/or issues arise. The software is developed through coding and testing after the CDR. This level of testing is commonly referred to as “debugging.” Design engineers, systems engineers, and configuration managers assess to make any adjustments to design if necessary. The Project Configuration Management Plan has identified the change process to be followed. Thorough early coordination and analyses will minimize required changes during the fabrication process; however, if changes are needed, Change Requests (CRs) with Engineering Orders (EOs) are typically used to document proposed changes. Floor Engineering Orders (FEOs), which require minimal approvals prior to manufacturing implementation, may be required in order to support the fabrication schedule. Since FEO changes may preclude thorough analyses prior to their incorporation, FEOs are kept to a minimum. Where possible, CRs/EOs are used instead of FEOs for design changes. FEOs are used for emergency purposes only. Even if an FEO is issued, a CR/EO is initiated as follow up to release the design change. The system analysis of proposed changes during this phase is important to ensure that any last minute changes will not adversely affect the overall function and performance of the system.

System performance analyses continue during this period to finalize mission planning and to ensure that all mission aspects have been analyzed and integrated. Safety analyses are continually worked to ensure that the proper mitigations have been established and recorded in the proper form. Verification planning is finalized, and tests planning procedures are prepared. Software test reviews may be scheduled at the conclusion of software coding and debugging, to assure conformance to test requirements and plans in the subsequent verification, validation, and system integration tests.

The PM directs the activities associated with the conduct of the CDR in accordance with the CDR Plan and the Project Plan, under the guidance of NPR 7123.1. This includes the conduct of lower-level CDRs for flight article components, assemblies and/or subsystems and the initiation of fabrication/procurement activities as appropriate and the initiation of qualification and acceptance testing of these items. Development of all products associated with the CDR is the PM's responsibility, including all flight and ground analyses, CAD models, and drawings associated with the CDR, and the development of a baseline Safety Analysis Package. The PM baselines the Mission Operations Plan (MOP) following its reiteration and finalization earlier in Phase C. A timely point to baseline is after the CDR and incorporation of any comments received. Also the Science Data Management Plan is to be finalized if the project yields science.

The fabrication process is one of the critical final steps during which hardware is acquired (either manufactured in-house, contracted out-of-house, or purchased off-the-shelf).

The PM and project team lift the CDR design freeze to allow the Verification Analysis Cycle to begin, taking into account the results of the CDR, and the matured project operation, mission concepts, and project baseline, utilizing the same methodology that has been used in earlier versions, consistent with the structural verification planning. Note that it is generally appropriate to limit the Verification load cycle to a single cycle if at all possible. It is the most mature load cycle, and can allow less margin in the loads compared to earlier loads cycles due to the uncertainty of. The analysis as part of this cycle is used to close all appropriate structural requirement verifications.

The buildup of the Avionics Test Bed, which is used to verify the avionics as part of the overall verification and validation process, is started. Depending upon the size and the overall schedule of the project, this time soon after CDR is generally the time at which the test bed is getting assembled, integrated and certified prior to use. Further, the project begins to formulate detailed test requirements for testing to be performed once the facility is certified for use. Long term use can include a software patch or update validation capability during the flight operations phase, assuming that the operations phase duration is commensurate with this uplink capability.

Prior to the SIR, the Project's Safety Review(s) with the next higher level of integration, or with the launch site support organization and with the spacecraft/payload carrier organization, are conducted per the Project's S&MA requirements. The PM provides a safety package prior to the CDR which includes resolution of any previous issues and an assessment of any new potential hazards identified as the project matures.

For Category 1 and 2 projects, a CADRe, based on the PDR technical baseline mission concept is updated following the CDR.

With interface requirements baselined, ICDs are baselined, as needed, with external Agency/Industry participants supporting the project, including the launch vehicle provider and pre-launch operations at KSC or other payload carriers. The timing for the baselining corresponds to the CDR and any comments obtained from the review.

The PM directs the development of I&T Procedures in preparation for the SIR. The test procedures are developed, consistent with the Project Verification Plan, to demonstrate that the test procedures address the role of the I&T program in verifying requirements by test. The integration procedures are developed with sufficient detail to fully integrate the hardware into its final system configuration.

Ten percent (typical) of design drawings unfinished at the CDR are finalized and released following the CDR and all design drawings are maintained under configuration control. This 10% does not include any major or significant system design features. At this point, the functionality of the hardware is already checking out, and the 10% is to account for minor closure of the design. The project determines what drawings are included in the 10%.

The development of a Software CDR Plan, consistent with the guidelines established in the Project Plan, is prepared for the software design review process. All supporting documentation reflecting the maturity of the project is completed and available to the review team. An iterative reassessment of the projected software delivery dates is performed to assure that the completion schedules from the software CDR are consistent with the I&T program's needs. The Project Test Plan and Flow, and/or the Logistics Plan iterated and developed earlier in Phase C is baselined. Generally, this plan is completed and in place at the SIR so that the project can phase into the I&T phase smoothly and without delay.

The PM directs the development of the SIR Plan, consistent with NPR 7123.1, Appendix G.10 and ensure that it demonstrates clear processes for payload integration into the spacecraft. Since the SIR typically indicates the boundary of Phase C, the PM also ensures that all products required for KDP D are completed consistent with NPR

7120.5, Table 4-3, and that the governing PMC review prior to KDP D is supported. These products include a baselined Pre-Launch Safety Package, a baselined Design Report, a preliminary Mission Operations Handbook, a baselined Range Safety Risk Management Plan, and a preliminary Systems Decommissioning/Disposal Plan.

Per the requirements of NPR 7123.1, Appendix G.10, all payload integration procedures are finalized, including mechanical and electrical interfaces, integration facilities, ground support equipment, etc., and verification that all qualification testing has been conducted successfully. All I&T procedures previously developed for the SIR are finalized consistent with the Requirements Verification Plan, the ongoing Requirements Verification process, and the I&T program. Early payload integration procedures are baselined upon completion in preparation for the SIR so that there is not a discontinuity in work as a result of the SIR. Therefore, those procedures that are planned to occur very soon after the SIR are completed and baselined prior to the SIR.

The PM, with the S&MA team and appropriate Systems Engineering support, finalizes all Flight Safety Hazard reports, focusing on the flight safety aspects, such as hazardous sharp edges, off-gasing materials, in-flight pyrotechnics use, etc. that represent a safety hazard to the flight crew as they perform in-flight handling and deployment of the payload. They also finalize all Ground Safety Hazard reports, focusing on the ground safety aspects, such as hazardous material handling (e.g., fuel, oxidizers, lubricants, batteries, etc.), pyrotechnics, Electromagnetic Interference (EMI) limits, radiation, grounding, launch abort/range safety, etc., that represent a safety hazard to the hardware handlers as they process the hardware for flight and early launch phase. The early I&T Procedures previously developed for the SIR are baselined so that there is not a discontinuity in work as a result of the SIR process. Therefore, those procedures that are planned to occur very soon after the SIR are completed and baselined prior to the SIR. As with the process of finalizing the procedures, the PM assures that they are consistent with the Requirements Verification Plan, the ongoing Requirements Verification process and the I&T program.

The Avionics Test Bed is completed and a formal acceptance/certification task performed to show readiness of the test bed for use during assembly and integration of the avionics subsystem, including the requirements verification process, short- and long-term use for subsystem and system level troubleshooting and as an aid to in-flight anomaly assessments. In addition to performing hazard analysis, on a payload, hazard analysis is also covered for a launch vehicle, payload, and test. Hazard analysis processing is done throughout the launch phase to the recovery phase.

The PM ensures that a Program Critical Hardware (PCH) list is finalized, that all listed hardware is maintained under configuration control and that unused hardware is maintained under a bonded storage process if it has possible future application to the project. Since PCH hardware is treated with a higher level of protection, rigor and cost, the PM strategically defines and rationalizes PCH as the subset of flight hardware that is most critical to the project. MWI 6410.1, *Packaging, Handling, and Moving Program Critical Hardware* provides additional guidance for PMs as to what hardware to designate PCH.

The findings of the SIR are utilized to reassess the cost and schedule baseline, reassess the Threat List consistent with SIR findings and recalculate Cost-To-Go and Estimate at Completion (EAC). If the contractor is required to utilize EVM, this baseline is also adjusted based upon the SIR.

All remaining payload integration procedures are baselined upon completion of the SIR and all remaining I&T Procedures previously developed for the SIR. These procedures are consistent with the Requirements Verification Plan, the continuing Requirements Verification process and the I&T program.

3.1.1.3.2 KDP D to KDP E: Phase D - System Assembly, Integration and Test (I&T), Launch and Checkout

In this phase, the focus is on the assembly, integration, and testing of the system. Phase D culminates in the system launch and checkout. The main activities include physical and analytical systems integration and verification and validation of the system. In addition, operations personnel undergo initial training and logistics, and spares planning commences. Prelaunch integration and launch are a main focus for flight activities. By the end of Phase D, the system is capable of achieving its mission.

Upon successful completion of the SIR, reassessment of the cost and schedule baseline for the EVM process, reassessment of the Threat List consistent with SIR findings, recalculation of Cost-To-Go and EAC and the baselining of all remaining payload I&T procedures, the PM authorizes initiation of the Payload Integration process, including assembly and test. As piece parts and components are produced or acquired, assemblies are initiated. As assemblies are produced, close coordination with verification requirements and procedures are necessary to ensure the proper performance and fit of the assemblies. The assembly of subsystems into a system is accomplished as components become available, and as planning schedules dictate.

Systems integration takes place to ensure that the various segments, elements, and/or subsystems of a functional entity are in accordance with systems requirements and will properly function as a total system. Systems integration also ensures proper internal and external interfaces. Systems integration is both an analytical and a physical process and encompasses all elements associated with the project, including the flight system, software, ground systems, associated launch interfaces, and mission operations. The process begins with the interface definitions arising from the design concept and may not be completed until on-orbit operations in some cases. As subsystems become available and are verified as called for at that level, they are transported to the location for integration into the final assembly where total system verification is accomplished.

The analytical integration process is comprised of the design integration analyses that ensure the various components, subsystems, and associated external systems interface and function together as required. The physical integration is the assembly of all piece parts, components, subassemblies, and subsystems into a functional entity. The physical integration of subassemblies and subsystems may occur at different locations, with final integration at an integration site or at the launch site.

A program establishes and implements analytical and physical integration processes for integration of multiple systems of a program. The processes are similar to the processes for systems integration. System external interfaces, driven by program design, are ensured during systems integration. Physical integration of the program systems generally occur at the launch site, but for a major payload the integration may occur at an integration site.

At this point, the PM ensures that the verification closure process is running smoothly and the data is flowing to the reviewers as planned. This takes a good bit of diligence and attention as time goes on, and it is important for the PM to keep the pressure on the Systems Engineering Team to keep the data flowing. Data utilized in this process may come from tests, analyses, or inspections, and it is critical that all discrepancies are resolved.

Verification is a process in which defined activities are accomplished in a manner that ensures a product meets its design and performance requirements. The planning, definition, and execution of a comprehensive verification program are essential to the success of a project. The basis for the verification process is the product's requirements. A verification program is established through in-depth verification: planning, requirements, success criteria, procedures, and compliance data. For MSFC managed projects, MSFC Management System MPR 7123.1, *MSFC Systems Engineering Processes and Requirements*, must be followed in the development of verification programs. Additionally, MSFC-HDBK-2221 Volume I, *MSFC Verification Process Handbook*, provides guidance and examples in developing verification programs. The verification process begins in the early phases of a project with planning activities that outline the verification approach and organizational structure for implementing the verification program. For a system verified by test, testing procedures based on the verification requirements are generated for each test. Flight software is subjected to Independent Verification and Validation (IV&V).

Hardware and software are brought together for systems integration testing and software validation. (Software validation is systems integration testing with emphasis on assuring software performance within the system environment.) The data resulting from a test is assessed to ensure all verification success criteria have been met. The results of the testing are documented in a test report that, along with the test data and as-run test procedure, becomes the compliance information that is documented as showing flight system performance is in compliance with system level design and performance requirements and with verification requirements. The verification process is completed when compliance to all verification requirements is documented. For some projects, verification compliance may not be completed until on-orbit operations.

Verification functions are further discussed in paragraph 4.2.2.2.

As the program transitions from design to assembly and test, the PM ensures that the manpower roll-off profile is adhered to as the design effort is completed and the system integration/assembly and test program is initiated. Note that project cost overruns can escalate quickly if the manpower roll-off process is not addressed in a timely manner.

With launch and operations on the horizon, the PM ensures that the Operations Control Center (OCC) is completed and ready to support mission simulations and for participation in the systems level testing as appropriate. Operations personnel are encouraged to participate in test planning and to be partners in the review of I&T procedures to assure familiarity with the payload operations.

The PM ensures that measurable mission success criteria are developed, are agreed to by all stakeholders, and are recognized by Center- and Agency- level management. These criteria establish threshold levels that define a fully successful mission, as well as the minimum acceptable levels of performance, below which the mission is classified as a failure. While these measures are usually defined at a high level within the Project Plan, a more detailed, measurable set derived from those in the Project Plan is appropriate.

The PM ensures that measurable Launch Commit Criteria are developed. Typical items to be considered to determine launch commit criteria include the launch vehicle, pad, environment, team, and range safety. The launch vehicle is concerned that all flight systems are configured for launch. It is also concerned that critical functions that are of sufficient critically be within upper and lower limits defined as go/no-go items. The environment includes the launch area and alternate weather constraints. The launch team includes mission operations and both are ready for launch.

The PM, in concert with the system test program initiated following completion of the SIR, reiterates the test schedule with Center management and external organizations as appropriate, to ensure that each test facility required by the test program is ready to support the testing as needed, that all support equipment utilized by those facilities has a calibration program in place to provide certified operation, and that each facility can provide qualified operators.

As part of the test campaign, the PM, Chief Engineer, and the Systems team, in conjunction with the discipline leads and the Mission Ops team, ensure that a set of off-nominal test cases are defined to be later run on the spacecraft. This set of test cases complements the nominal mission timelines and activities to demonstrate the performance of the design to respond to off-nominal situations that may arise during deployment, or flight operations of the spacecraft or payload following launch. Care is taken in designing the off-nominal tests to avoid damage to the payload.

Upon completion of the physical integration of the payload, the PM ensures that a full baseline functional test is performed to establish a baseline expectation for spacecraft and/or instrument health and to determine that the payload performance is as expected. The functional test is repeated following additional system level testing and prior to each subsequent environmental test. Note that for some projects, the functional performance baseline test may include such things as focus checks, alignment checks, or other unique tests that demonstrate payload, spacecraft, or instrument health. Avoid the use of non-flight hardware/software during functional testing, if possible. Any non-flight hardware/software installed in the payload at the time of functional testing is addressed to determine the need for and degree of additional testing when the flight equivalents are available. The test is conducted utilizing the OCC if practical, to give the most experience and exposure to the flight operations team. If this is not possible, and the test is conducted utilizing other command/control equipment at the location of the test, OCC monitors the functional test to the maximum extent possible.

The PM and the project team oversee the conduct of environmental testing, per approved Test Procedures, for Thermal/Vacuum (T/V) and other environments as required, in which the payload will be exposed to the operational environment of space. Personnel involved in the Avionics Test Bed activities provide assistance during system environmental testing, and apply the results to the Test Bed operation to enhance support capabilities for future in-flight anomaly management. Typically, some form of the Baseline Functional Test is run at both the hot dwell and cold dwell cycles while in

T/V testing. Some types of instruments can only be run in T/V and these are exercised as the final proof of integration success for those instruments.

The PM ensures that a rigorous, robust Mission Operations Simulation program is developed and conducted successfully. This program complements the training that mission operations personnel have received by allowing them to be involved in command uplink/data downlink activities associated with nominal operations of the payload, and provides the needed familiarity with the operations of the payload under simulated mission scenarios. Simulations include activities associated with the pre-launch, launch, deployment, initial operations and checkout, and sustained operations segments. The program includes repeat scenarios so that all mission operations personnel are adequately involved, and includes shift-change handover simulations. These simulations occur from this point until launch, and also address failure scenarios that might occur that stress the Mission Operations Teams.

The PM provides to the Launch Site Support Manager (LSSM) all procedures associated with the handling of the payload at the launch site, from receipt at a support facility through integration into the launch vehicle. These procedures identify safety-critical tasks where both the safety of the payload and the safety of personnel performing the work are paramount. These procedures complement the Project's Safety Analysis package submitted to the LSSM. In addition to performing hazard analysis on a payload, hazard analysis is also completed for a launch vehicle, payload, and test.

The PM and the project team ensure that the environmental testing is completed successfully. Great care is given to accurate and expeditious analysis of test results, as it is very expensive to have to repeat any portion of the testing after the payload is removed from the environmental test fixture. Many requirements are verified as a result of successful completion of environmental testing, and the applicable data is reviewed and verified prior to test equipment disassembly. Successful completion of environmental testing is a major project milestone.

Upon completion of the environmental testing, the PM ensures that a Post-Environmental full baseline functional test is performed and that the results are as expected based on the initial full functional test. Assuming that no hardware/software changes are made during the mission simulations and off-nominal test cases that follow this baseline functional test, this test may serve as a pre-ship functional test, and will be repeated (in some form) at the launch site with a post-ship functional test. The test is conducted utilizing the OCC in a command/control function.

The PM ensures that one of the key elements of the design verification process, the "day in the life" of the payload, is conducted successfully on the flight hardware using the latest flight software. This simulation test (sometimes called "Day in the Life" or Mission Sequence Test) provides a "dress rehearsal" for routine operations, and is a full 24-hour multi-shift activity supported from the OCC, including shift-handover activities, development, validation and uplink of command loads (if required), conducting science with appropriate data downloads (if required) and processing of engineering data downloads. The success of this test is critical, and any evidence of weakness detected in equipment or personnel is to be addressed immediately. Typically, if successful mission operations simulations have preceded this dress rehearsal, very few problems occur.

Once the Post-Environmental Full Functional test is complete, the PM ensures that the mandatory off-nominal test cases developed earlier are executed on the spacecraft. These tests are formal, and repeated until successful, with the procedures and results documented for future application. In most projects, there is usually a second set of cases that are not deemed as critical or mandatory, but is run on the flight system on an as-available basis. In any event, all of these test cases are run on the avionics test bed, and the OCC is fully engaged to follow the activities.

The PM directs the activities associated with the development of the System Acceptance Review (SAR) Plan in accordance with the Project Plan and the entrance and exit success criteria defined in NPR 7123.1, Appendix G12. As well, even though it is always the goal to have 100% verification closure, it is hardly ever practical to have them all closed at this point. Some strategy is needed to determine how high a percentage of verification closures (and open RIDs, actions, etc) is adequate prior to this review as documented in the SAR Plan.

Prior to the Pre-Ship review (usually conducted with the SAR), the PM ensures that the final level of integration, or with the launch site support organization and with the spacecraft/payload carrier organization, are conducted. The PM provides a baselined safety analysis package prior to the launch provider's Ground Operations Review (GOR) which includes verification that all safety requirements have been satisfied, or will be satisfied at the appropriate time, that any associated waivers have been approved, and provides the Safety Verification Tracking Log identifying any open verifications from the Hazard Reports.

The PM finalizes the measurable mission success criteria developed earlier in Phase D, and secures full agreement of these criteria by all stakeholders, including Center and Agency management. These criteria establish threshold levels that define a fully successful mission, as well as the minimum acceptable levels of performance.

Upon successful completion of the first set of Mission Operations Simulations and with the SAR preparations ongoing, the PM refines the mission Cost-To-Go and Mission Operations costs. The Mission Operations Simulations provide verification that initial projections of mission operations costs were accurately forecast. If significant differences between cost projections and actuals exist, Estimate at Completion (EAC) numbers are adjusted. Similarly, any adjustments to EAC for the project phases E and F are refined at this time.

The PM directs the activities associated with the conduct of the SAR in accordance with the SAR Plan and the Project Plan, consistent with NPR 7123.1, Appendix G12. In most cases, this review is combined with a Pre-Ship Review, but doesn't necessarily have to be linked. (A Pre-Ship Review establishes the status of the hardware, software, plans, logistics, and procedures for shipment.) Typically, a list of ship constraints is generated at this review (assuming that it is combined) and then burned down to get to the actual ship event. Also, even though it is always the goal to have 100% verification closure, it is hardly ever practical to have them all closed at this point. Some strategy is needed to determine how high a percentage of verification closures (and open RIDs, actions, etc.) is adequate prior to this review as documented in the SAR Plan. A successful conclusion of the SAR portion of the review ends with the signing of the Department of Defense Form 250 (DD250) document which turns over responsibility of the hardware to the government, which can be MSFC or KSC.

Following completion of a successful SAR, the PM and the program manager review the EPO products developed for pre-launch and ensure that they are available for release, that they meet the guidelines of NPR 7120.5, Section 3.15, and that they are released to the public at the appropriate time.

The PM ensures that the MOP is finalized prior to execution. This plan (or equivalent) discusses the Flight Operations Teams as well as Technical Engineering support necessary during the checkout or commissioning of the spacecraft or payload, as well as the Management Team to be in place for launch, ascent, and orbital operations. This includes the names of all operations personnel, their roles and responsibilities, and identification of logistical needs, including floor space, console usage, tools, shifting, certification (if required), etc. It addresses all orbital phases including launch/ascent, orbital checkout/commissioning, and normal operations. All operators requiring certification are to be certified at this point.

The PM, following the SAR and in preparation for the Flight Readiness Review (FRR) and completion of Phase D, defines, and with the COTR and CO, establishes contract performance criteria based on mission success (if applicable). The ongoing completion of performance requirement verifications provides ample criteria for expected spacecraft, instrument, or payload performance on orbit, and produces mission success criteria acceptable to the government and the contractor. Since significant contractor fee could be involved, it is important to make these criteria as quantitative and measurable as practical.

The PM ensures that the payload, upon completion of environmental and pre-ship functional testing, is transported safely to the launch site or to the next higher level of integration, as appropriate. The physical integrity of the payload is preserved, and the PM determines the need for monitoring environmental exposure and control. The shipping mode, route, and logistics have been reviewed by the PM and the Transportation Team to assure that all potential safety hazards to the payload and to personnel handling the payload have been eliminated or minimized. A “pathfinder” or test case of the shipment of the payload may be utilized if appropriate.

Upon delivery of the payload to the launch site facilities, the PM ensures that a final full baseline functional test is performed and that the results are as expected based on the previous functional test which followed environmental testing. This test is conducted in the identical manner as the pre-ship (or post-environmental) functional test, using the full OCC capability if practical.

The PM ensures that all safety-related verifications have been closed prior to the initiation of integration of the payload into the launch vehicle or into the next higher level of integration. This process includes completion of all appropriate safety verifications and providing evidence of closure to the LSSM or next higher level integration manager, as well as completion of all procedures associated with the handling of the hardware at the launch site, from receipt through integration into the launch vehicle. Verifications address all safety-critical tasks where both the safety of the hardware and the safety of personnel performing the work are involved.

The PM and the launch site support team, or the next higher level integration team, ensures that the payload is successfully integrated into the launch vehicle or spacecraft. This process is completed in preparation for the end-to-end testing exercising all uplink/downlink communication assets. Integration procedures have been developed and approved utilizing the LSSM and the Launch Site Integration Team. All potential safety hazards associated with payload integration have been addressed and eliminated or minimized prior to initiation of the integration process.

The PM, project team and the Mission Operations Team ensures that a full end-to-end test exercises the spacecraft, the payload (if applicable), all mission operations equipment and all communications assets. This test is designed to demonstrate readiness of all project entities associated with the launch, deployment and initial operations are ready to support the launch.

The PM ensures the completion of the iterative process of closure of performance verifications in accordance with the Requirements Verification Plan, utilizing the appropriate level of Systems Engineering support, assuring that the I&T program has provided the required data for closing out performance requirements verified by test, and that all requirements verified by non-test processes have been sufficiently analyzed and documented to assure acceptance.

The PM directs all activities associated with the development of the FRR Plan in accordance with the Project Plan and the entrance and exit success criteria defined in NPR 7123.1, Appendix G12, including approved launch plans, and ensures all gate products required for KDP E, consistent with NPR 7120.5, Table 4-3, are complete and available to the review teams, and that the governing PMC review prior to KDP E is supported. The PM ensures that all “as-built” and “as-deployed” hardware and software documentation is complete, including “close-out” photo/video products.

Following completion of a successful integration of the payload into the spacecraft or into the next higher level of integration, the PM and the program manager review the EPO products developed for the mission and ensure that they are available for release, that they meet the guidelines of NPR 7120.5, Section 3.15, and that they are released to the public at the appropriate time.

The PM participates in all activities associated with the conduct of the FRR in accordance with the FRR Plan and the Project Plan, consistent with NPR 7123.1, Appendix G14, and ensures all gate products required for KDP E, consistent NPR 7120.5, Table 4-3, are complete and available to the review teams. The PM polls the project team, the contractors (if required) and the engineering discipline owners to certify to the FRR Board that the spacecraft/payload is ready for launch and operations. Numerous other reviews are required prior to launch, and the PM commits payload readiness, as required, in each of these.

The PM commits the payload to launch during the final pre-launch polling of the launch team. This entails conducting a final assessment with the project team and the contractors (if required) in order to make the launch commitment. Phase D culminates in the launch of the payload.

3.1.1.3.3 KDP E to KDP F: Phase E - Operations and Sustainment

Implementation of this phase begins immediately following launch. During launch operations, the flight system is prepared for shipping to the launch site for integration into the launch vehicle, or to some other site if the item is to be integrated with another spacecraft. Simultaneous with the shipping and final post-shipping and integration testing, the mission operations preparations are finalized. Final project reviews including the FRR are conducted and launch is approved.

During on-orbit operations, the mission is executed. The execution of on-orbit operations begins with liftoff of the launch vehicle and consists of all of the in-flight activities necessary for the flight article to perform its intended mission. This may include a period of subsystem checkout, whereby all of the subsystems are powered and checked out and scientific payloads are calibrated. There may be both flight system stand-alone operations and operations associated with the launch vehicle. On-orbit operations may vary from the project being autonomous (requiring no ground or flight crew intervention) to requiring continuously active flight or ground crew operations for commanding the flight system and receiving and processing flight system data. The PM ensures that the Mission Operations activity is being performed as planned and described in the MOP.

As the project transitions to the Operations phase, the PM ensures that the manpower roll-off profile is adhered to as the launch, deployment, and initial operations effort is completed, and the Mission Operations activities assume the majority of the project work. The PM also prepares to enact significant staff reductions as the project enters Phase E, including the possible replacement of the PM. It is essential that the PM has mentored a deputy to possibly assume project leadership.

If applicable, the PM ensures that the element/spacecraft/payload undergoes a thorough checkout of its systems during the first part of orbital operations. During this phase, the science/payload operations can be performed on a non-interference basis, ensuring that this phase can be completed within the shortest timeframe practical before turnover to science or payload or to “nominal” operations.

The PM ensures that the Ops Team has a rigorous process in place to document, work, and close flight anomalies and problems. The temptation during this time is to get caught up in the various activities and pressures such that loss of focus and detail could hurt quick recovery from issues. Therefore, it is important to have a rigorous, formal method in place at the start of flight operations to capture the issues and work them expeditiously, including an adequate sustaining engineering workforce.

One of the most important parts of the mission operations is the data collected from the mission. Data may either be collected and stored for post mission analysis, or transmitted to ground collection and distribution sites during the mission. Many missions require that data be collected during the mission and analyzed for system performance and/or science data. The PM ensures that data collected during orbital checkout is carefully planned beforehand so that the checkout phase goes as smoothly as possible. This data is used to determine performance of the carrier/spacecraft, and therefore, mission success, and could be used for contract performance evaluations and fee determination. There is no real-time determination of specific data items needed to evaluate unless there are failures that require more focused data.

The PM balances the need during the orbital checkout phase between the spacecraft or payload subsystems against the science desire to operate as soon as possible. Persistence to ensuring a thorough checkout early during the mission allows for shorter and smoother science operations or “normal” operations if an anomaly occurs and can help in understanding idiosyncrasies with the spacecraft that would not normally have shown up until later, thereby having a disproportionately bigger schedule impact in the mission.

The PM takes every opportunity during early operations to keep public visibility of the project and to take proactive steps to properly communicate any flight difficulties. If things are going well, the PM acts as a “staunch public advocate” of the mission. If things are not going well, the PM is the calming, sage NASA technical spokesman to prevent unwarranted negative attention.

Once orbital checkout is complete, the PM updates the operations cost as part of the total cost-to-go calculations. There may be unanticipated additional personnel or hardware/software that becomes required based upon activities during the orbital checkout that are reflected in the cost picture for the project. In addition, the PM ensures that the engineering system performance is documented in the Mission Report. All pertinent data has been collected during the orbital checkout for this report consistent with NPR 7120.5, Section 4.8.2 (1) and (2).

In a small set of possible projects, the spacecraft may have the ability to take action to avoid orbital debris. If the spacecraft has this capability, the PM and the mission operations team ensures that the orbital environment is being monitored for potential conjunctions with other space objects per NPR 8715.6, Section 3.4. In the case that there are possible future conjunction events, these (and corrective actions) are communicated to the program/HQ as soon as possible for increased situational awareness and coordination with other U.S. government entities.

Based upon a solid performance baseline during orbital checkout, the PM makes an initial assessment of Mission Success and communicates this to the program and HQ. While the final assessment cannot be made until the end of the primary mission, an initial assessment gives NASA managers information for future planning if change of direction or resources is needed.

For Category 1 and 2 projects, the PM ensures that an updated CADRe (parts A, B, and C), based on the “as-built” baseline, has been developed and is available 180 days after launch.

Some Contracts may have significant Award Fee contingent upon mission performance. If this is the case, the PM plans the data collection during orbital checkout sufficient to characterize award fee. It is expected that the PM carefully defined Award Fee criteria as quantitatively as possible so that this determination can be straightforward and non-controversial.

Documenting lessons learned for use by future projects is a contributor to continued mission success. Depending on the size and scope of the project, lessons learned can either be a stand-alone deliverable or part of a Mission Report. In any event, the PM ensures that all aspects of the project undergo an assessment of lessons learned for potential use by future projects.

Depending upon mission type, the PM ensures that a Critical Event Review is performed prior to the actual flight event. This usually occurs for major orbit burns, planetary encounters, etc. These reviews are important to act as forcing functions to ensure that everything is prepared and the Mission Ops team is prepared for the encounter.

One of the main time-consuming tasks post-launch within the project office is the disposition of documentation prior to and post End of Mission (EOM). The PM does this prior to closure of Phase F, but it is suggested that the PM begin this activity as soon after post-launch and post-orbit checkout as possible.

Assuming that things have gone well during the primary mission timeline, the PM proactively advocates the need for extended operations to the program and to HQ, as well as supports the analysis that would justify such a decision.

If applicable and at least 6 months prior to EOM, the PM, and the mission operations team develops a Systems End of Mission Plan (EOMP) per NPR 8715.6, Section 2.2.2, and NASA-STD-8719.14 to describe the decommissioning/ disposal process, providing information and planning for how the spacecraft will be dispositioned at EOM. This can either be via active deorbit, or simply a managed shutdown of spacecraft subsystems. This plan may be formalized through an End of Mission Review (if applicable).

Just prior to the EOM, the PM provides a final assessment of the mission's success, including any additional information that quantifies the benefits received from any extended mission phases. This assessment is provided to the program and to HQ for future use.

As a more formal identification to the larger community, the PM declares EOM after the spacecraft has completed its primary and any extended or secondary mission phases. Note that this does not actually include the dispositioning of the spacecraft, although in some cases this can be rather immediately after declaration of EOM.

The PM and the project team ensure that all products required at KDP F have been incorporated into a Project Gate Products Maturity Matrix per NPR 7120.5, Table 4-3 and that the governing PMC review prior to KDP F is supported.
The activities typically occurring during mission operations and products of these activities are shown in Figure 3.2.

3.1.1.3.4 Phase F: Closeout

For project flight systems returned to Earth in a controlled manner after flight, ground operations processing also includes the process of de-servicing, de-integrating, and returning the flight systems to the site where they re-enter processing for another launch or are otherwise dispositioned. For payload projects, in the event that the payload and/or payload carrier requires reconfiguration or refurbishment, the payload is returned to the integration site or developer's facilities for these activities. Other hardware will be stored until final disposition is determined. In order to ensure orderly disposition of project assets, the PM implements the Systems Decommissioning/Disposal Plan, which may be formalized through an EOM Review (if applicable).

Prior to and during the hardware de-integration activities, the hardware is inspected for general condition and failures or anomalous conditions. Flight anomalies may require some limited testing of the system prior to complete de-integration. The condition of the hardware is carefully observed and documented at completion of the de-integration activity.

Another post-mission activity is the processing of engineering and science data that are typically collected during a mission. In some cases data are retrieved post-mission. Data are processed and distributed for analysis as soon as possible. The PM, the Mission Operations Team, and the Science Team ensure that analysis and archiving of mission and science data and curation of any returned samples has been completed, and this activity may be formalized through a Final Archival of Data Review (if applicable). In addition, the PM ensures that project engineering and technical management data and documentation has been archived in accordance with NPD 1440.6, NASA Records Management, and NPR 1441.1, NASA Records Retention Schedules.

Mission operations personnel evaluate system performance including any operations activities, and will document any observations, anomalies, and/or lessons learned in mission evaluation reports. Even though most of the Lessons Learned effort was captured in Phase E, there might be additional polish or new information after EOM that requires updating of the Lessons Learned. The PM and the project team document Lessons Learned in accordance with MSFC and Agency policy.

The PM also disposes of all project assets. This includes all hardware and software owned by the government. This can include disposal in place, donation to another project, storage, or other disposition. This is concluded prior to closing the project. In addition, the PM, working with the COTR, supports Contract closeout activities that are executed and controlled by the CO. In some cases, this may last greater than a year after EOM and safe disposal due to property closeout, final rates adjustments, etc.

3.1.2 Technology Development Projects

This section describes the processes followed by projects that have technology development as the project's primary goal. Many of these projects at MSFC may also support space flight system development projects since space flight projects (or the aeronautics community) are the ultimate customer/beneficiary of the technology development results (i.e. the advanced technology end items).

Note: The Technology Development Project type was formerly known as "Advanced Technology Development" (ATD) and may be still referred to in that manner, in some documentation.

While many of the processes for space flight projects also apply to technology development projects, the intent of the following sub-paragraphs is to highlight the differences between the two types of projects. A technology development project's processes are discussed, which includes project formulation (including planning), evaluation, approval, and implementation.

3.1.2.1 Technology Development Project Formulation

The formulation process for technology development projects is similar to the formulation process for space flight system development projects. The process consists of identifying the need for the project, exploring the full range of implementation options involving varying concepts and approaches, performance analyses of feasible concepts, and establishing the target TRL and the technical performance goals that will be used to measure the project's progress throughout the project life-cycle. The process also establishes the internal management control functions that will be used throughout the life of the project, assesses requirements and develops plans that include options for partnering and commercialization, and performs total life-cycle cost estimates (which are analogous to Total Investment Cost (TIC) in the case of technology development projects). The outcome of the formulation process is documented, as in a flight project, in the Project Plan. For technology development projects, the formulation process can be divided into the following phases.

3.1.2.1.1 <u>Technology Need Identification</u>

In the normal course of the NASA Mission Directorates fulfilling their separate functions, technology gaps and/or shortfalls are identified. These gaps/shortfalls emerge as a result of the Mission Directorates' visions of development activities needed to conduct their missions. Technology gaps/shortfalls can also be identified through a literature search and/or gap analysis of related technology development activities in other Government agencies and the commercial sector. As these technology gaps and shortfalls are identified, studies are performed to determine priority of these needs for expending NASA's resources to fill the gaps. This process confirms the validity of the need and also identifies a technology development project's objectives and content. As NASA related technology needs, gaps and their associated priorities are defined; opportunities are created for internal NASA organizations, academia, and commercial enterprises to develop the needed technologies. These opportunities come in the form of NRAs or AOs. Technology development projects can also be identified through RFPs associated with a space flight system development project.

3.1.2.1.2 <u>Technology Development Project Planning</u>
As in the formulation of other type projects, up front analysis and project planning is key in convincing independent evaluators and NASA management that a technology development project is ready to proceed to the implementation phase. Activities that are performed during the planning phase are described in the following sub-paragraphs.

The technology development project has aggressive, yet feasible, goals/ requirements. In many cases, the goals/requirements are dictated to the project manager at the outset by definition of the need, or gap. The concept and usage of the term “requirements” has a different meaning in technology development compared to the development of flight hardware. In a technology project, requirements are goals that may or may not be met. Schedules are set on the basis of “predicted” times to resolve problems that are only partially known, and costs (as well as schedules) are in the end dictated by overcoming problems that were unknown at the beginning of the project. This is in contrast to a space flight system project where requirements lead to a derived set of costs and schedules with interim milestones, and the milestones are expected to be accomplished in an orderly fashion, on schedule and within cost. In a technology project the expectation is that the product may or may not meet the requirements, and this expectation drives the planning for the project. A technology project has multiple paths to success, fallback positions, and quantifiable milestones with periodic “gates” for changing project directions when needed. However, technology projects have established goals and technical success criteria that are expressed in an objective, quantifiable, and measurable form, in order to allow the project’s progress to be evaluated and tracked throughout the project life-cycle. The following sub-paragraphs describe how this is typically done in a technology project.

3.1.2.1.2.1 Assessing the Technology Readiness Level and Establishing Key Performance Parameters

An initial step in establishing the performance goals of a technology project is to first determine the TRL of the present state of the technology being pursued. The TRL describes the state-of-the-art of a given technology, and represents the level of maturity of that technology relative to its readiness for safe/successful flight operations. For the technologies being undertaken for development, the initial TRL provides a “baseline” from which further development is leveraged. Both the current TRL and a target for the advanced TRL are assessed and identified. These TRLs assessments will be used, in conjunction with technical performance goals and measures (such as KPP), to assess the maturity of the technology throughout the project life-cycle. Table I depicts the definition of the various TRLs that the Agency uses to define the state of technology maturity.

Table I. Technology Readiness Levels

TRL Level	Description Summary

1	Basic principles observed and reported
2	Technology concept and/or application formulated
3	Analytical and experimental critical function and/or characteristic proof-of-concept
4	Component and/or breadboard validation in laboratory environment
5	Component and/or breadboard validation in relevant environment
6	System/subsystem model or prototype demonstration in a relevant environment (ground or space)
7	System prototype demonstration in a space environment
8	Actual system completed and “flight qualified” through test and demonstration (ground or flight)
9	Actual system “flight proven” through successful mission operations

Note: Refer to NPR 7120.8, Appendix F for more specific hardware/software descriptions and exit criteria associated with each TRL level.

The TRL assessment is accomplished by comparing the development, analysis and test history of the system/subsystem/component in question with the descriptions shown in Table I and Appendix F of NPR 7120.8. It is important to clearly define all terminology used in the TRL assessments to ensure consistent understanding throughout the life of the project. When assessing an element of development, analysis or test history, it will be necessary to make “judgment calls” on the basis of past experience, to determine how similar a given element is relative to what is described for each TRL. Describing what has been done in terms of form, fit and function provides a means of quantifying an element based on its design intent and subsequent performance. It is extremely important to have a well-balanced, experienced assessment team. Team members do not necessarily have to be “discipline experts.” The primary expertise required for a TRL assessment is that the systems engineer/user understands the current state of the art in applications.

TRLs are identified and assessed within the context of the work breakdown structure. In other words, TRLs are assessed at the system/subsystem/component level, and the subsystem/component with the lowest TRL determines the overall TRL for the system. The current state of integration for the overall system is also considered when determining the overall TRL of the system. All of the elements can be at a higher TRL, but if they have never been integrated as a system, then the TRL will be lower for the system overall.

In a technology development project, technical performance goals are also established to assess the project's progress toward its ultimate objective of advancing the maturity of the technology being pursued. These goals are associated with a type of technical performance measure that is called a Key Performance Parameter (KPP). KPPs consist of measurable engineering parameters that would be readily understood and used by engineers concerned with the ultimate application of the technology end item. For each KPP, both a goal and a threshold value will be specified. The goal is a performance level that the project team is striving for, and the threshold is the minimum performance level that users agree is acceptable for the end item deliverable. Typically, the threshold KPP values are set beyond the current state-of-the art to warrant investment in the project. KPPs include information that enables an assessment of the advancement of the maturity of the technology throughout the development process. The process of defining the KPP includes defining the appropriate environment and the component, subsystem, or system within which the KPP measurements are to be made.

3.1.2.1.2.2 Assessing the Advancement Degree of Difficulty

Once the current and target TRL and the KPP goals and thresholds have been established for the various elements of the system/subsystem/ component under development, an assessment is performed to determine what will be required to advance the technology to the level required by the project. The importance of this step cannot be overemphasized because everything that transpires from this point forward will depend upon the accuracy of this assessment. The ability to prepare realistic schedules, make accurate costs projections, meet milestones, and ultimately produce the desired results depends directly upon determining the difficulty of advancing the technology to the desired advanced TRL. The term Advancement Degree of Difficulty (AD^2) is an assessment of the effort required to raise a technology from its present TRL to a desired higher TRL. The degree of difficulty in advancing the TRLs considers aspects such as materials development, manufacturing capabilities, processes development, anticipated testing difficulties, whether the advanced TRL is human rated, and many other aspects that may affect the advancement progress. The AD^2 of the overall system under development will be a function of the AD^2 of the individual subsystems and components. It is not a straightforward combination of AD^2's. Neither is it determined solely by the most difficult element. The more elements you have with high AD^2 values, the greater the difficulty in advancing the system as a whole to the requisite level. There are various process methodologies that have been developed to categorize and quantify the degree of difficulty for each element and the system technology overall.

3.1.2.1.2.3 Creating the Technology Roadmap

A technology road map charts the development path of a specific technology or suite of technologies. The road map identifies key technologies and describes the steps necessary to bring the technologies to a TRL that will permit them to be successfully integrated into a program. In a technology project, the road map serves as the initial guide, quantifying the activities to be undertaken, the steps to be followed and providing the overall direction of the effort. The road map is initially laid out based on technology needs and serves to provide the basis for initial project costing and scheduling. The road map is developed after the completion of the TRL and AD^2 assessments and is the basis for the subsequent implementation plan. The TRL assessment and the AD^2 assessment provide the data required for the road map. The road map is a hierarchical collection of maps that starts at the highest system level and follows the breakdown into subsystems and components as established in the TRL assessment.

3.1.2.1.2.4 Technology Assessment and Architecture Studies

The TRL assessment identifies the key technologies to be incorporated into the project and the AD^2 assessment provides the most important aspect of establishing the relative priorities of these key technologies. The AD^2 assessment is also used to determine where parallel approaches are to be put in place, and provides insight into what breadboards, engineering models and/or prototypes will be needed and what type of testing and test facilities will be needed. The AD^2 assessment process identifies concepts that will produce the advanced technology. Once candidate concepts have been identified, further studies are necessary to identify the paths thought to produce the best chance for successful advancement. Detailed architecture studies are then performed. The architecture studies refine end-item system design to meet the overall requirements of the project. Continued technology assessments are done in parallel with the architecture studies to identify those critical technologies that were not identified in the initial assessment and to investigate new technologies required as the design evolves.

3.1.2.1.2.5 Risk Management in a Technology Development Project

Project risk identification and mitigation planning is also accomplished during the technology development project planning. One common risk that has to be considered is underestimating the degree of difficulty in achieving the new technology level. This emphasizes the importance of the AD^2 assessment because the project success from this point forward will depend upon the accuracy of the assessment. The ability to prepare realistic schedules; make accurate costs projections; meet milestones; and ultimately produce the desired results, will all depend directly upon the AD^2 assessment. Inaccurate assessment of AD^2 can contribute to cost and schedule overruns and to project failure. Sufficient time and effort is expended in performing this assessment to ensure that the most accurate assessment possible is obtained. To maximize probability of success, a technology development project plans for making adjustments to the development path during the course of the development. A successful technology development project plan enhances its flexibility by:

a. Planning for parallel development paths.

b. Scheduling decision gates at appropriate times to decide on any adjustments to the development paths.

c. Having alternate paths planned to respond to development problems.

d. Having fallback positions as part of the response to unsuccessful events.

3.1.2.1.2.6 Earned Value Management and Work Breakdown Structure in a Technology Development Project

Technology development project planning includes earned value management. Earned value management requires that a firm time-phased performance baseline be developed that is based on target cost and schedule. Meaningful and quantifiable TPMs are established to track and measure project progress toward the delivery of a product within a given time frame and for a given cost. The establishment of TPMs requires in-depth knowledge of the technology development being undertaken, the current status, and the desired result.

In a technology project, the earned value management system is responsive to changes that affect cost, schedule, and technical requirements to be effective. As is the case in a space flight hardware development project, the framework for earned value management is the WBS, and the earned value management system has milestones that quantitatively measure progress where the focus is on maximizing the probability of success. A technology assessment provides the basis for establishing the critical elements in preparing an earned value management system. The technology development project planning also includes the establishment of the WBS.

3.1.2.1.2.7 Life-cycle Cost and Total Investment Cost in a Technology Development Project

A difference between a technology program and a flight hardware program is in the concept of LCC. For a pure technology development project, an analogous term is the TIC. Actual technology development project costs are dictated by overcoming problems that were unknown at the beginning of the program. However, technology development project planning defines the TIC to the maximum extent possible. This requires detailed activity planning estimates. Upon project approval, the TIC typically reflects the predetermined amount the Agency is willing to invest in order to obtain the needed technology. The LCC comes back into play as the technology is incorporated into a flight hardware program. In fact, the LCC is considered in the initial stages of technology development since the technology may have a large impact on the LCC of the flight program into which it is subsequently incorporated.

3.1.2.2 Technology Development Project Evaluation

The evaluation process for a technology project is much the same as for a space flight project (see 3.1.1.2). Periodic comparison of cost and schedule performance against planned budgets and schedules is done in order to determine variances, isolate factors causing deviations, provide corrective actions, and to stay abreast of cost and schedule estimates to completion. The evaluation process uses the benefits of peer experiences, customer/beneficiary appraisal, and management expertise and tools in the independent review of program or project goals, objectives, concepts, plans, status, risk levels and performance. Requirements for the reviews and assessments are tailored based on such factors as program and project size, criticality, and risk, and are detailed in project plans. Effective evaluation processes are extremely beneficial in the development of technology projects. Since the very nature of technology projects is to create technology that does not exist, the evaluation teams need to be well grounded in the topic and intimately familiar with the technology development process. The evaluation process can be broken down into two elements, an initial review for transition from formulation to implementation and annual reviews to assess progress and direction. In addition, each of these review elements has both an internal component and an external component (i.e. the independent assessment team).

3.1.2.3 Technology Development Project Approval

The approval process for a technology project is the same as for a space flight project (see 3.1.1.3). An Independent Assessment team, the MSFC CMC, and the GPMC successfully reviews the proposed project first.

3.1.2.4 Technology Development Project Implementation

The implementation process develops, integrates, and provides management control for the overall implementation approach; works closely with customers to ensure mutual understanding of plans, objectives, and requirements; converts and controls project and program requirements into implementation specifications; establishes supporting infrastructure; and develops the technology. The implementation team is as important to a successful technology project as it is to a space flight project. The primary difference is in the experience of the individuals involved. Once a project has been approved, detailed implementation plans are updated based upon the technology assessments from the formulation process. The next step is to begin the implementation process. Activities occurring during the implementation process are discussed in the following paragraphs.

3.1.2.4.1 Technology Development Project Design

The implementation road map is updated based on the approved budget and schedule. The road map lays out the overall plan for the project showing critical elements, parallel approach paths, interim milestones, decision gates, fallback positions, and critical tests. Road map updating is the first activity undertaken after overall budget and schedule issues are resolved**.**

Similar to space flight hardware projects, design of concepts and technology development architectures are initiated. Technology assessments continue in parallel with the architecture designs to identify those critical technologies that were not identified in earlier assessments, and to investigate new technologies required as the design evolves. There is a continuous relationship between architectural studies and technology development. The architectural designs incorporate the results of the technology developments, planning for alternate paths, and identifying new areas required for development as design activities continue. The technology development process identifies requirements that are not feasible and development routes that are not fruitful and transmits that information to the architecture designs in a timely manner. Similarly, the architecture designs provide feedback to the technology development process.

Also during the initial design phase, schedules are developed on the basis of predicted times to accomplish tasks since not all problems have been identified. However, schedules are generated to the lowest level possible in order to measure and stay abreast of problems encountered as soon as possible. At the top level, the milestones on the schedule are the major events in the life of the project that are used to measure progress toward the end product of the project. At the level of finest granularity, the milestones become the steps of the process involved in manufacturing a component or testing a subsystem. Consequently, the identification of meaningful, quantifiable milestones (and intermediate sub-steps) that measure progress toward project goals is critical. Although establishing these intermediate progress markers is difficult, an effective earned value management system cannot be established without them. Establishing quantifiable metrics is the only way a project manager can measure progress toward the final objective. Once the schedule hierarchy and elements are developed based on the WBS, the critical paths are defined and highlighted.

3.1.2.4.2 Technology System Development Activities

Based upon the continued technology assessment, architecture studies and technology system design, a breadboard of the new technology is developed and tested. Test specimens are developed for testing the new technology. Breadboard models and test specimens are updated as testing progresses to enhance the technical performance of the new technology. These activities may require multiple cycles depending on changes in requirements, architecture, and/or design dictated by results of the tests and as defined in the implementation road map, or as directed by an evaluation review. Development paths may be adjusted and requirements may be modified based on testing results. Engineering models and/or prototypes of the advanced technology system are fabricated, assembled, and tested. With successful demonstration of the prototype advanced technology system, the final activity is the fabrication, test, and acceptance of the advanced technology system for the target TRL certification.

3.1.2.4.3 Progress and Evaluation

As with a space flight project, project evaluation occurs throughout the life of the technology development project to ensure the successful completion of the formulation, approval and implementation processes. During the implementation phase, the evaluation of progress for a technology project is significantly different from a space flight project. In a project where some failure is expected, the determination of progress becomes somewhat problematic. Evaluation is made easier, however, by the previous effort expended in defining the lowest level of development activities and the schedules for these activities. The task is also enhanced by the selection of TPMs that are used to measure progress.

There are two basic types of reviews necessary for a successful technology development project, internal project reviews and external independent assessment reviews.

Internal reviews are set up to periodically review project TPMs to keep abreast of progress, successes, and problems being encountered. Special reviews are held at any time a significant event such as a critical test has occurred. Internal review teams consist of both project management and technology experts in the technology being pursued. The team evaluates progress and problems and be proactive in decisions on any adjustments to the implementation road map. Decisions may consist of venturing to alternate paths, or curtailing a path (off-ramping). The reviews also are useful in gaining a consensus on successes. These internal reviews are conducted annually.

External IA reviews are held to review the project's overall progress and to assess the progress and expenditures of the project. The IAs provide an important endorsement of the progress and plans for the future. The IAs are also important in assessing the need for additional funding and providing concurrence for path adjustments and schedule changes. IAs may be conducted concurrently with the annual internal reviews.

3.1.2.4.4 Closeout Review and Certification of Advanced TRL

Once a technology development project has achieved its goals, it is important to obtain consensus that the new TRL has been achieved. A special Independent Assessment review by a panel of technology experts is held to review test results, the goals of the project, the success criteria, and ascertain that the new TRL has been reached. The results of such a review will certify the target TRL, or identify any need for additional development, and/or testing.

3.1.2.4.5 Infusion of New Technology

Upon completion of obtaining the advanced technology, the final phase of the project is the assistance of the project in dispersing knowledge of the new technology to potential customers. The project will work with the Technology Development and Transfer Office by providing information and transferring knowledge to the users of the technology. The project will assist and serve as consultants in infusing the new technology into space flight system development programs/projects. Documentation of new technological developments and current lessons learned/best practices may be accomplished through the development of NASA Technical Standards to capture this knowledge for the Agency.

3.2 Project Team Organization

Organization is the establishment of authority relationships between positions that have been assigned specific tasks required for the achievement of project objectives. A full understanding of the project objectives is necessary to identify the specific tasks required. Effectively delegated authority ensures coordination of group activities and assignments.

A project's organizational structure and staffing are dependent on the character of the project and may change as the project matures and areas of emphasis shift. The Project Manager is responsible for planning, organizing, staffing, directing, and controlling all project activities. Depending on the requirements of the project, a Project Scientist may or may not be required. A Resident Office may not be needed at a contractor's plant if the Project Office personnel maintain cognizance of the project activities and status through travel or other communications, or if resident personnel from other government agencies are available at the plant who can accept delegation of authority relative to product assurance, property management, contract administration, etc., as may be needed.

In any type of team or organization, it is important that roles and responsibilities for all members are documented and understood. Team members need the authority to make decisions in their areas of responsibility. In addition, accountability and responsibility are driven as low in the organization as possible.

The WBS will affect the project's organization as well as the contractor's organization. Since the objective of most projects will be to develop and deliver specific end items, the WBS will be structured to include the tasks leading to these end items; that is, it will be end item (product) oriented rather than discipline oriented. As a result, the project can be most effective if its organization is structured such that each major task in the WBS is assigned to a single individual. For a contracted project, the contractor's organization will also reflect points of commitment or assignments of responsibility for the various WBS elements. The WBS tends to align the contractor and project office working-level interfaces.

3.2.1 Project Manager

The Project Manager is the individual accountable for project execution. The Project Manager is responsible for all aspects of the project, ultimately making sure the project requirements are met within budget and schedule, and that the team members who support the project are properly recognized for the achievement of those goals. The Project Manager is responsible, in accordance with NASA and MSFC management directives, for the successful planning and implementation of project resources, schedule, and performance objectives. The Project Manager is also responsible for overall project safety and risk management. The Project Manager receives authority via a chain of delegation beginning with the PCA and the Program Plan, which is the agreement between the Center Director, Program Manager and the Enterprise Associate Administrator (EAA). The agreement between the Center Director, Program Manager and the Project Manager is documented in the Project Plan and approved prior to implementation of the project. The Project Manager has the authority and responsibility to execute the Center Director’s commitment as reflected in the Project Plan.

The PM penetrates all aspects of project development to develop a clear perception and intuitive grasp of progress and problems. For a contracted project, the Project Manager develops and maintains an understanding of the contractor’s activities. The Project Manager brings some degree of technical expertise and management skills to a project. There are, however, other attributes that are required in a good PM.

One of these is leadership. Leadership implies more than managerial skills such as scheduling, budgeting, etc. It includes the ability to lead a team toward the successful development of a mission despite the problems that any project will always encounter. A PM needs to look ahead to see the whole picture, anticipate potential problems, give direction to the team for moving around these obstacles, and provide the environment that enables a team to be successful. A can-do, but realistic, attitude is part of the leadership challenge. A strong commitment by the PM to the success of the project, backed by a strong work ethic, will go a long way to providing the leadership necessary for a successful team. The institutional support that provides the needed resources and environment for the team to succeed is an important component of this leadership.

Leadership requires proactivity. A proactive PM anticipates problems and takes action so as to preclude, or at least minimize, the impacts of issues that arise. A reactive PM will always be behind the curve and will seldom, if ever, catch up. A proactive leader is always questioning the way things are done to make sure the project is on the right track. The PM also ensures that a formal process for handling dissenting opinions is in place.

Timely decision-making is necessary to keep Project development moving. Ideally, the PM would like to have all the information possible before making a decision. This would go a long way to assuring a correct decision in all cases. However, that is a luxury generally not available to a PM during the development cycle. Often, decisions are made with minimal information. The ability to make good decisions with less than complete information is a distinguishing characteristic of a good PM. Keep in mind that a wrong decision can be reversed if it places the project on the wrong track. A non-decision, however, cannot be reversed and can have severe consequences.

A flight Project development is an intense activity that requires a strong team. Although the PM does not have total control over the staffing, the PM needs to ensure the team is properly staffed, especially with experienced people in key positions. Delegating proper authority to team members is critical to team self-confidence and to getting the work done. The PM has adequate control over the staffing process, especially the key positions. With proper leadership, the team will be confident in its decisions and willing to work hard to ensure a successful mission. In addition to experienced team members, it is necessary to include less experienced members and to mentor them in the teaming environment. This ensures proper experience is passed along to subsequent programs/projects.

Managing relationships with Project stakeholders is critical to a successful project. Stakeholders include the scientists, the program office, Center management, other NASA Centers, international partner institutions, Headquarters (HQ), other government agencies, personnel from the legislative and executive branches, etc. Stakeholders understand problems are inevitable and are a normal part of the process. By taking proactive, aggressive steps to solve problems, the PM will get the support of these stakeholders rather than their distrust. Part of this process is managing expectations. For example, if the project budget is cut, the PM needs to be realistic and work with the stakeholders to develop the new baseline without promising all original goals can be met despite the reduced resources. The main objective when working with stakeholders is to continually communicate with them – supplying and receiving input – to maintain the support they provide and that the PM will need.

PMs will often work with major contractors. PMs are responsible for the end products delivered from these contractors. To do this successfully, the project team works with the contractor to get the work done, not just passively monitors the contract. If the PM has a strong, capable team, the contractor will respond with a similarly strong team. This enables both teams to work together with confidence in their decisions. The PM, when seeing what work is not getting done, takes early and proactive action to correct the problem because despite issues, the program's or project's requirements still need to be met. For example, if you as a PM or a project team member ascertain there is some issue not getting addressed by the contractor that will become a problem later, don't wait for this to surface in routine reporting. Start questioning it immediately. Waiting will reduce your reaction time.

Most NASA PMs don't have a legal background. Although not a lawyer, the PM is still responsible for the sound legal foundation of the Project during implementation. Thus, for issues such as International Trafficking in Arms Regulations (ITAR), Export Administration Regulations (EAR), Sensitive but Unclassified (SBU) information, contract oversight issues, etc., the PM needs to seek appropriate advice from legal staff, the CO, Center Export Administrator, etc. Export control issues, for example, can take a long time to resolve, so these need to be addressed at the very beginning of an international project. It is also imperative to go through the CO to make any changes to the contract. Changes, no matter how desirable, cannot be directed by anyone else on the project. The CO is the *only* project team member who has the authority to provide contractor direction that will have an impact on the contract scope of work.

Underpinning all these leadership attributes and actions is the integrity and honesty of the PM. When maintained, these things are the key to successful application of all the other attributes, including stakeholder interactions, team strength and morale, contractor relationships, etc. Even during difficult times, it is possible to proactively work problems as long as the PM consistently stays within a sound legal and ethical framework.

3.2.2 Systems Engineering

The Systems Engineering community is responsible for integrating across all disciplines to define, develop, and deliver a system product for a program's/project's particular use, mission, or function. Through a series of processes, practices, and assessments, the systems engineer is responsible for addressing the following activities: stakeholder's expectations definition, technical requirements definition, system architecture definition, logical decomposition, product integration, product implementation, product verification/validation, requirements management, interface management, technical risk management, configuration management, data management, trade studies, and technical assessment. The systems engineer collaborates across all disciplines and works closely with the Chief Engineer to assure the product will meet project requirements.

3.2.3 Safety and Mission Assurance

Consistent with NPD 1000.0, NASA Governance and Strategic Management Handbook, a Chief S&MA Officer (CSO) will be assigned to the program/project through the S&MA Directorate to serve as the S&MA Technical Authority. The S&MA Technical Authority is organizationally separate from the program/project. The CSO is usually co-located with the Project team. An S&MA representative(s) may also be co-located in a resident office for a contracted project. In this capacity, the S&MA Representative will: (1) assist the Project Manager in assuring that all S&MA requirements are appropriately defined and implemented; (2) provide for an independent S&MA oversight and assessment function for the project; and (3) serve as the single point-of-contact between the Project team and the S&MA Directorate, assuring proper coordination of all safety, reliability, maintainability, and Quality Assurance (QA) responsibilities and practices.

To support the implementation of the NASA Governance Model, the CSO will serve as the S&MA Technical Authority on Program decision-making boards and any other forums or processes that may be associated with safety and mission success risk acceptance. The CSO is responsible for certifying S&MA readiness at appropriate decision points such as lifecycle reviews and test/flight readiness reviews.

3.2.4 Procurement

The Project Manager’s interface to the Procurement Office is a Procurement Office Representative in a co-located assignment to the project team (if this function is required). The Procurement Office Representative is responsible for development of the Master Buy Plan submission; the Acquisition Strategy Meeting with NASA Headquarters; MPR 7120.3, MSFC Data Management Guidance Manual, if required; SOW; draft RFP; and the formation and operation of a SEB. The Procurement Office Representative is also responsible for contract negotiation for a contracted project. The representative supports the development of a change order control system to implement contract changes.

3.2.5 Project Planning and Control

The Project Planning and Control function is responsible to the Project Manager for providing direction, assessing progress and assisting the Project Manager in control of project resources and activities, including budget, schedules, customer agreements and overall project management to ensure that project implementation execution is consistent with approved project customer agreements, budgets, schedules, and acquisition strategies. Other areas where the Project Planning and Control assists the Project Manager include management information systems, programmatic reviews, and performance measurement surveillance including earned value management. In addition, business experts who understand earned value analysis, integrated baseline and integrated master schedules support the PM. Schedulers experienced in schedule logic, critical path analysis, network diagrams and resource-loaded schedules also support the PM.

Establish monthly reporting that details funding and workforce utilization against plans and earned value status. Program Planning and Control (PP&C) will also develop a monthly phasing plan for resources as well as an annual PPBE budget forecast that details cost and workforce plans for 6 years beyond the current year.

3.2.6 Resident Office Representative

A resident office is established at a project's contractor facility for some projects to provide an on-site interface with the contractor, if required. The resident office is headed by a representative of the Project Manager's office and serves as the liaison between the Project Manager and contractor management. The responsibilities of the Resident Office Representative are delegated by the Project Manager and are dependent on the particular project and the manager. The representative is generally tasked to assist the Project Manager with contract administration, contractor activity oversight, and provides the Project Manager with contractor status and continuity. As in all functions of the project, the Project Manager is responsible for project contractor management and for contract execution.

3.2.7 Project Support Organizations

Many of the Center's organizations provide technical and institutional support to the Project as described in the following paragraphs. Project support from organizations other than the managing organization is documented in Collaborative Workforce Commitments (CWCs). (See MSFC-HDBK-PPC, for guidance in resource planning.)

3.2.7.1 Chief Engineer

The Chief Engineer is a key member of the project team. The Project Chief Engineer serves as the "Technical Manager" for the project to ensure engineering adequacy and coordination of in-depth engineering support from the across the Engineering Laboratories and Departments. The Chief Engineer leads and coordinates the technical activities, problem solving, and issue resolution within the Engineering Directorate (ED) and assures that technical cognizance is maintained over associated contractor activities. The Chief Engineer works closely with the Systems Engineering organization to constantly review and evaluate the technical aspects of the project to assure that the products are properly defined, developed, integrated, and verified to meet project requirements. For larger projects, a dedicated Chief Engineer is the systems technical authority and leads the engineering team in the execution of the project. For smaller projects a Lead Systems Engineer may provide this function; however, the LSE relies on the directorate level Chief Engineer or designee for technical authority matters pertaining to the project.

3.2.7.2 Engineering Design Disciplines

The various Engineering design disciplines provide valuable input into creating an overall design solution. The design disciplines provide management of particular subsystems, and are responsible for the technical performance of assigned subsystem(s). The design disciplines are also responsible for cost and schedule status and use a variety of management tools (e.g., Earned Value Management, Critical Path Analysis, Stop Light Reports, etc.) that pertain to the applicable subsystem(s).

3.3 Project Management Functions

The primary function of project management is to ensure that the project is implemented to meet the established budget, schedule, safety, and performance requirements to satisfy its objectives. As discussed in section 3.2, it takes an organized team to fulfill this primary function. Vital to successful project management is the role of the Center's engineering organizations. The well-planned use of technical expertise and "corporate memory" in not only the detailed assessment of contractor approaches but also in the performance of independent design analyses can be an invaluable (and less expensive) resource. Other techniques considered in project management are the establishment of a Problem/Action Item Tracking System, and the use of consultants for problem resolutions. Even though it takes a team to implement, many of the project management functions have been partitioned into the basic functions discussed in the paragraphs below.

3.3.1 Project Planning and Control

Planning and control of project resources is one of the key functions of a project manager, and in varying degrees, virtually all topics discussed in this handbook can be related to the understanding and control of cost.

Among the critical elements of successful cost planning and control efforts are:

a. Requirements: The availability of complete, accurate, and realistic performance and interface requirements at an early stage is very desirable. Well-defined requirements breed mature designs and cost estimates and less risk of problems downstream.

b. WBS: Work planning and accounting, earned value management, cost reporting and scheduling at the various levels are all interrelated through the WBS. The contract WBS is developed to the cost account level, that is to the level at which the performance of a single functional organization on a well-defined and scheduled task can be measured.

c. Planning and Scheduling: Project work is planned, scheduled, and authorized at the cost account level. For each cost account, resources are specified (dollars, material, manpower) and a firm schedule established. Performance at level III (subsystem) is reported based on the aggregate performance of the sub-tier cost accounts. The interdependence of cost account schedules supports the overall project schedule. Monitoring of the critical path is integral for project success.

d. Cost Tracking and Analysis: Early identification of potential cost problems rests to a large degree on thorough analyses of not only the NASA Form 533 reports but also monthly reports, program review material, and other data such as the contractor Cost Performance Report (CPR) for earned value management. It is important to note that this function is not limited to the Program Control Office. The Subsystem Lead Engineer (SLE), Lead System Engineer (LSE) and WBS Element Managers in the Project Office and/or the Engineering Directorate are responsible for a certain degree of understanding of not only technical but also cost and schedule matters. Trend analyses at the subsystem level of individual cost categories (direct labor, overtime, engineering, etc.) and comparative analyses of cost to schedule and cost to technical performance (e.g., value of work planned vs. value of work accomplished) is the essence of earned value management and provides an effective means for the early identification of cost variances which the contractor may not be inclined to voluntarily identify. The PM integrates the opinions and recommendations of the Project Office personnel involved in technical/cost assessment, and those of the LSE, with his or her own observations, to arrive at a timely, thorough, and realistic understanding of project status. Once a potential problem is identified, alternative solutions including performance, cost, and schedule impacts can be defined. The contractor or WBS Manager (if in-house) prepares a recovery plan (or alternative plans) showing what is to be done, when, associated cost, and impact on other work.

e. Management of Changes: To minimize extra costs to the project, proposed changes need to be thoroughly understood and questioned. Potential impacts and mitigation on performance, cost, and schedule are identified. Tracking the progress of major changes to work planning and scheduling and performance and cost reporting procedures are important.

3.3.2 Product Data and Life-cycle Management (PDLM)

PDLM is the set of processes and associated information used to plan for, acquire, control, and manage the product definition data (PDD) and product related data for the entire life-cycle of the product data from conception through design, test, manufacturing, service, and disposal. PDLM requirements, established by NPR 7120.9, extend to all MSFC space flight single-project and tightly coupled programs and projects subject to NPR 7120.5. The purpose for enacting consistent, high-quality PDLM processes is to ensure that the Center's investment in processes and tools reduces life cycle costs and that risks associated with data interoperability across disparate systems, internal and external, are identified and managed.

NPR 7120.9 envisions a process and environment where detailed engineering models and product-related data are prepared, evaluated, documented, and configuration controlled. The data is managed to include the following key features:

a. Ensure that data is accessible.

b. Ensure that the right data is discoverable and understandable.

c. Ensure that the right data will exist.

d. Ensure that the state of the data (e.g. in work, under review, approved, released) and its relationship to the product design is defined.

e. Ensure that solutions are agile and flexible.

f. Ensure near real-time data queries and exchanges.

g. Develop and use common vocabularies via one or more communities of interest.

h. Designate operational data producers.

i. Include both contractor and government developed engineering and programmatic data.

MPR 7120.1, MSFC Engineering and Project Management Requirements, establishes the MSFC-specific PDLM responsibilities and requirements.

3.3.3 Safety and Mission Assurance

Safety is the foundation for program and project management mission success. As NASA's core value and number one priority, every program/project/activity is committed to protecting its people and hardware. It is important to note that the program/project manager is ultimately responsible and accountable for the safety of the program/project's products and activities. S&MA supports the program/project/activity team by ensuring that safe and best processes are implemented and followed and assisting the program/project/activity in making risk-informed decisions that properly balance technical merit, cost, schedule, and safety across the system. S&MA also provides Technical Authorities who independently oversee programs/projects/activities as a system of checks and balances. S&MA has the technical and management efforts of directing and controlling the safety and mission assurance elements of the program/project/activity including: design, development, review, and verification of practices and procedures and mission success criteria intended to ensure that the delivered product meets performance requirements and functions for the intended lifetimes. S&MA also assists programs/projects in developing and implementing mishap contingency response and operations.

The purpose of the SLS S&MA requirements is to document the minimum S&MA requirements that must be allocated and implemented to help NASA achieve the mission while protecting the public, the astronauts, the NASA workforce, and high-value equipment and property. Collectively, these requirements describe rigorous S&MA analyses and processes, which in turn assure safety and mission success. The S&MA

requirements encompass Safety, Reliability, Maintainability, Quality Assurance, Software Assurance, Risk Management, and Probabilistic Risk Assessment (PRA).

3.3.3.1 *System Safety*

System Safety is an engineering discipline that is applied during system development to study the entire system during its total life-cycle or process in order to identify, mitigate, and document system hazards under all possible conditions, and in so doing eliminate or reduce the risk of potential mishaps and incidents. See NPR 8715.3 and MWI 8715.15. System safety is concerned with the safety aspects of aerospace flight and flight demonstration systems, related support and test equipment/facilities, computer software, and personnel during research, development, design, integration, test, flight, post- landing, recovery, and refurbishment whether for manned or unmanned systems. MSFC system safety is dependent on reliability analyses including FMEA and PRA assessments to aid in the identification of hazard causes and safety risk evaluation

3.3.4 Systems Engineering Management

A systems engineering function is needed on every development and operational project. The planned systems engineering and integration activities for a project are normally described in a SEMP that is used in managing the systems engineering functions. (A SEMP is normally not required for small, research type projects.) Systems engineering is responsible for ensuring the top project system requirements are ultimately met and the system performs as required. The systems engineering functions are described in section 4.

3.3.4.1 *Subsystem Engineering Management*

In addition to the overall systems engineering management (as discussed above) the development of each subsystem is also managed. As the systems requirements are defined, the subsystem requirements are flowed down from the systems requirements. Subsystem examples include structures, thermal, propulsion, attitude control, electrical power, guidance and navigation, communications, and instrumentation. The project ensures the subsystem risks are identified, risk management activities are properly executed, and the subsystem requirements are achieved within budget and schedule. This includes development of subsystem design documentation to support scheduled design reviews, and the planning and conducting subsystem fabrication and verification activities.

Analysis of the integration of the subsystem into the overall system ensures functional and physical compatibility. Subsystem technical issues are evaluated for system level impacts and all issue resolution.

3.4 Project Reviews

Project review scope generally falls into two categories: (1) discharging design, development, delivery, and operational responsibilities; and (2) reviewing status, acquiring resources, reporting utilization, and reporting Project status.

Since no manager of a substantial project can maintain current, in-depth expertise in the multiplicity of technical and programmatic disciplines required, the importance of reviews in the program management process cannot be overemphasized. Recently the desire to reduce risk of cancellation of programs/projects has led to the goal of having Life-cycle Reviews where both technical and cost/schedule baselines are reviewed at the same time. Life-cycle reviews provide the mechanism by which one assesses performance, acquires managerial confidence, enforces technical and programmatic discipline, and conveys requirements and progress. Reviews also provide a means of assuring projects have addressed the TPMs correctly. Project Manager may combine reviews as long as the intent is still met. Technical reviews, in particular, are thoroughly planned and interrelated from near project inception. Caution is taken, however, not to hold formal reviews at inappropriate times merely to meet the projected schedule. It is sometimes better to delay these reviews until proper design maturity is reached. The PDRs are typically held when design is approximately 50% complete with corresponding drawings available. The CDR is held when design and drawings are 90%-95% complete (drawings signed, but before submittal for configuration control). The content of the remaining pending design and drawings is negotiated by the project and defined in the review plans. The PDR and CDR establish technical baselines for the purpose of controlling requirements/ configuration as the program evolves through the implementation phase. This control is not the same as contract scope control.

Each project defines their specific reviews Project Plan. The project phases these project reviews to correspond with the associated program reviews. The review list below is for a typical project, although a review may be called by another name on any given project, and other reviews, principally operational oriented, may be required depending on the specific project. Life-cycle reviews evaluate both the programmatic (schedule and budget) and technical status. The goal is to have these at the same time but a short time period can be placed between these reviews. Additional guidance on life-cycle reviews can be found in Appendix D of MPR 7123.1. The following are all the “required” reviews according to MPR 7123.1, MPR 7120.1, NPR 7120.5 and NPR 7120.8

Program Reviews

a. P/SRR

b. P/SDR

Project Technical Reviews:

a. MCR

b. SRR

c. SDR

d. PDR

e. CDR

f. SIR

g. Design Certification Review (DCR) SAR

h. Test Readiness Review (TRR)

i. SAR

j. Operational Readiness Review (ORR)

k. FRR

l. PLAR

m. CERR

n. Post-Flight Assessment Review (PFAR)

o. Decommissioning Review (DR)

The Project Plan provides the name, purpose, content and schedule of all scheduled reviews for the project. A review plan that defines the details of the review is prepared for each review. The review plan describes the conduct of the review, the data included in the review with the data's expected maturity level, the documentation and disposition process for discrepancy items found during the review (RIDs), the detailed schedule for the review, the review teams and their responsibilities, and the review Board and Pre-Board membership as applicable.

The conduct of a major review is not complete until all resulting RIDs and action items are dispositioned and their effect on the project resolved. Follow-up work is pursued aggressively to ensure timely closure of RIDs and actions items. This follow-up effort will help assure that the results of the review are expeditiously reflected in the project and will also serve as a solid basis for the next review.

There is a subset of reviews that is inherent in each of the above technical and, to a lesser degree, programmatic reviews. Specifically, qualification, quality, reliability, risk management, supportability, maintainability, safety, and crew station (in the case of human spacecraft) reviews are an integral and identifiable part of each project review; or specific, separate provisions are made for such subset reviews. It is assumed that these reviews are inherent in the project reviews. Involvement of upper management in the review process during Pre-boards and Boards keeps them informed, integrates corporate memory, and builds advocacy for the activity.

3.4.1 Technical Reviews

Many of the technical reviews, in particular the PDR and CDR, may be conducted on the overall system or incrementally on the subsystems. Incremental reviews are typically conducted on large programs where it is necessary or desirable to allow design of the system or its sub-elements to proceed in the most efficient manner or to allow initiation of long lead-time procurement or manufacturing. In those cases where incremental reviews are utilized, summaries of the results of these incremental reviews are included in the overall, comprehensive reviews to assure that the incremental activity is compatible and satisfies project requirements.

The certification reviews support the need for an incremental readiness verification covering key activities after development is complete and leading to flight readiness. This incremental approach builds upon previous data and certification status established at prior reviews.

The timing of the conduct of each of the reviews is ultimately left to the discretion of the project management, but typically, reviews are conducted as identified in the following paragraphs. (See Appendix D of MPR 7123.1 for additional information and entrance and success criteria for these reviews).

3.4.1.1 Program System Requirements Review (P/SRR)

The PRR may be thought of as the culmination of the mid/late formulation phase of a project and is held prior to project approval for implementation. Its purpose is to review and establish or update project requirements and to evaluate the management techniques, procedures, agreements, etc. to be utilized by all project participants. During the PRR, configuration concepts, project/system requirements, mission objectives, the qualification approach, and the system safety and QA plans are evaluated. Careful consideration is given to how the project addresses Certification of Flight Readiness (COFR) and the level of technical penetration required. Products from the PRR support the SRR.

Depending on the project, it may be necessary at this time to begin planning for new or modified test and launch facilities, in order to meet the Verification and Validation plans and requirements. This may require a significant investment in personnel from multiple centers and contracts may be necessary to support the construction or modification. Likewise, it may also be necessary to begin planning for fabrication of major systems or integrated systems test articles.

3.4.1.2 Program System Definition Review (P/SDR)

The P/SDR looks at the proposed system architecture and how it flows down to the system's functional elements. The P/SDR determines if a program is ready to enter an approved Program Commitment Agreement (PCA), which allows programs to transition from Formulation to Implementation. To provide an independent assessment of the readiness of a program, a Program Approval Review (PAR) takes place as part of the P/SDR. In P/SDR, the program architecture and flow down of requirements is assessed. In addition, the review looks at the program's objectives, key technologies, and other risks.

3.4.1.3 Mission Concept Review (MCR)

The MCR determines the mission need and looks at the proposed objectives of the mission. MCR is an internal review conducted at the organization responsible for development of the system in question and it examines the concept proposed for meeting mission objectives. The MCR is to be completed before entering Phase A of the development life-cycle.

3.4.1.4 System Requirements Review (SRR)

The SRR evaluates the “formulation-phase” generated project requirements that have been decomposed into lower level system requirements. The review confirms that the requirements and their allocations contained in the system specification are sufficient to meet project objectives and that systems engineering processes are in place. The SRR encompasses all major participants (NASA and contractors), and a product from this review will be the project system specification that is formally baselined and placed under configuration control. The SRR is chaired by the Project Manager.

3.4.1.5 System Design Review (SDR)

The SDR looks at the proposed system architecture and design and how it flows down to all functional elements of the system. SDR occurs at the end of Phase A and before entering Phase B. The SDR presents specifications of the overall system and its elements at a level of detail such that at completion, design and acquisition of end items can occur.

3.4.1.6 Preliminary Design Review (PDR)

The PDR is conducted when the basic design approach has been selected and typically when 10% of drawings are complete (all top level and long lead items drawings) and overall design maturity is approximately 50% with corresponding drawings available. The project determines what drawings are included in the 10%. Actual review documentation required is defined in the PDR plan. The PDR is a technical review of the basic design approach for configuration items to assure compliance with program (Levels I and II) and project (Level III) requirements and is intended to accomplish the following:

a. Establish the ability of the selected design approach to meet the technical requirements (i.e., Verifiability/Traceability).

b. Establish the compatibility of the interface relationships of the specific end item with other interfacing items.

c. Establish the integrity of the selected design approach.

d. Establish producibility of the selected design.

e. Identify components that are to be subjected to detailed value engineering analysis.

f. Address test and demonstration planning, safety, risk, reliability and maintainability (R&M) assessment, producibility, and cost and schedule relationships.

The Project PDR is chaired by the Project Manager and includes the major organizations of the Center and the prime contractor (if one exists). A product of the project PDR is the official release and placement under configuration control of the Part I Contract End Item (CEI) Specification(s). In the event a Part I CEI Specification(s) has been previously placed under configuration control, it will be updated accordingly as a result of the PDR. If available, and the preliminary design end-items are not expected to have much change traffic, ICDs are baselined and placed under configuration control. As a minimum, the PDR establishes interface requirements and establish a basis for continuing the ICDs. The PDR also approves the design approach for proceeding to detail design.

Depending on the project, it may be necessary to begin component or materials development or proof of concept testing prior to PDR. The TRLs are defined in NPR 7120.8 “NASA Research and Technology Program and Project Management Requirements”. Depending on the TRL of the item, successive test programs may be necessary to develop the technology, down-select the best option and reduce risk. This will require fabrication of test articles, test planning, test facility modifications, and analysis of test data.

3.4.1.7 Critical Design Review (CDR)

The CDR is the technical review of the detail design of the selected configuration. The CDR provides assurance that the detail design is in accordance with the Part I CEI Specification prior to manufacturing. The Part I CEI specification is used to specify technical requirements peculiar to the performance, design, and verification of a CEI that are flowed down from the higher level specification and allocated to the CEI. “Part I is a product of the early design effort; and when completed and approved, establishes the design requirements baseline for the CEI.” The CDR is generally held when the design and drawings are approximately 90% to 95% complete (drawings signed, but before submittal for configuration control). Actual review documentation required is defined in the CDR plan.

Subjects that are addressed include finalization of system compatibility, design integrity, reliability assessments, maintainability assessments, safety assessments, and cost and schedule relationships. Test, verification/validation, and manufacturing and assembly plans are available, as well as the Part I CEI specification(s).

The participants and chairmanships are basically the same as the project PDR. Generally, the level of NASA control following the completion of the CDR remains at the Part I CEI Specification and ICD level, and the detail drawing control remains with the design contractor for contracted items. If not previously baselined, all ICDs are baselined and placed under configuration control at the conclusion of the CDR. The primary product of the review is the final technical approval for formal release of specific engineering documentation that will be authorized for use in manufacture of the end items.

As noted above, some projects may need to have made considerable progress in preparation for verification and validation by this time. MSFC HDBK-2221 and MSFC-HDBK-670 provide details of V&V planning, which may require new or modified test and launch facilities, and test article fabrication. Fidelity of the test articles to the final design may be a risk item due to the possible long lead times involved. The development testing is nearing completion by this time.

3.4.1.8 Design Certification Review (DCR)

The DCR (sometimes referred to as Functional Configuration Audit (FCA)) is conducted to evaluate the results and status of verification planning, testing, and analyses to certify the design. Generally, the DCR is scheduled after CDR and prior to FRR; but depending on program structure, may occur subsequent to other significant events such as completion of verification flights. The DCR addresses the design requirements, makes an as-designed comparison, assesses what was built to meet the requirements and review substantiation, determines precisely what requirements were actually met, reviews significant problems encountered, and assesses remedial action taken. The ISS employs the FCA in lieu of the DCR to perform the same review function.

3.4.1.9 Configuration Inspection/Physical Configuration Audit (CI/PCA)

The CI (sometimes referred to as a PCA) is the optional review that can be used to establish the product baseline and to verify that the end items have been, and other like items can be, manufactured, tested, etc. to the released engineering documentation. This is accomplished by a comparison of the “as-built” configuration to the “as-designed” requirements. The CI is a one-time review conducted for each family of CEIs.

The CI is normally not concerned with whether the end item can perform its intended function. This task is accomplished in the earlier reviews. The CI is chaired by the Project Manager and includes the same basic organizations as the previous reviews.

The product of the CI is the formal baselining of the Part II CEI Specification. The Part II CEI specification is used to specify exact configuration requirements peculiar to the production, quality control, acceptance verification, and preparation for delivery of the CEI. “Part II is a product of development and operations; and when completed and approved, establishes the product configuration baseline.” The Part II CEI Specification defines the product baseline (detailed engineering documentation) for the item reviewed and all subsequent like items. The CI will be scheduled by project management to be compatible with implementation of the Part II CEI Specification and always occurs prior to turnover of responsibility from one organization to another (e.g., prior to NASA acceptance).

The ISS employs the PCA in lieu of the CI to perform the same review function.

3.4.1.10 System Acceptance Review (SAR)

The AR is the final review conducted for product delivery and NASA acceptance. The AR consists of a detailed configuration review of all major end items of deliverable hardware and software and encompasses not only flight hardware and Ground Support Equipment (GSE) but also any deliverable test articles, spares, special test equipment, support software, etc. An ADP is supplied by the developer to support the AR. All aspects of qualification, verification/validation, and acceptance testing are addressed. The ADP, with supporting documentation, is examined for compliance with project requirements and to ensure that all open/deferred work is identified and disposition plans have been developed and agreed upon. The ADP Data Requirements Description (DRD) defines the ADP contents. The combination of the configuration inspection and acceptance reviews will formally establish and document the as-built configuration of each item of hardware/software at the time of acceptance by NASA.

3.4.1.11 Pre-Ship Review (PSR)

A PSR is an optional review and similar to the SAR but is normally conducted to ensure that subsystems/system(s) that have been developed are ready for shipment. The review consists of assessing the configuration of the article(s) being shipped, assessing the verification status to ensure that all planned testing has been successfully completed, and that all required paper associated with the article(s) is complete. All open/deferred work is identified and plans to complete the open work are agreed upon and documented. Shipping plan details such as method, special instrumentation requirements, and security are assessed to identify open items to be complete prior to shipment.

3.4.1.12 Test Readiness Review (TRR)

The TRR provides confidence that all test requirements are properly understood and addressed and that the test setup can safely accomplish the test objective. The review includes the examination of test requirements, test procedures, the article to be tested, test facilities, GSE, supporting software, instrumentation and data acquisition, hardware handling, and personnel certification requirements. A comprehensive institutional and system safety assessment will be of highest priority during the review process, to assure safety of personnel, facility, and test article hardware. The TRR is conducted prior to all hazardous testing. TRRs for other non-hazardous testing are conducted as required by the PM and the performing test organization.

3.4.1.13 Operational Readiness Review (ORR)

The ORR ensures that the ground operation requirements from hardware fabrication through delivery have been defined and that the necessary support has been defined and allocated. In addition, launch site planning documentation will be reviewed to allow finalization of support for the physical integration and launch of the system. Defined post-mission operations will also be reviewed to ensure necessary support provisions.

3.4.1.14 Flight Readiness Review (FRR)

The FRR is a detailed review by which the system will be certified as flight worthy. Planning for the FRR is initiated during the formulation phase. The FRR includes a review of the system verification process (both testing and analyses), system compatibility, operational planning, and team preparedness. The review will result in certification of the flight readiness to be signed by members of the operational team, the acceptability of the system for flight, and the readiness of the system to achieve all flight objectives.

3.4.1.15 Post-Launch Assessment Review (PLAR)

The PLAR evaluates the spacecraft's readiness to proceed with full, routine operations. The PLAR looks at the flight operations experience since launch and evaluates the status of project plans and capability to conduct a mission. This review normally occurs after early flight operations and initial checkout.

3.4.1.16 Critical Event Readiness Review (CERR)

The CERR determines that a system is ready to execute the mission's critical activities during flight operation.

3.4.1.17 Post-Flight Assessment Review (PFAR)

The PFAR looks at the flight activities after recovery. This review helps identify anomalies that occurred with the flight and mission and determines mitigating actions to prevent anomalies for future flights. A log of lessons learned is submitted to center and Headquarters management for posting on the NASA Lessons Learned Information System.

3.4.1.18 Decommissioning Review (DR)

The DR confirms the decision to terminate or decommission the system. It also looks at whether the system is safe for decommissioning and how to dispose of system assets. Normally, the DR is held near the end of routine mission operations. Assets may be useful on upcoming flights, or for display at museums or NASA centers, but keep a property certificate of where the property goes.

4. SYSTEMS ENGINEERING

Systems Engineering is as an engineering approach that systematically considers all aspects of a project in making design choices. Systems engineering as a methodology is applicable to all levels of a project, and to all levels of a design (i.e., system, subsystem, and component). The success of complex space vehicles and space vehicle projects is highly dependent upon the systems engineering process being properly exercised at all levels of design and management. More specifically, systems engineering is the application of scientific and engineering efforts to:

a. Transform an operational need into a description of system performance parameters and a system configuration through the use of an iterative process of definition, synthesis, analysis, design, test, and evaluation;

b. Integrate related technical parameters and assure compatibility of all physical, functional, and program interfaces in a manner which optimizes the total system definition and design

c. Integrate reliability, maintainability, operability, safety, survivability, human aspects, and other such functions into the total engineering effort.

d. Assisting the Project Manager in assessing risks and identifying mitigations. Proper project planning will then strive to mitigate the identified risks.

A Systems Engineering function is needed on every development and operational project. The planned systems engineering and integration activities for a project are normally described in a SEMP that is used in managing the systems engineering functions. (A SEMP is normally not required for small, research type projects.) Systems engineering is responsible for ensuring the top project system requirements are ultimately met and the system performs as required.

In addition to the overall systems engineering management (as discussed above) the development of each subsystem is also managed. As the system requirements are defined, the subsystem requirements are flowed down from the system requirements. Subsystem examples include structures, thermal, propulsion, attitude control, electrical power, guidance and navigation, communications, and instrumentation. The project ensures the subsystem risks are identified, risk mitigation is executed, and the subsystem requirements are achieved within budget and schedule. This includes development of subsystem design documentation to support scheduled design reviews, and the planning and conducting subsystem fabrication and verification activities.

Analysis of the integration of the subsystem into the overall system ensures functional and physical compatibility. Subsystem technical issues are evaluated for system level impacts and resolution.

The integration of components/subsystems and their verification at planned levels are critical to final system acceptance. The project ensures that all assembly and integration activities and support are identified, planned, scheduled, and executed to support the overall project mission schedule.

The system level testing is the key activity that verifies, to the extent possible, in the Earth environment, that the total integrated system will fulfill its requirements and perform on-orbit as intended. The project ensures testing facilities are developed and verified and ready to support the project schedule. Identifying any special test equipment early ensures its availability. The project ensures the development of all system level test procedures, conduction of Test Readiness Reviews (TRRs), and conduction of the tests, as well as ensuring the test data collected meets the success criteria as defined by the test requirements. After completion of system testing, the testing results are documented in a test report.

The development of this guidance was based on the following assumptions:

a. The NASA SE Engine represents a set of integrated systems engineering processes.

b. The scope and level of activity associated with each systems engineering process is dependent on the context of the system life cycle.

c. Each systems engineering process applies to all levels of the system architecture.

d. The recursive and iterative application of the system design processes is necessary to derive and develop the detailed design of the system or product.

The **NASA SE Engine** establishes an integrated set of 17 individual systems engineering processes. This manual describes the integration of these processes by showing how the work products or outputs from a particular process are mapped to the inputs of another or other systems engineering processes. This integration ensures that the work associated with each process is valued added and shows how the downstream processes are dependent on the successful accomplishment of this work.

The three main process areas in Systems Engineering are: System Design Processes, Technical Management Processes and the Product Realization Processes. Each of these groupings is broken out into lower level processes to make up the total of 17 required processes. See Figure 2.

Within the NASA Systems Engineering Engine, the **System Design Processes** consist collectively of the Stakeholders Expectations Definition Process, the Technical Requirements Definition Process, the Logical Decomposition Process and the Design Solution Definition Process.

The level of activity associated with the Systems Design Processes is high during the early system design and development phases and tapers off during the ensuing life-cycle phases.

Within the NASA Systems Engineering Engine, the **Technical Management Processes** consist collectively of the Technical Planning Process, the Requirements Management Process, the Interface Management Process, the Technical Risk Management Process, the Configuration Management Process, the Technical Data Management Process, the Technical Assessment Process, and the Decision Analysis Process.

The Technical Management Processes connects project management with the technical team. The integration of the eight crosscutting technical management processes allows the design solution to be realized. Each member of the technical team relies on the eight processes to meet the project's objectives. The project management team also uses the eight technical management processes to execute project control.

The level of activity associated with Technical Management Processes is somewhat the same during the various phases of the life-cycle with peaks of effort around technical assessment milestones.

Within the NASA Systems Engineering Engine, the **Design Realization Processes** consist collectively of the Product Transition Process, the Product Verification Process, the Product Validation Process, the Product Implementation Process and the Product Integration Process. The Product Implementation Process is used to generate a specified product of a WBS model through buying, making, or reusing in a form consistent with the product-line life-cycle phase exit criteria and that satisfies the technical requirements and specifications for that particular product. The Product Integration Process is used to assemble and integrate lower level, validated system elements, subsystems, and components.

The level of activity associated with Product Realization Processes is a low level of activity initially, but then ramps up considerably during the later phases of the life-cycle.

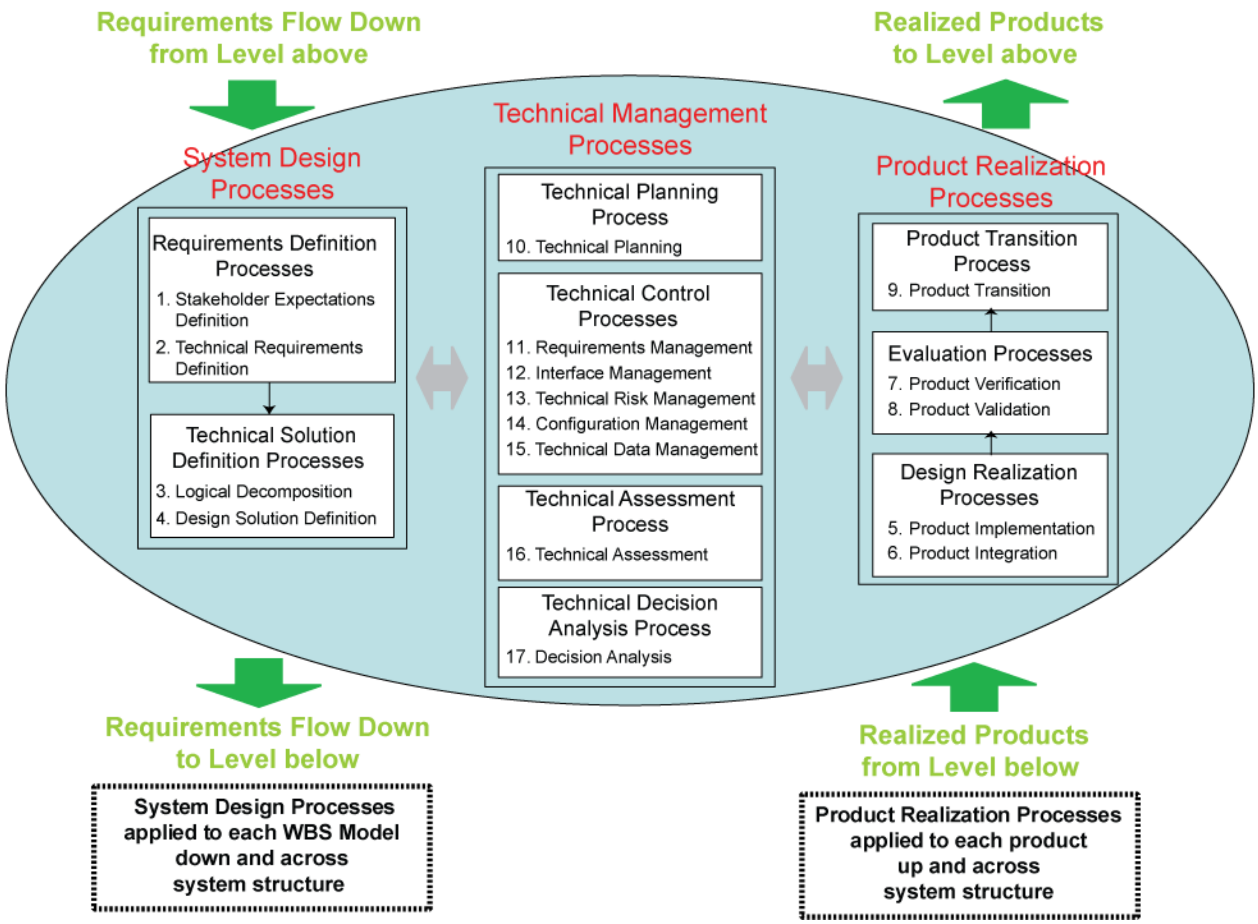


Figure 2. The NASA Systems Engineering Engine

The ***System Design Processes*** employ a "top down" design of each product in the system structure. The *System Design Processes* include stakeholder expectations, technical requirement definition, logical decomposition, and design solution processes.

The ***Product Realization Processes*** employ a "bottoms up" realization of each product in the system structure. The *Product Realization Processes* include the product implementation, product integration, product verification, product validation, and product transition processes.

The ***Technical Management Processes*** are used for planning, assessing, and controlling the implementation of the system design and product realization processes and to guide the technical decision making (decision analysis). The *Technical Management Processes* include the technical planning, requirements management, interface management, technical risk management, configuration management, technical data management, technical assessment, and decision analysis processes.

The NASA Systems Engineering Handbook states the system structure (e.g. program, project, system, segment, subsystem, etc.) comprises the Product Breakdown Structure (PBS). As defined by MPR 7123.1, the WBS Model consists of the PBS, the supporting or enabling products (for development; fabrication, assembly, integration, and test; operations; sustainment; and end-of-life product disposal or recycling), and any other work products (plans, baselines) required for the development of the system.

As depicted in Figure 3, the S*ystem Design Processes* are four interdependent, highly iterative and recursive processes, resulting in a validated set of requirements and a validated design solution that satisfies a set of stakeholder expectations.

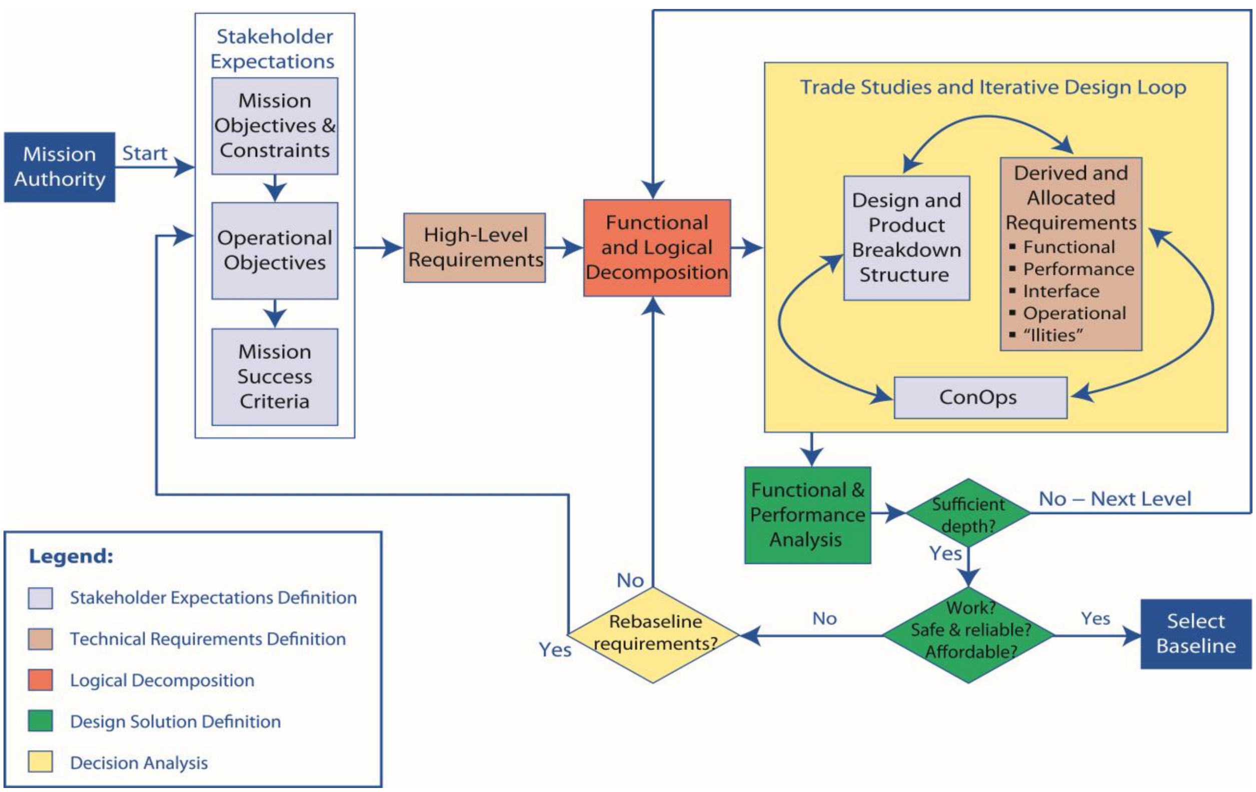


Figure 3. Interrelationships Among the System Design Processes

The System Design Processes are primarily applied in the Pre-Phase A and continue through Phase C. Each iteration through the System Design Processes provides additional refinement and detail in the design and development of the system and its components.

All the process groups have some relationship with each other. All these processes are continuous and iterative in nature. The System Design Processes and Product Realization Processes (as seen in Figure 3) have much more of a serial relationship with one another. In the Technical Management Processes the relationship is much more parallel in nature.

4.1 <u>Systems Design Processes</u>

4.1.1 Requirements Definition Processes

4.1.1.1 Stakeholder Expectation Definition

The Stakeholder Expectations Definition (SED) Process is the initial process within the SE engine that establishes the foundation from which the system is designed and the product is realized. The stakeholder expectations are typically captured in a Project Plan and/or SEMP. Stakeholder expectations that are formally received from the Agency can be done so or may be provided via a FAD, through an Agency generated Needs, Goals, and Objectives (NGOs) Document, or through documentation capturing DRMs. In this case, the Project Plan and/or SEMP will point to this higher level Agency documentation for the capturing the stakeholder expectations. The stakeholder expectations definition process is used to elicit and define use cases, scenarios, concept of operations, and stakeholder expectations for the applicable product-line life-cycle phases and WBS model. Examples of such use cases, scenarios, and expectations that are sought during this process and will eventually evolve into requirements include the following:

a. operational end products and life-cycleenabling products of the WBS model;

b. expected skills and capabilities of operators or users;

c. expected number of simultaneous users;

d. system and human performance criteria;

e. technical authority, standards, regulations, and laws;

f. factors such as safety, quality, security, context of use by humans, reliability, availability, maintainability, electromagnetic compatibility, interoperability, testability, transportability, supportability, usability, and disposability; and

g. local management constraints on how work will be done (e.g., operating procedures).

During the application of the SED Process, activities from other processes of the SE engine and to repeatedly execute the activities performed within the SED Process in order to arrive at an acceptable set of stakeholder expectations.

Once the stakeholder expectations have been approved and baselined, the stakeholder expectations are used for validation of the WBS model end product during product realization. It is vital to have baselined stakeholder expectations, to demonstrate when scope has been changed and to show why schedule and possibly budget may be impacted. Validation of the WBS model end product is obtaining confirmation from the stakeholders that the right product was built to meet their expected needs. The SED process is tightly linked to the Technical Requirements Definition, Logical Decomposition and Design Solution Processes. This linkage is important since some requirements will become fully defined only through system decomposition at later stages of development. All three of these processes deal with the development and refinement of various types of requirements.

Enabling products at all levels of the WBS model are to be considered during the SED process. For example, a launch pad is an enabling product for a launch vehicle system, which is likely to impose constraints on the launch vehicle that needs to be identified early in the system life-cycle. Key stakeholders may impose an expectation in the form of a constraint that the development of the launch vehicle use existing launch pad infrastructure with little to no modification.

The following are key inputs and outputs to the Stakeholder Expectations Definition Process.

Key Inputs and Sources:

a. Customer expectations (from users and program and/or project).

b. Other stakeholder expectations (from project and/or other interested parties of the WBS model products recursive loop).
c. Customer flow-down requirements from previous level WBS model products (from Design Solution Definition Process recursive loop and Requirements Management and Interface Management Processes).

Note: This would include requirements for initiating enabling product development to provide appropriate life-cycle support products and services to the mission, operational, or research end product of the WBS model.

Key Outputs and Destinations:

a. List of stakeholders with Point of Contact (POC) name, organization, contact information, and brief description of stakeholder's involvement in the program (to Technical Data Management Process).

b. Set of validated stakeholder expectations, including interface requirements (to Technical Requirements Definition, Requirements Management, and Interface Management Processes).

c. Baseline Concept of Operations (ConOps) (to Technical Requirements Definition Process and Configuration Management Processes).

d. Measures of Effectiveness (MOEs) (to Technical Requirements Definition Process and Technical Data Management Process).

4.1.1.1.1 Stakeholder List

Advocacy for new programs and projects may originate in many organizations within the space community. These organizations are commonly referred to as stakeholders. A stakeholder is a group or individual who is affected by or is in some way accountable for the outcome of an undertaking.

Stakeholders can be classified as customers and other interested parties. Customers are those who will receive the goods or services and are the direct beneficiaries of the work.

Other interested parties are those who affect the project by providing broad, overarching constraints within which the customers' needs are to be achieved. These parties may be affected by the resulting product, the manner in which the product is used, or have a responsibility for providing life cycle support services.

A comprehensive list of stakeholders is compiled early in the SED process. The stakeholder list is updated and maintained throughout the life-cycle. Once the role and involvement of the stakeholder is understood, the stakeholder list serves as the basis for identifying communication needs across the project.

The following tasks and steps are provided to assist with satisfying the requirements contained in MPR 7123.1.

Tasks	Steps
Identify Stakeholders	a. Identify stakeholders (e.g., acquirers, users, operators, etc.) who will have input to the operational capabilities and requirements for the system. Examples include Congress, NASA Headquarters, NASA Centers, NASA advisory committees, the National Academy of Sciences, the National Space Council, scientists, project managers, and subsystems engineers and many other groups in the science and space communities. b. Identify other interested parties who will be impacted by or will impact the development and use of the system. Examples include the Project Manager, Engineering, Safety and Mission Assurance, Facilities, Logistics, Test, Operations, Procurement, Contractors, Vendors, etc.
Capture and compile stakeholder list	a. For each stakeholder, capture the following information: 1) Organization 2) A short description of the stakeholder relative to project interest 3) POC name and contact information 4) Life-cycle Phase(s) of interest

	5) Organize by level of involvement
Manage and maintain stakeholder list	a. Maintain stakeholder list throughout the life-cycle 1) Update as necessary

Examples

International Council on Systems Engineering (INCOSE) Systems Engineering Handbook, Section 4.1.2.1	a. Provides methodology to identify stakeholder

Stakeholder List Example
A stakeholder list provides stakeholder contact information and a description of their role and level of involvement. Stakeholders are initially identified at an organizational level. This will ensure organizational involvement is maintained even if there is a turnover of personnel.

A compiled stakeholder list includes information on the stakeholder's roles and their level of involvement during the system life-cycle. This information can then be used to assist with the development of working group charters and membership on other programmatic and technical boards. A stakeholders list can assist with communication planning and management by identifying stakeholder information needs in terms of status reports or other project deliverables.

Typically, the stakeholder list will be contained in the SEMP. A separate stakeholder roster can be maintained with stakeholder contact information and updated on a regular basis.

An example of a stakeholder list is provided in the table below.

Example of Notional Stakeholder List.

Stakeholder Organization	Stakeholder Name	Stakeholder Title	Stakeholder e-mail	Stakeholder phone	Stakeholder Scope and Involvement

4.1.1.1.2 Documenting Validated Stakeholder Expectations

Stakeholder expectations are the basis for developing functional and performance requirements for the system of interest or product. Therefore, stakeholder expectations need to be developed properly to ensure proper bi-directional traceability between the stakeholder expectations and the system's technical requirements.

Stakeholder expectations are developed using different means, techniques, and from a variety of sources. Stakeholder expectations can be received formally after receipt of a FAD or through an Agency generated NGOsDocument. Stakeholder expectations can also be elicited informally through an interview process or working group/Integrated Product Team (IPT) approach.

Stakeholder expectations are defined in individual and complete sentences where the expectation is clear and concise. The following are characteristics of stakeholder expectation statements.

a. Individual Stakeholder Expectation statements:
   1) Stated in a qualitative or quantitative manner. A qualitative expectation example would be that crew capsule will comfortably seat a crew of 4 astronauts. A quantitative expectation example would state that the launch vehicle will deliver a 25-metric ton payload to low earth orbit (LEO).
   2) Stated in manner that is feasible to satisfy. An expectation may not be technically feasible outright or, if technically feasible, it may not be feasible within the constraints of cost and schedule.
   3) Stated in a manner that will ensure the right system gets built to satisfy the needs of the user or customer.
   4) Stated in a manner that is not misleading or lends itself to multiple interpretations.

b. Multiple Stakeholder Expectation statements (in pairs or as a set)
   1) Stated without redundancy or without stating the same expectation across multiple expectation statements.
   2) Stated using consistent terms and terminology. A rocket and launch vehicle may be synonymous, however, one term needs to be selected and used consistently throughout.
   3) Stated without being in conflict with other stakeholder expectation statement(s).
   4) Stated without invoking questionable utility. Stating an expectation that the crew living quarters needs to provide a quiet and relaxing environment may

initially appear to be of questionable utility, but it may turn out to be a reasonable expectation for a long-duration space mission.

5) Stated without invoking a risk of dissatisfaction. A design implementation is likely to be based on decision made after considering different alternative designs. If the customer or user is expecting toggle switches rather than push button switches, then this expectation is captured to preclude a risk of satisfaction.

Stakeholder expectations are used to define and create use cases, scenarios, and operational concepts. Stakeholder expectations can be provided as needs, wants, desires, capabilities, external interfaces, and constraints.

Stakeholders are engaged at all levels of the system and their involvement will be instrumental to the development of the Concept of Operations. At higher levels of the system, engagement of the stakeholders may be more formal using working groups or IPTs. At lower levels of the system, stakeholder expectations may be elicited less formally through an interview process. Regardless, stakeholders exist at all levels of the system and their engagement, participation and involvement throughout the product life-cycle is critical overall mission success.

At the system level, MOEs are defined in conjunction with the development of stakeholder expectations.

The following tasks and steps are provided to assist with satisfying the requirements contained in MPR 7123.1. They are provided for eliciting, compiling, prioritizing, and validating stakeholder expectations.

Tasks	Steps
Identify sources of stakeholder expectations	a. Identify sources of stakeholder expectations b. Agency NGOs c. FAD d. Project Plan e. Statutory and Regulatory Requirements f. NASA Standards g. Industry Standards h. Higher level system requirements
Engage and elicit stakeholder expectations	a. Establish applicable working groups

	and IPT or combination to engage stakeholders b. Schedule and conduct stakeholder engagement meetings and/or interviews, as needed c. Track progress of planned vs. actual stakeholder engagement meeting and/or interviews
Compile and assemble list of candidate stakeholder expectations	a. Create stakeholder expectation statements 1) Needs, Goals and Objectives (see guidance for writing expectations statements below) 2) Ensure MOEs can be derived from candidate stakeholder statements b. Develop and maintain a stakeholder expectations database with necessary attributes 1) Create a unique-identifier (ID) 2) NGO Description 3) Rationale
Prioritize list of candidate stakeholder expectation statements	Collaborate with stakeholders to develop and maintain expectation statements using a means to facilitates prioritization
Validate stakeholder expectation statements	a. Confirm each stakeholder expectation statement is understood, achievable, and complete b. Confirm the prioritized set of stakeholder expectation statements is free of conflicts, inconsistencies, inaccuracies, and contradictions
Develop traceability matrix	a. Develop and prepare bi-directional traceability matrix b. Validate the bi-directional traceability of the stakeholder expectations
Prepare Stakeholder Expectations Document, or equivalent	Use the outline provided in the Stakeholder Expectations Document template and include validated bi-directional traceability matrix

Submit Stakeholder Expectations Document, or equivalent, for approval	a. Obtain approval from the project set of stakeholders that the Stakeholder Expectations Document has achieved sufficient maturity to be baselined b. Obtain signature approval to baseline the Stakeholder Expectations Document from the appropriate Director Governing Authority (DGA) or TA
Manage and maintain Stakeholder Expectations Document	The baselined Stakeholder Expectations Document is placed under formal configuration control in accordance with established configuration management procedures

Examples

Expectations Prioritization Matrix	Prioritization will facilitate the decision making process when conflicts and inconsistencies when collecting and analyzing stakeholder expectations.
NASA Systems Engineering Handbook, NASA/SP-2007-6105, Figure 4.1-2	Stakeholder Expectation Product Flow

4.1.1.1.3 Measures of Effectiveness

MOEs are the “operational” measures of success that, if met, indicate achievement of mission or operational objectives in the intended operational environment. MOEs are intended to focus on how well mission or operational objectives are achieved, not on how they are achieved, i.e., MOEs are independent of any particular solution. As such, MOEs are the standards against which the “goodness” of each proposed solution may be assessed in trade studies and decision analyses. Measuring or calculating MOEs not only makes it possible to compare alternative solutions quantitatively, but sensitivities to key assumptions regarding operational environments and to any underlying MOPs can also be investigated.

In the systems engineering process, MOEs are used to:

a. Define high-level operational requirements from the stakeholder viewpoint.

b. Compare and rank alternative solutions in trade studies.

c. Investigate the relative sensitivity of the projected mission or operational success to key operational assumptions and performance parameters.

d. Determine that the mission or operational success quantitative objectives remain achievable as system development proceeds.

NASA Systems Engineering Handbook SP 6105, Figure 6.7-4, shown as Figure 4 below, shows the relationships of MOEs, MOPs, and TPMs. A set of mission critical MOEs may also be referred to as Key Performance Parameters (KPPs). This set of mission critical MOEs or KPPs represents an expectation that is critical to the success of the system, and failure to satisfy these measures will cause the stakeholder to deem the system unacceptable. Examples of typical MOEs are weight, availability, mobility, user/operator comfort, computer processing unit (CPU) capacity, and parameters associated with critical events during operations. Whereas weight is generally stated in quantitative terms and can be easily allocated to lower level system products, other MOEs may be qualitative or not easily allocated and thus will need MOPs derived that can be used as design-to requirements. MOPs are derived during the technical requirements definition process activities.

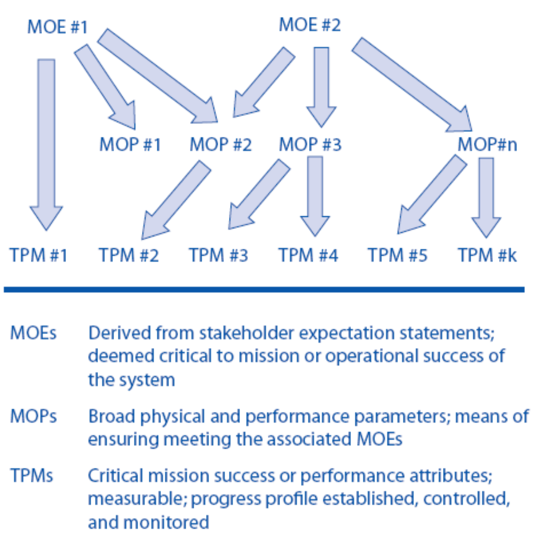


Figure 4. Relationships of MOEs, MOPs, and TPMs

MOEs and KPPs are maintained at the system level and are used to validate the demonstrated system performance against the stakeholder expectations or top-level requirements. They will also be needed for test and evaluation planning purposes during the System Design phase. Test and evaluation planning will use MOEs, MOPs and TPMs to derive and develop test objectives and corresponding data measurement requirements. The data measurement requirements for the developmental test flights will need to be considered as part of the design and development of the system.

The following tasks and steps are provided to assist with satisfying the requirements contained in MPR 7123.1.

Tasks	Steps
Derive and compile a list of MOEs from stakeholder expectation statements	Prepare MOEs in accordance with INCOSE Technical Measurement Guide, INCOSE-TP-2003-021-01, Version 1.0 [2005], Section 6.3.1, Selecting and Specifying MOEs
Identify a set of MOEs that are critical to the success of the system	Identify as set of MOEs or KPPs that, if not satisfied, will deem the system unacceptable.
Baseline MOEs	a. Obtain approval from the project set of stakeholders that the MOEs have achieved sufficient maturity to be baselined b. Baseline the MOEs in accordance with established configuration management procedures
Manage and maintain MOEs	The baselined MOEs are placed under formal configuration control in accordance with established configuration management procedures

Resources / Examples for MOE Development

NASA Systems Engineering Handbook, NASA/SP-2007-6105, Section 6.7.2.2	Status Reporting and Assessment: Technical Measures – MOEs, MOPs, and TPMs
INCOSE Technical Measurement Guide, INCOSE-TP-2003-021-01, Section 6.3.1	Selecting and Specifying MOEs
Defense Acquisition University (DAU) Systems Engineering Fundamentals [2001], Chapter 14	Metrics
DAU Test and Evaluation Management Guide, Fifth Edition, [2005], Chapter 13	Evaluation

4.1.1.1.4 Concept of Operations

A ConOps is a user-oriented document that describes system characteristics for a proposed system from the users' viewpoint. The ConOps is used to communicate system characteristics to the user, buyer, developer, and other stakeholders.

A ConOps is developed for each product in the Product Breakdown Structure (PBS) The system level ConOps is provided during the concept studies phase and provided for the MCR. The ConOps supports the system requirements activity and be included in the SRR to bounce against requirements.

Developing and baselining a thorough ConOps in the early phase of the project and refining it through the requirements development and design phases is critical to precluding an unsuccessful validation of the system of interest or product during the product realization phase.

The following information is captured in conjunction with the development of the ConOps. Individual operational concepts are developed across the system life-cycle and compiled for insertion into the system's ConOps.

List all assumptions that were made while developing the operational concepts. An assumption provides insight into what else has to be true for your operational concept to be true.

List all interfaces that were identified while developing the operational concepts. Additionally, there may unique interfaces that are only used during one life-cycle, but not used during a different life-cycle phase. An example would be identifying interface requirements for Developmental Flight Instrumentation (DFI) which is not normally installed in production hardware.

List all drivers and constraints that were identified while developing the operational concepts. Again, there may be drivers and constraints that are used during one life-cycle, but not for a different life-cycle phase. A key driving example would be developing a design for a crew vehicle that accommodates six astronauts while being constrained by size and weight.

List any additional functionality beyond what is included in the current system of interest. Given the realities of budget, schedule, and technical constraints, establishing priorities is fundamental to the development of any program or project. The proposed capabilities are listed order of priority (importance) in terms of meeting the stated needs, goals, and objectives of the system of interest and its parent.

List all issues, concerns, and risks that were identified during development of the operational scenarios and ConOps. These can include areas of uncertainty, feasibility questions, and inconsistencies or conflicts. Emerging technologies needed to get the performance that matches your expectations are identified. The current maturity level of these technologies is the basis for quantifying the level of risk to the program or project.

The following tasks and steps are provided to assist with satisfying the requirements contained in MPR 7123.1.

Tasks	Steps
Validate the mission scope and the system boundary	Identify, analyze, clarify and prioritize: 1) End product uses 2) Operational profiles 3) Scenarios
Develop description of the system	Develop description that includes: 1) Operational environment 2) Constraints 3) Drivers 4) Users/operators and their roles and characteristics
Develop and document ConOps	Develop ConOps to include: 1) Operational scenarios and/or DRM 2) Operational phases 3) Operational timeline 4) Command and Data Architecture 5) Facilities and logistics support 6) End-to-end communication strategy 7) Critical Events
Synthesize, analyze, and assess key implementing concepts for the system and its elements	a. Identify strategies for development and integration, production, test, operations and logistics b. Identify, analyze and clarify constraints resulting from these strategies
Baseline the ConOps	a. Obtain approval from the project set of stakeholders that the ConOps has achieved sufficient maturity to be baselined b. Baseline the ConOps in accordance with established configuration management procedures

Manage and maintain ConOps	The baselined ConOps is placed under formal configuration control in accordance with established configuration management procedures

Resources / Examples for Con Ops Development

NASA Systems Engineering Handbook, NASA/SP-2007-6105, Figure 4.1-3	Flow diagram of typical ConOps development for a science mission
NASA Systems Engineering Handbook, NASA/SP-2007-6105, Figure 4.1-4	End-to-end operational architecture
NASA Systems Engineering Handbook, NASA/SP-2007-6105, Figure 4.1-5a	Lunar sortie timeline
NASA Systems Engineering Handbook, NASA/SP-2007-6105, Figure 4.1-5b	Lunar sortie DRM
NASA Systems Engineering Handbook, NASA/SP-2007-6105, Figure 4.1-6	Detailed, integrated timeline for a science mission
NASA Systems Engineering Handbook, NASA/SP-2007-6105, Table 4.1-1	Typical Operational Phases for a NASA mission
Guide for the Preparation of Operational Concept Documents, ANSI/AIAA G-043-1992	A guide that describes a technique the Operational Concept, which is used to support the definition, development, and maintenance of a system. Its purpose is also to provide practical guidelines regarding how to apply this technique and recommends how to package the results of this work into an Operational Concept Document (OCD); a.k.a., ConOps
IEEE Concept of Operations Document, IEEE Std 1362™-1998 (R2007)	A guide prescribing the format and contents of the ConOps document

4.1.1.1.5 Data Requirements Description (DRD)

For any DRDs that are applicable to this process, refer to MPR 7123.1.

4.1.1.2 Technical Requirements Definition

The Technical Requirements Definition (TRD) Process transforms the baselined stakeholder expectations into unique, quantitative, and measurable technical requirements used for defining a design solution for the end product.

TRD is a recursive and iterative process that develops the stakeholders' requirements, product requirements, and lower level requirements. These requirements enable the description of all inputs, outputs, and required relationships between inputs and outputs. Requirements documents are developed to organize and communicate requirements to the stakeholders. The TRD process is applied to all levels of a system or product.

The following are key inputs and sources to the TRD process.

<u>Key Inputs and Sources</u>:

a. Baselined set of stakeholder expectations (from Stakeholder Expectations Definition and Configuration Management Processes).

b. Baselined Concept of Operations (from Stakeholder Expectations Definition and Configuration Management Processes).

c. Baselined Enabling Product Support Strategies (from Stakeholder Expectations Definition and Configuration Management Processes).

d. Measures of Effectiveness (from Stakeholder Expectations Definition and Technical Data Management Processes).

Note: Enabling product information supports the identification of functions and constraints associated with a particular level of the system of interest. These functions and constraints are used to develop technical requirements. The NASA SE Engine is also employed to develop and design enabling products for a system or product, which gives rise to having baselined enabling support information available to support the execution of the TRD process.

The following are key outputs and destinations from the TRD process.

<u>Key Outputs and Destinations</u>:

a. Set of baselined requirements that represents a reasonably complete description of the problem to be solved, including interface requirements (to Logical Decomposition and Requirements and Interface Management Processes).

b. Sets of MOPs that satisfy the MOEs to which a set is related to (Logical Decomposition and Technical Data Management Processes).

c. Set of critical TPMs that if not met will put the project in cost, schedule, or performance risk (to Technical Assessment Process).

4.1.1.2.1 Developing a Set of Technical Requirements

Collectively, the TRD process inputs consisting of the Stakeholder Expectations Document, ConOps, and enabling product support strategies are used to identify functions that the system of interest is expected to perform. These functions form the basis for developing a set of technical requirements that are approved and baselined by the project stakeholders.

The Logical Decomposition process continues to further decompose and be allocated to lower levels of the system for every level of the Product Breakdown Structure (PBS) that has requirements.

A set of technical requirements is developed and used for defining a design solution at each level of the system of interest and corresponding set of enabling products.

The iterative and recursive nature of the system design processes will continually refine the technical requirements that support the full definition of the system of interest or product. Additional guidance on developing quality requirements can be found in Appendix C.

The following tasks and steps are provided to assist with satisfying the requirements contained in MPR 7123.1.

Tasks	Steps
Prepare a context diagram for the system of interest	a. Identify the system boundary b. Identify external interfaces c. Describe interaction with external interfaces

Perform functional analysis to identify specific functions called out in the ConOps	a. Methods to perform functional analysis include: 1) Functional Flow Block Diagrams (FFBDs) 2) Enhanced FFBDs 3) N-squared (N^2) Diagrams 4) Timing Analysis b. Perform trade studies as needed to develop performance parameters to populate technical performance requirements c. Ensure each identified function is assigned a unique-ID and categorized; e.g., derived interface functions are categorized as interface functions to support the development of interface requirements
Define technical requirements that satisfy each of the identified functions	a. Follow the guidance on writing good technical requirements contained in NASA Systems Engineering Handbook 6105, Appendix C b. Check each technical requirement against the following criteria: 1) Clarity 2) Completeness 3) Consistency 4) Traceability 5) Feasibility 6) Functionality 7) Performance 8) Interfaces 9) Maintainability 10) Reliability 11) Verifiability c. Generate a requirements rationale statement that explains how the specific

	requirement was derived by referencing source material versus trying to justify the requirement d. Generate a bi-directional traceability matrix between the functions and operations performed by the system of interest and the technical requirements e. Ensure derived technical requirements trace back to a single parent requirement f. Ensure each derived technical requirement is assigned a unique -ID and categorized; e.g., derived interface requirements are categorized as interface requirements to support interface design activities
Validate technical requirements	a. Vet a subset or complete set of technical requirements with the appropriate stakeholders to obtain their concurrence b. Maintain a requirements health chart that monitors each requirements status against the aforementioned criteria: 1) Passes: green 2) Fails: red 3) Pending Analysis: yellow 4) Not applicable: white c. Prepare and manage action items to resolve any requirement validation issues d. Refer to NASA Systems Engineering Handbook, Appendix C: How to Write a Good Requirement

Consolidate and prepare Technical Requirements Document	a. Refer to DRD Standard/SE-Requirement Specification (STD/SE-REQSPEC), Specifications, for a description on preparing the specification for a specific Configuration Item (CI). b. Additional guidance for preparing specifications in accordance with MIL-STD-961 is contained in MIL-HDBK-520, Systems Requirements Document Guidance, Section 6.1, System Requirements Document (SRD) Preparation
Submit the completed set of technical requirements for approval	a. Obtain approval from the project set of stakeholders that the set of technical requirements has achieved sufficient maturity to be baselined b. Obtain signature approval to baseline the set of technical requirements from the appropriate TA
Manage and maintain the set of technical requirements	The baselined set of technical requirements document is placed under formal configuration control in accordance with established configuration management procedures.

Examples

NASA Systems Engineering Handbook, NASA/SP-2007-6105, Appendix F	Context Diagrams
NASA Systems Engineering Handbook, NASA/SP-2007-6105, Appendix F	Figure F-1, FFBD
NASA Systems Engineering Handbook, NASA/SP-2007-6105, Appendix F	Figure F-4, Enhanced FFBD
NASA Systems Engineering Handbook, NASA/SP-2007-6105, Appendix F	Figure F-6, N^2 Diagram
NASA Systems Engineering Handbook, NASA/SP-2007-6105, Appendix F	Figure F-7, Timing Diagram
NASA Systems Engineering Handbook, NASA/SP-2007-6105, Appendix F	Figure F-8, State Analysis
NASA Systems Engineering Handbook NASA/SP-2007-6105, Section 4.2.2.3	Figure 4.2-3, The flow down of requirements
NASA Systems Engineering Handbook, NASA/SP-2007-6105, Section 6.8.2.2	Trade Studies
NASA Systems Engineering Handbook, NASA/SP-2007-6105, Appendix F	Requirements Allocation Sheet, Figure F-5
Requirements Analysis Metrics	Appendix C
MIL-HDBK-520(USAF), Systems Requirements Document Guidance	Systems Requirement Document guidance, based on MIL-STD-961D, Department of Defense (DoD) Standard Practice Defense and Program-Unique Specifications Format and Content, and Data Item Description (DID) DI-IPSC-81413A, System/Subsystem Specification

4.1.1.2.2 Measures of Performance (MOP)

MOPs are derived from MOEs. Each MOPs contains a specific quantitative parameter that can be measured. Collectively, MOPs are the measures that characterize the physical or functional attributes relating to the system. Monitoring and tracking MOPs during the design and development phase will ensure adequate progress is being made in reducing overall project risk.

Examples of MOPs are contained in the NASA Systems Engineering Handbook 6105, Section 6.7.2.2.

The following tasks and steps are provided to assist with satisfying the requirements contained in MPR 7123.1.

Tasks	Steps
Derive and compile a list of MOPs	a. Decompose MOEs to derive MOPs b. Ensure each derived MOPs can be used as a measure of actual performance to support system test and evaluation planning and execution
Manage and maintain MOPs	The baselined MOPs are placed under configuration control in accordance with established configuration management procedures

Examples

NASA Systems Engineering Handbook, NASA/SP-2007-6105, Section 6.7.2.2	Status Reporting and Assessment: Technical Measures – MOEs, MOPs, and TPMs
INCOSE Technical Measurement Guide, INCOSE-TP-2003-021-01, Section 6.3.2	Selecting and Specifying MOPs

4.1.1.2.3 Technical Performance Measures (TPM)

TPMs are typically derived from the defined set of MOEs and MOPs. Significant time and effort could potentially be spent monitoring and tracking TPMs during the system design phase. To preclude this, scrutiny of candidate TPMs will ensure a minimal set is selected to accurately reflect the projected technical performance of the system of interest.

TPMs are monitored collectively because they interact with other TPMs. Any significant changes to one TPM are likely to impact one or more other TPMs. For example, if the overall mass of the system is increasing, there is likely to be a corresponding impact to system performance parameters such as velocity, acceleration, and payload capability.

NASA SE Handbook 6105, Section 6.7.2.2, describes an approach to selecting TPMs.

The following tasks and steps are provided to assist with satisfying the requirements contained in MPR 7123.1.

Tasks	Steps
Develop TPM hierarchy	Decompose MOEs and MOPs to derive TPMs
Manage and maintain TPMs	The baselined TPMs are placed under formal configuration control in accordance with established configuration management procedures
Status and Report TPMs	Prepare and submit TPM status reports in accordance with project communication requirements

Examples

NASA Systems Engineering Handbook, NASA/SP-2007-6105, Section 6.7.2.2	Status Reporting and Assessment: Technical Measures – MOEs, MOPs, and TPMs
INCOSE Technical Measurement Guide, INCOSE-TP-2003-021-01, Section 6.3.3	Selecting and Specifying TPMs

4.1.1.2.4 <u>Data Requirements Description (DRD)</u>

For any DRDs that are applicable to this process, refer to MPR 7123.1.

4.1.2 Technical Solution Definition Processes

4.1.2.1 Logical Decomposition

Logical Decomposition (LD) is the process for creating the detailed functional requirements that enable NASA programs and projects to meet stakeholders' expectations. The LD process identifies "what" will be achieved by the system at each level to enable a successful project. LD utilizes functional analysis to create a system architecture and to decompose top-level (or parent) requirements and allocate them to the desired level of the project.

The LD process is used to:

a. Improve the understanding of the defined technical requirements and the relationships among the requirements, and

b. Decompose the parent requirements into a set of logical decomposition models and their associated sets of derived technical requirements for input to the Design Solution Definition Process.

<u>Inputs and Sources</u>:

a. The baselined set of validated technical requirements, including interface requirements (from Technical Requirements Definition and Configuration Management Processes).

b. The defined MOPs (from Technical Requirements Definition and Technical Data Management Processes).

<u>Outputs and Sources</u>:

a. Set of validated derived technical requirements, including interface requirements (to Design Solution Definition and Requirements and Interface Management Processes).

b. The set of logical decomposition models (to Design Solution Definition and Configuration Management Processes).

c. Logical decomposition work products (to Technical Data Management Processes).

For each product in the PBS, the LD process begins by taking the top-level (parent) requirements and identifying functions that achieve a desired system objective (or stakeholder need). At each level, the LD process begins with the requirements that have been allocated to that product and defines the functions necessary to meet those requirements. These functions are used to derive functional requirements for the product, define interfaces, and start the system architecture for the next level of the PBS. These partitioned functions are organized and constitute the functional architecture for a specific level of the system. The constituted functional architecture is then used to derive a set of corresponding technical requirements. This process is repeated until the partitioned functions contain enough detail to begin the Design Solution Definition (DSD) process.

The partitioned functions and derived technical requirements need to be consistent with the MOPs.

The LD process interacts significantly with the Requirements Management (RM), Interface Management (IM), Technical Data Management (TDM) and CM processes.

Any derived technical requirements will need to be managed per the RM process. A description of the RM process is normally contained in the project SEMP. Interface requirements that are identified will be managed using the IM process. Similarly, a description of the IM process is normally contained in the project SEMP.

The LD process employs similar tools and techniques that were used to perform the TRD process. As described in the NASA SE Handbook 6105, Section 4.3.2.2 and Appendix F, these tools and techniques include FFBDs, Enhanced FFBDs, N^2 diagrams, timing diagrams, and state analysis. These LD work products need to be captured and maintained in a repository using the TDM process. Thereby, the LD work products are readily available to support the information needs of the Decision Analysis (DA) and Technical Assessment (TA) processes.

Information produced by the LD process is primarily used to derive requirements and support the major technical reviews that are conducted during Pre-Phase A through Phase C. The logical decomposition models and corresponding sets of derived technical requirements are developed, baselined and refined during this phase of the overall system life-cycle. During the Product Realization Process, these models are used to validate that the system being designed performs all the necessary functions and therefore meets the stakeholders' expectations, needs, objectives, and goals.

4.1.2.1.1 System Architecture

The system architecture lays out the elements of the system or product hierarchy so that the roles, relationships, dependencies, and interfaces can be clearly defined and understood. The NASA Systems Engineering Handbook 6105 provides a depiction of the product hierarchy as shown in Figure 5 below.

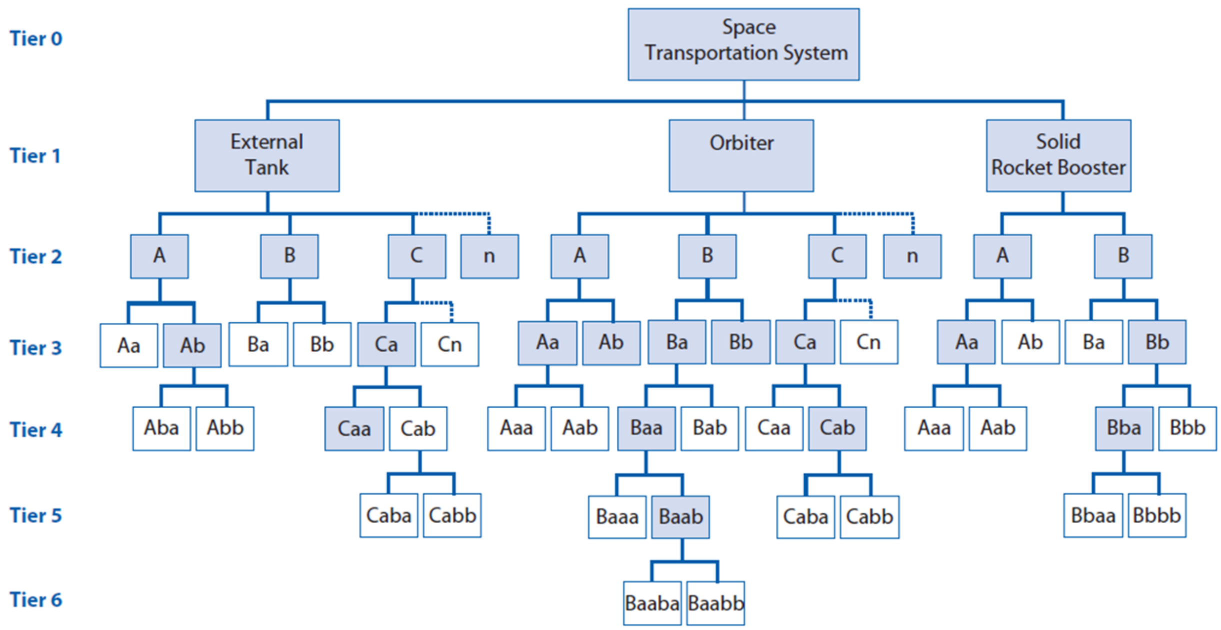


Figure 5. Product Hierarchy: Complete Pass through System Design Processes Side of the SE Engine

Defining the system architecture is recursive and iterative and continues until all desired levels of the architecture/system have been analyzed, defined, and baselined.

The following tasks and steps are provided to assist with satisfying the requirements captured in MPR 7123.1.

Tasks	Steps
Define system architecture model	Define the structure and relationships of hardware, software, communications, operations, etc. Typically identified in a PBS
Manage and maintain depiction and description of the system architecture model	The baselined system architecture model is placed under formal configuration control in accordance with established configuration management procedures

Examples

NASA Systems Engineering Handbook, NASA/SP-2007-6105, Section 2.3.2.1	Figure 2.3-6, Product hierarchy: complete pass through system design processes side of the SE engine
NASA Systems Engineering Handbook, NASA/SP-2007-6105, Section 4.3.2.1	Figure 4.3-2, Example of a Product Breakdown Structure

4.1.2.1.2 Decomposed and Allocated Set of Derived Technical Requirements

As the system architecture is defined, the top-level system requirements (defined in the Technical Requirements Definition Process) can be decomposed through logical decomposition and allocated to the products of the PBS within the system architecture. The requirements that have been decomposed then become the basis for developing derived Technical Requirements.

The tools and methods described here are similar to those used in the TRD process.

The following tasks and steps are provided to assist with satisfying the requirements captured in MPR 7123.1.

Tasks	Steps
Decompose and analyze previously defined technical requirements	Decompose and analyze by: 1) Functions 2) Time 3) Behavior 4) Data Flow 5) Objects 6) States and Modes 7) Failure Modes and Effects
Allocate decomposed functions to the System Architecture Model	Assign a specific function or set of decomposed functions to a specific element of the system architecture
Perform functional analysis to identify specific functions	Methods to perform functional analysis include: 1) FFBDs 2) Enhanced FFBDs 3) N^2 Diagrams 4) Timing Analysis

	Perform trade studies as needed to develop performance parameters to populate technical performance requirements Ensure each identified function is assigned a unique -ID and categorized; e.g., derived interface functions are categorized as interface functions to support the development of interface requirements
Define a set of derived technical requirements that satisfy each of the identified functions	Follow the guidance on writing good technical requirements contained in NASA SE Handbook 6105, Appendix C Check each technical requirement against the following criteria: 1) Clarity 2) Completeness 3) Consistency 4) Traceability 5) Feasibility 6) Functionality 7) Performance 8) Interfaces 9) Maintainability 10) Reliability 11) Verifiability Generate a requirements rationale statement that explains how the specific requirement was derived by referencing source material versus trying to justify the requirement Generate a bi-directional traceability matrix between the functions and operations performed by the system of interest and the technical requirements Ensure derived technical requirements trace back to a parent requirement(s) Ensure each derived technical requirement is

	assigned a unique-identifier (unique-ID) and categorized; e.g., derived interface requirements are categorized as interface requirements to support interface design activities
Validate the set of derived technical requirements	Vet a subset or complete set of technical requirements with the appropriate stakeholders to obtain their concurrence Maintain a requirements health chart that monitors each requirements status against the aforementioned criteria: 1) Passes: green 2) Fails: red 3) Pending Analysis: yellow 4) Not applicable: white Prepare and manage action items to resolve any requirement validation issues Refer to NASA SE Handbook, Appendix C: How to Write a Good Requirement
Submit the completed set of derived technical requirements for approval	Obtain approval from the project set of stakeholders that the set of technical requirements has achieved sufficient maturity to be baselined Obtain approval from the project set of stakeholders that the set of technical requirements has achieved sufficient maturity to be baselined Obtain signature approval to baseline the set of derived technical requirements from the appropriate TA
Manage and maintain a set of derived technical requirements	The baselined set of derived technical requirements are placed under formal configuration control with established configuration management procedures.

Examples

NASA Systems Engineering Handbook, NASA/SP-2007-6105, Appendix F	Context Diagrams
NASA Systems Engineering Handbook, NASA/SP-2007-6105, Appendix F	Figure F-1, FFBD
NASA Systems Engineering Handbook, NASA/SP-2007-6105, Appendix F	Figure F-4, Enhanced FFBD
NASA Systems Engineering Handbook, NASA/SP-2007-6105, Appendix F	Figure F-6, N^2 Diagram
NASA Systems Engineering Handbook, NASA/SP-2007-6105, Appendix F	Figure F-7, Timing Diagram
NASA Systems Engineering Handbook, NASA/SP-2007-6105, Appendix F	Figure F-8, State Analysis
NASA Systems Engineering Handbook NASA/SP-2007-6105, Section 4.2.2.3	Figure 4.2-3, The flowdown of requirements
NASA Systems Engineering Handbook, NASA/SP-2007-6105, Section 6.8.2.2	Trade Studies
NASA Systems Engineering Handbook, NASA/SP-2007-6105, Appendix F	Requirements Allocation Sheet, Figure F-5
MIL-HDBK-520(USAF), Systems Requirements Document Guidance	Systems Requirement Document guidance, based on MIL-STD-961D, Department of Defense Standard Practice Defense and Program-Unique Specifications Format and Content, and DID DI-IPSC-81413A, System/Subsystem Specification
Requirements Analysis Metrics	Appendix C
System Requirements Document template	STD/DRD-SE-REQSPEC

4.1.2.1.3 Data Requirements Description (DRD)

For any DRDs that are applicable to this process, refer to MPR 7123.1.

4.1.2.2 Design Solution Definition

The DSD process translates high-level requirements derived from stakeholder expectations and the outputs of the Logical Decomposition process into a design solution. The process involves transforming the defined logical decomposition models and their associated derived technical requirements into alternative solutions, which are then analyzed through detailed trade studies. A preferred alternative is selected and is then defined into a final design solution that satisfies the technical requirements. The DSD is used to generate the end product specifications that will be used to produce the product and to conduct product verification. This process may be further refined depending on whether there are additional subsystems or enabling products that need to be defined.
The following are key inputs and outputs to the DSD process.

<u>Inputs and Sources</u>:

a. A baselined set of logical decomposition models (from Logical Decomposition and Configuration Management Processes).

b. A baseline set of derived technical requirements including interface requirements (from Logical Decomposition and Configuration Management Processes).

<u>Outputs and Sources</u>:

a. A WBS model design solution definition set of requirements for the system, including specification configuration documentation and external interface specification (to Requirements and Interface Management Processes).

b. A baseline set of “analyze-to,” “make-to,” “buy-to,” reuse-to,” or set of “assemble and integrate-to” specified requirements (specifications and configuration documents) for the desired end product of the WBS model, including interface specifications (to Requirements and Interface Management Processes).

c. The initial specifications for WBS model subsystems for flow down to the next applicable lower level WBS models, including interface specifications (to Stakeholder Expectations Definition, and Requirements and Interface Management Processes).

d. The requirements for enabling products that will be needed to provide life-cycle support to the end products, including interface requirements (to Stakeholder Expectations Definition Process for development of enabling products or to Product Implementation Process for acquisition of existing enabling products, and Requirements and Interface Management Processes).

e. A product verification plan that will be used to demonstrate that the product generated from the design solution definition conforms to the design solution definition specified requirements (to Product Verification Process).

f. A product validation plan that will be used to demonstrate that the product generated from the design solution definition conforms to its set of stakeholder expectations (to Product Validation Process).

g. Baseline operate-to and logistics procedures (to Technical Data Management Process).

The System Design Processes are primarily applied in the Pre-Phase A and continue through Phase C. The System Design Processes recursively applies the Stakeholder Expectations, Technical Requirements Definition, Logical Decomposition, and Design Solution Definition processes to select a preferred design solution at the PDR and a final design solution that satisfies the technical requirements at the CDR.

The SE community often makes reference to a series of technical baselines that correlate with the major technical reviews contained in MPR 7123.1. The evolution of a system's technical baseline is based on iteratively and recursively refining the detailed design in sufficient detail to support the production and manufacturing of the end product. Table II lists and correlates the maturation of the technical baseline with the corresponding technical design review.

Table II. Evolution of the Technical Baseline

Technical Baseline	Technical Design Review
Functional Baseline	SRR
“Design-to” or Allocated Baseline	PDR
“Build-to” or Product Baseline	CDR
“As-built” (or “coded-to”) Baseline	SAR
“As-deployed” Baseline	ORR

The technical data package will continue to evolve as additional artifacts are generated to support the production and manufacturing of the end product. The complete technical data package is usually provided in conjunction with the acceptance and delivery of the end product to the customer.

Figure 6 and Figure 7 illustrate the recursive and iterative nature of the system design processes. As each level of the system is decomposed, enabling products and external interfaces are identified. The identified enabling products may become

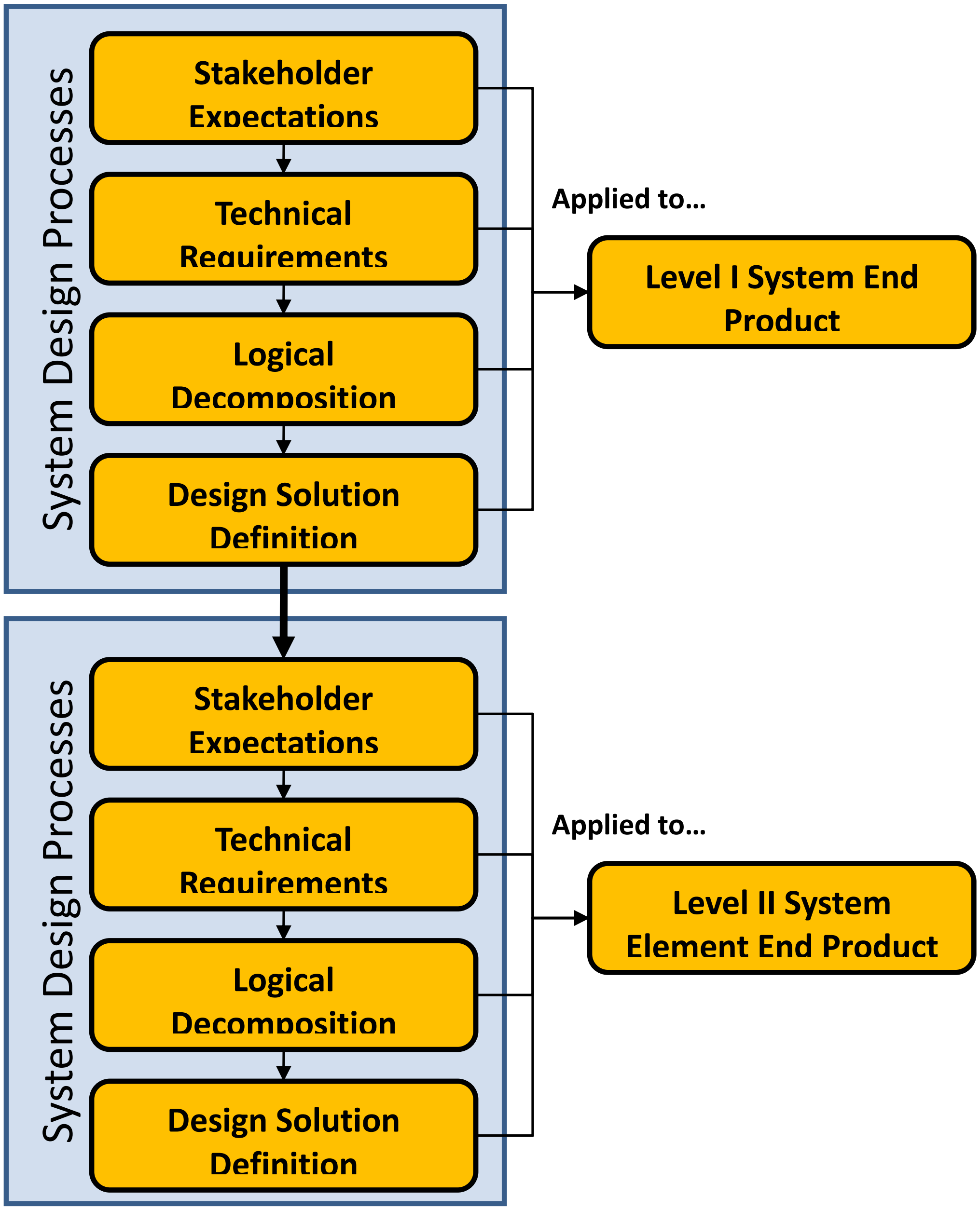


Figure 6. Recursively Applying System Design Processes

standalone projects in and of themselves and the SE Engine is once again applied to realize a design solution that satisfies the technical requirements specific to a particular enabling product. As an example, while performing the Logical Decomposition Process, special handling requirements were identified as part of transporting a rocket segment of a notional launch vehicle system. These special handling requirements are needed in order to properly and safely transport the rocket segment from the manufacturing site to other locations to support testing and launch operations. The enabling products to transport this particular rocket segment by barge, airplane, or truck would likely result in managing these enabling products as separate and distinct projects. Meanwhile, the Integrated Logistics Support Plan (ILSP) would provide a conceptual description of the different transportation methods envisioned for transporting the system.

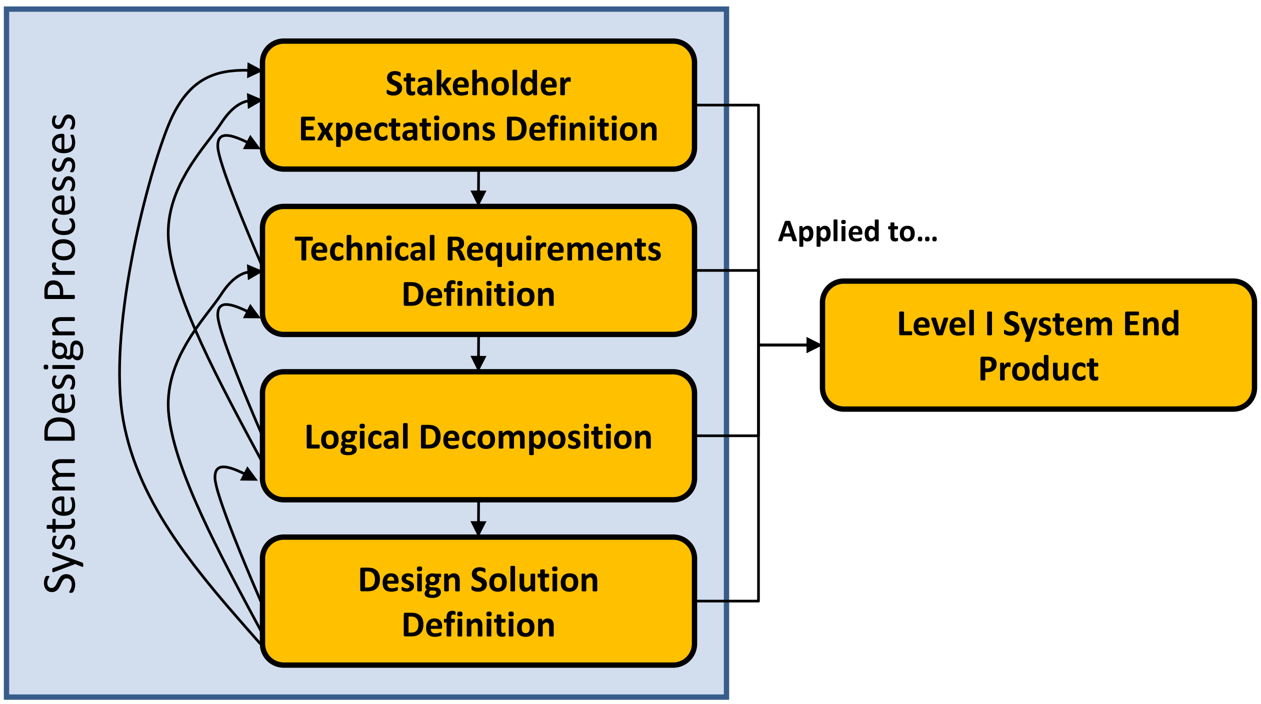


Figure 7. Iteratively Applying the System Design Processes

Transportation specific interface requirements for transporting the system would be contained in the IRD. Based on these IRD requirements, an ICD would be prepared in order to define and document the design solution between the system and the enabling product that will transport the system. Additionally, the DSD process is employed to develop the selected interface design solution that is contained in the ICD.

Internal system interfaces between two subsystems will similarly require the preparation of an IRD and/or ICD.

With each iteration through the System Design Processes, additional refinement and detail in the design and development of the system and its components is realized.

4.1.2.2.1 Developing a Design Solution Definition

The DSD process is an iterative process that is performed concurrently with SED, TRD, and LD processes.
As noted earlier, the result of the successive refinement will support the development of all of the CIs that collectively comprise the PBS.

DSD outputs occur throughout the iterative process, but they vary in scope and detail based on the project's position with the product life-cycle.

A sample of DSD metrics include the following:

a. Trade Study Satisfaction Assessment

b. For approved engineering problem reports:
   1) Quantity, by type of problem report
   2) Cycle time from disposition to incorporation of change into released engineering documents, by type of report

c. Technical Performance Measurements: objective versus achieved values

d. Number of approved engineering changes: by product, type, and life-cycle phase

e. Documents/drawings submitted for engineering release:
   1) Unacceptable submittals
   2) Total submittals

f. Number of technical action items identified during reviews and audits

g. Design efficiency metrics, such as weight, required power, and envelope dimensions (volume)

h. Cost and schedule variance for completion of the DSD steps

i. System requirements not met

j. Number or percent of system requirements verified by system analyses

k. Number of items yet to be determined within the system architecture or design

l. Number of interface issues not resolved

m. Percent of identified system elements that have been defined

The following tasks and steps are provided to assist with satisfying the requirements contained in MPR 7123.1.

Tasks	Steps
Assemble and organize all data and define objectives to support the development of a specific design solution	Review technical requirements and functional architecture Establish design objectives 1) Performance 2) Reliability 3) Compatibility 4) Design flexibility to adapt to changing environment 5) Extensibility to be used in new or multiple applications 6) Cost 7) Schedule Prioritize objectives and prepare an objectives hierarchy
Identify and define alternative design solutions	Develop alternative design solutions for each of the functional elements that perform the needed functions and adhere to the technical requirements for that functional area Identify technology requirements and assess the availability and risk Identify potential off-the-shelf solutions Integrate with Specialty Engineering 1) Safety and Reliability 2) Quality Assurance 3) Software Assurance 4) Integrated Logistics Support 5) Maintainability

	6) Producibility 7) Human Factors Engineering
Analyze each alternative design solution	a. Perform trade studies and effectiveness analyses b. Initiate requirements feedback if a viable design alternative cannot satisfy a specific functional area under consideration c. Initiate design feedback if promising physical solution or open-system opportunities have different functional characteristics than those foreseen by initial functional architecture requirements d. Assess Failure Modes and Effects e. Assess Testability Needs f. Assess Standardization opportunities to use design elements that implement commercial or international standards g. Assess life-cycle factors
Select the best design solution alternative	a. Evaluate each alternative in terms of MOEs and system cost by employing the DA process b. Rank the alternatives according to appropriate selection criteria c. Drop less promising alternatives and proceed with the next level of resolution of the design
Fully describe and document the selected design solution	a. Continue refinement of the design to fully establish the physical architecture b. Scope and content of the full design description depends on what is appropriate for the product life-cyclelife-cycle phase, the phase success criteria, and the product position within the PBS and may include: 1) Diagrams 2) Schematics 3) Concept drawings

	4) Tabular data 5) Narrative reports
Verify the design solution	a. Verify the design solution by means of a peer review per the guidelines contained in NASA SE Handbook 6105, Section 6.7 b. Report any concerns raised by the peer review that may have design and verification impacts to other system elements
Validate the design solution	a. Validate the design solution against the set of stakeholder expectations b. Continue with design solution validation until there is consistency between the system architecture, ConOps, and technical requirements
Identify enabling products	As enabling products are identified, initiate the acquisition or development of those enabling products
Baseline the design solution	a. To support the recursive nature of successive refinement that is employed to derive the physical architecture b. Avoid baselining too early to preclude stifling innovative and creative ideas, concepts and implementations

4.1.2.2.2 Logistics and Operate-to Procedures

The applicable logistics and operate-to procedures for the system describe such things as handling, transportation, maintenance, long-term storage, and operational considerations for the particular design solution.

Integrated Logistics Support (ILS) activities ensure that the product system is supported during development and operations in a cost-effective manner. ILS is primarily accomplished by early, concurrent consideration of supportability characteristics;

performing trade studies on alternative system and ILS concepts; quantifying resource requirements for each ILS element; and acquiring the support items associated with each ILS element. During operations, ILS activities support the system while seeking improvements in cost-effectiveness by conducting analyses in response to actual operational conditions. These analyses continually reshape the ILS system and its resource requirements.

An ILSP is developed and documented early in the project life-cycle. It addresses the elements in the tasks and steps provided below and include how they will be considered, conducted, and integrated into the systems engineering process needs.

The following tasks and steps are provided to assist with satisfying the requirements contained in MPR 7123.1.

Tasks	**Steps**
Develop logistics and operate-to procedures	Develop procedures with consideration to: 1) Maintenance support planning 2) Design interface 3) Technical data and technical publications 4) Training 5) Supply support 6) Test and support equipment 7) Packaging, handling, storage, and transportation 8) Personnel 9) Logistics facilities 10) Computer resources support
Review the draft logistics and operate-to procedures	Conduct review of the draft logistics and operate-to procedures
Submit for approval	Submit the final logistics and operate-to procedures for approval to the proper designated governing authority
Maintain the logistics and operate-to procedures	Update the logistics and operate-to procedures, as required Major program milestone review Major technical review

Examples

NASA Systems Engineering Handbook NASA/SP-2007-6105	Table 4.4-1, ILS Technical Disciplines

4.1.2.2.3 Data Requirements Description (DRD)

For any DRDs that are applicable to this process, refer to MPR 7123.1.

4.2 Product Realization Processes

4.2.1 Design Realization Processes

4.2.1.1 Product Implementation

The formulation of the product implementation approach is done in conjunction with the development of the project's SEMP. Development and subsequent revisions to the project's compiled SEMP are undertaken and performed as part of the Technical Planning process. The overall scope of the project will ultimately determine the resources and schedule needed to complete the project within its prescribed constraints of cost and schedule. Similarly, the scope of the technical effort will be based on the development, preparation, and approval of the work products needed to support the product implementation process. If the scope of the product implementation effort is significant, then the project may elect to develop a subordinate product implementation management plan.

The product implementation planning effort is a concerted effort by the technical team and participatory stakeholder collaboration.

The purpose of this planning activity is to lay out the approach that will be used to support the decision-making process of deciding whether to make, buy, or reuse a product that will satisfy and meet the technical and design-to requirements.

Preparing the Product Implementation Approach also includes an awareness of the specific details for each of the technical performance and non-technical selection factors that will be used to support the decision-making process on whether to purchase, buy, or make the product. The planning effort considers each of these factors and estimates the work that will need to be done in order to develop the supporting information needed. The selection factors include:

a. Technical Performance Factors
   1) Hardware configuration
   2) Software configuration
   3) Standards
   4) Functionality
   5) Usability
   6) Supportability
   7) Interoperability
   8) Reliability
   9) Performance
   10) Adaptability/Flexibility

b. Non-technical Selection Factors
   1) Vendor characteristics
   2) Product characteristics
   3) Documentation
   4) Training
   5) Licenses

The NASA Cost Estimating Handbook provides details on preparing a credible and realistic cost analysis as part of the design alternative(s) evaluation and assessment to support the make, buy, or reuse decision-making process.

The following tasks and steps are provided to assist with satisfying the requirements contained in MPR 7123.1.

Tasks	Steps
Analyze the scope of developing, preparing, and maintaining the Product Implementation Approach	a. Assemble and review the list of work products required to support the product implementation approach b. Review Stakeholder NGOs 1) FAD 2) PCA 3) Project Plan c. Review DRL and corresponding DRDs d. Obtain information on availability and skills of personnel

	needed to conduct implementation e. Obtain information on availability of any raw materials, enabling products, or special services f. Conduct stakeholder interviews 1) Assess roles and their level of involvement during the development of the product implementation approach 2) Obtain tailoring guidance, if needed
Develop a schedule for preparing the Product Implementation Approach	a. Annotate due dates for draft and final inputs from planning team and other key stakeholders b. Recognize iterative nature of the approach development effort c. Identify timelines for development of parallel management plans, if required d. Incorporate resource requirements and update, as required
Conduct Product Implementation Approach kick-off meeting	a. Provide an overview on the scope of the project's product implementation strategy and approach b. Provide an overview on how the planning team is organized and description of roles and responsibilities c. Provide an overview on the schedule needed to develop the product implementation planning information to include specific deliverables, major milestones and due dates
Conduct specialized training for personnel supporting the product implementation approach	a. Identify specialized training and level of proficiency needs by personnel job category b. Prepare and obtain approval of the specialized training c. Conduct the specialized training d. Upon successful completion of the specialized training, evaluate the level of proficiency of trained personnel
Co-develop and capture IMS inputs and updates	Support concurrent effort of developing technical schedule inputs based on the product implementation strategy and

	approach
Review the draft Product Implementation Approach	Conduct review of draft Product Implementation planning information with the planning team and corresponding project stakeholders
Submit for concurrence and/or approval	Submit the final product implementation planning information for concurrence and/or approval to the proper designated governing authority
Maintain the Product Implementation Approach	Update the product implementation strategy and approach, as required, based on: 1) Major program milestone review 2) Major technical reviews

4.2.1.1.1 Make, Buy or Reuse Product Implementation Decision Recommendation

Applying the Product Implementation approach for each system element under consideration, an evaluation and accompanying recommendation will be conducted and prepared to support the decision-making process to buy an existing product, to reuse an existing product currently in the government inventory, or to make the product.

The following tasks and steps are provided to assist with satisfying the requirements contained in MPR 7123.1.

Tasks	Steps
Evaluate and assess approaches and options for make, buy, or reuse products that will comply with the technical and design-to requirements	a. Perform required trade studies and analyses needed to support the evaluation and assessment effort b. Conduct and prepare an evaluation and assessment report to include a recommendation that supports the decision-making process
Obtain make, buy, or reuse decision from designated decision authority	a. Prepare necessary presentation materials along with supporting back-up information; e.g., technical risk, technical feasibility, credible and realistic cost analysis

Tasks	Steps
	b. Present the evaluation and assessment results along with a recommendation to the designated decision authority
roceed with the make, buy, or reuse product implementation decision obtained from the designated decision authority	a. Proceed with the approved product implementation decision b. Manage, monitor, and control the product implementation decision in order to meet the cost and schedule constraints and technical performance and design-to requirements
apture work products associated with the approved product implementation decision	Capture, manage, and maintain process implementation work product in accordance with the approved technical data management process; to include: 1) Design drawings 2) Design documentation 3) Code listings 4) Model descriptions 5) Implementation procedures 6) Operator manuals 7) Maintenance manuals 8) etc.

4.2.1.1.2 Data Requirements Description (DRD)

For any DRDs that are applicable to this process, refer to MPR 7123.1.

4.2.1.2 Product Integration

The planning activity associated with the development of the Product Integration approach is part of the broader technical planning effort. Based on the overall level of technical risk, time-phased resource requirements will need to be compiled to support product integration across the product life-cycle.

A description of the Product Integration approach will likely be incorporated into the project SEMP. For smaller projects, the project SEMP may be used to fully describe how the system will be assembled, integrated, and verified.

NASA Systems Engineering Handbook 6105, Appendix H, provides an Integration Plan outline. The integration plan defines the integration and verification strategies for a project interface with the system design and decomposition into the lower level elements.

The Manufacturing and Assembly Plan, DRD STD/Materials and Processes (MP)-Manufacturing and Assembly Plan (MP), can be used to scope the entire magnitude of the task to be accomplished and provide technically sound, efficient, and cost effective plan of action to ensure projected schedules can be maintained. The Manufacturing and Assembly Plan defines the objective, methods and procedures to be used in the manufacture and assembly of the deliverable hardware per NASA-STD-6016, Standard Materials and Processes Requirements for Spacecraft.

The following tasks and steps are provided to assist with satisfying the requirements contained in MPR 7123.1.

Tasks	Steps
Analyze the scope of developing, preparing, and maintaining the Product Integration Approach	a. Assemble and review the list of work products required to support the product integration approach b. Review Stakeholder NGOs 1) FAD 2) PCA 3) Project Plan c. Review DRL and corresponding DRDs d. Obtain information on availability and skills of personnel needed to conduct integration e. Obtain information on availability of any raw materials, enabling products, or special services f. Conduct stakeholder interviews 1) Assess roles and their level of involvement during the development of the product integration approach 2) Obtain tailoring guidance, if needed
Develop a schedule for preparing the Product	a. Annotate due dates for draft and final inputs from planning team and other key stakeholders

Integration Approach	b. Recognize the iterative nature associated with developing a workable approach to product integration c. Identify timelines for development of parallel management plans, if required d. Incorporate resource requirements and update, as required
Conduct Product Integration Approach kick-off meeting	a. Provide an overview on the scope of the project's product integration strategy and approach b. Provide an overview on how the planning team is organized and description of roles and responsibilities c. Provide an overview on the schedule needed to develop the product integration planning information to include specific deliverables, major milestones and due dates
Conduct specialized training for personnel supporting the product integration approach	a. Identify specialized training and level of proficiency needs by personnel job category b. Prepare and obtain approval of the specialized training c. Conduct the specialized training d. Upon successful completion of the specialized training, evaluate the level of proficiency of trained personnel
Co-develop and capture IMS inputs and updates	Support concurrent effort of developing technical schedule inputs based on the product integration strategy and approach
Review the draft Product Integration Approach	Conduct review of draft Product Integration planning information with the planning team and corresponding project stakeholders
Submit for concurrence and/or approval	Submit the final product integration planning

	information for concurrence and/or approval to the proper designated governing authority
Maintain the Product Integration Approach	Update the product integration strategy and approach, as required, based on: 1) Major program milestone review 2) Major technical reviews

4.2.1.2.1 Assemble and Integrate End Product

The focus of this effort is to successfully assemble, integrate, and verify the project interface. Appendix F, Technical Analysis and Assessment, contains additional guidance on technical analyses, assessments, and technical/analytic integration.

System integration is both an analytical and physical process and encompasses all elements associated with the project, including the flight system, software, ground systems, associated launch interfaces, and mission operations. The analytical integration process consists of the design integration analyses that ensure the various components, subsystems, and associated external systems interface and function together, as required. The physical integration process is the assembly of all piece parts, components, subassemblies, and subsystems into a functional entity. The following are examples of physical integration:

a. Integrated Ground and Flight Flight Test Objectives (FTOs)

b. Ground objectives
   1) Final requirements verification and closeout
   2) Stacking flow
   3) Operability
   4) Off-nominal processing
   5) Supportability
   6) Human factors
   7) Etc.

c. Flight objectives
   1) Vehicle performance verification
   2) Aborts
   3) DFI verification
   4) Etc.

Integration of the complete system can be quite extensive. Performing detailed planning in advance will ensure there is sufficient lead-time to budget and procure the necessary resources and enabling products to support product integration.

If the potential and currently assessed schedule and technical risk is deemed acceptable, then opportunities to combine and conduct product integration activities in conjunction with other product verification and validation activities are pursued as a means to potentially compress schedule and reduce costs.

A SIR is a mandatory technical review to ensure the system is ready to be integrated. NASA Systems Engineering Handbook 6105 provides additional information on objectives, entrance and success criteria, and a listing of data products needed to support the SIR.

The following tasks and steps are provided to assist with satisfying the requirements contained in MPR 7123.1.

Tasks	Steps
Monitor and control preparations for the SIR for a specific product integration activity	a. Track the completion and approval of the integration plans and procedures required to support a specific product integration activity b. Track the progress of required resources and enabling products needed to support a specific product integration activity
Conduct the SIR in accordance with Technical Assessment process requirements	a. Refer to the Technical Assessment section of this document for a description of tasks and steps needed to conduct a successful technical review b. Obtain approval to proceed with the specific product integration activity by meeting all of the SIR success criteria and resolving any issues and/or assigned actions
Conduct and perform the specific product integration activity	a. Follow the approved product integration plan and procedures to perform product integration b. Formally track and obtain approval to adapt or modify the product integration plan or procedures, if needed

	c. Conduct out-brief upon the completion of the specific product integration activity by reporting out preliminary results and identifying any additional product integration requirements or needs
Prepare a formal report on the results of the specific product integration activity	a. Prepare a formal integration or exception report on the results and conclusions from the specific product integration activity b. Capture and compile the product integration work products in accordance with technical data management process requirements

4.2.1.2.2 Product Support Documentation

The focus of this effort is to develop and prepare supporting documentation that may be needed to support product integration. As noted earlier, there may be opportunities to combine and conduct product verification and product validation in conjunction with assembling and integrating the end product.

Accordingly, the development of support documentation for product verification and product validation is discussed in the Product Verification and Product Validation Processes section of this document.

4.2.1.2.3 Data Requirements Description (DRD)

For any DRDs that are applicable to this process, refer to MPR 7123.1.

4.2.2 Evaluation Processes

4.2.2.1 Product Verification and Product Validation

The Product Verification process is used to demonstrate that an end product conforms to its specifications/requirements and design description documentation generated from the system design processes. The Product Validation process is used to confirm that a verified end product fulfills its intended use when placed in its intended environment. In other words, verification provides objective evidence that every" requirement was met, whereas validation provides objective evidence that stakeholders' expectations were met.

Product Verification and Product Validation can be accomplished by the following methods:

a. **Analysis**: The use of mathematical modeling and analytical techniques to predict the suitability of a design to stakeholder expectations based on calculated data or data derived from lower system structure end product verifications/validations. Analysis is generally used when a prototype, engineering model, or fabricated, assembled, and integrated product is not available. Analysis includes the use of modeling and simulation as analytical tools. A model is a mathematical representation of reality. A simulation is the manipulation of a model.

b. **Demonstration**: Showing that the use of an end product achieves the individual specified requirements/specifications (verification) and the stakeholder expectations (validation). It is a basic confirmation of performance capability, differentiated from testing by the lack of detailed data gathering. Demonstrations can involve the use of physical models or mockups. A demonstration could also be the actual operation of the end product.

c. **Inspection**: The visual examination of a realized end product. Inspection is generally used to verify/validate physical design features or specific manufacturer identification.

d. **Test**: The use of an end product to obtain detailed data needed to verify/validate performance, or provide sufficient information to verify/validate performance through further analysis. Testing can be conducted on final end products, breadboards, brass boards or prototypes. Testing produces data at discrete points for each specified requirement under controlled conditions and is the most resource-intensive verification technique. Testing is the detailed quantifying method of both verification and validation but it is required in order to validate final end products to be produced and deployed. Testing may include functional testing, environmental testing, combined environments testing, flight testing, and integrated systems testing.

e. **Validation of Records**: The use of vendor-furnished/supplied manufacturing or processing records to ensure the requirements/specifications have been incorporated or met. Validation of records is used as the method to satisfy incorporation of requirements for such items as commercial off-the-shelf products and products purchased to standards.

f. **Similarity**: The process of assessing prior data, configuration, processes, or applications and concluding that the item under assessment is similar or identical to another item that has previously been verified to equivalent or more stringent specifications or validated to an equivalent use or function. Similarity may only be used when each of the following criteria is met:

1. Engineering evaluation(s) reveals that design configurations between the item under assessment and the similar item would produce the same results if the verification/validation activity was performed on the item under assessment.

2. The similar item was designed for and verified/validated to equal or higher environmental (e.g., thermal, stress) levels than those required for the item under assessment.

3. The item under assessment was built by the same manufacturer using the same manufacturing processes and the same quality control procedures as the similar item.

4. Similarity assessment will undergo an independent evaluation by a technically qualified person or group other than the person(s) performing the assessment. Similarity will not be used when either of the following conditions exists:

(a). The similar item used in the assessment was itself verified/validated using similarity as the method.

(b). Items whose criticality is 1 or 1R (i.e., items whose failure or malfunction could result in loss of vehicle, life, or serious injury). For additional information on criticality definition, see Organizational Work Instruction, QD-R-001.

From a process perspective, Product Verification and Product Validation are similar in nature, but the objectives are fundamentally different. It is essential to confirm that the realized product is in conformance with its specifications and design description. However, from a stakeholder viewpoint, the interest is in whether the end product will do what the stakeholder intended within its operational environment. When cost effective and warranted by analysis, the expense of validation testing can be mitigated by combining tests to perform verification and validation simultaneously.

The outcomes of the Product Verification and Product Validation processes are confirmation that the “as-realized product” conforms to its specified requirements and meets the stakeholders’ expectations.

The following are key inputs and outputs to the Product Verification process.

Inputs and Sources:

a. End product to be verified (from Product Implementation Process or Product Integration Process).

b. End product specification and configuration baselines, including interface specifications, to which the product being verified was generated (from Technical Data Management Process).

c. Product verification approach (from Design Solution Definition Process and Technical Planning Process).

d. Product verification enabling products (from existing resources or Product Transition Process for enabling product realization).

Outputs and Destinations:

a. A verified end product (to Product Validation Process).

b. Product verification results (to Technical Assessment Process).

c. Completed verification report to include for each specified requirement:

(1) the source paragraph references from the baseline documents for derived technical requirements, technical requirements, and stakeholder expectations;

(2) bidirectional traceability among these sources;

(3) verification type(s) to be used in performing verification of the specified requirement;

(4) reference to any special equipment, conditions, or procedures for performing the verification;

(5) results of verification conducted;

(6) variations, anomalies, or out-of-compliance results;

(7) corrective actions taken; and

(8) results of corrective actions (to Technical Data Management Process).

d. Product verification work products needed to provide reports, records, and undeliverable outcomes of process activities (to Technical Data Management Process).

The following are key inputs and outputs to the Product Validation process.

Inputs and Sources:

a. End product to be validated (from Product Verification Process).

b. Baselined stakeholder expectations (from Configuration Management Process).

c. Product validation approach (from Design Solution Definition Process and Technical Planning Process).

d. Product validation enabling products (from existing resources or Product Transition Process for enabling product realization).

Outputs and Destinations:

a. A validated end product (to Product Transition Process).

b. Product validation results (to Technical Assessment Process).

c. Completed validation report for each stakeholder expectation or subset of stakeholder expectations involved with the validation, for example:

(1) the source requirement paragraph reference from the stakeholder expectations baseline;

(2) validation type(s) to be used in establishing compliance with selected set of stakeholder expectations and match with each source expectation referenced;

(3) identification of any special equipment, conditions, or procedures for performing the validation, which includes referenced expectation;

(4) results of validation conducted with respect to the referenced expectation;

(5) deficiency findings (variations, anomalies, or out-of-compliance results);

(6) corrective actions taken; and

(7) results of corrective actions (to Technical Data Management Process).

d. Product validation work products needed to provide reports, records, and undeliverable outcomes of process activities (to Technical Data Management Process).

Successful Verification and Validation will lead into qualification of the final hardware/software design.

4.2.2.1.1 Product Verification/Product Validation Requirements

Product Verification/Product Validation requirements provide the basis for verification and validation planning covered in Section 4.3. These product verification and validation requirements are compiled with the set of Project/activity requirements per DRD STD/SE-VVREQ, Verification/Validation Requirements. Verification and validation requirements identify “what” is required to satisfy each of the technical requirements or stakeholder expectation statements respectively.

The Product Verification/Product Validation Requirements are prepared to support the SRR and are baselined as part of the SRR success criteria.

In addition to baselining of the V&V requirements at the SRR, it may be necessary at this time for some projects to begin detailed planning for new or modified test and launch facilities, test article fabrication, test article/facility interface requirements, or other long lead items.

The following tasks and steps are provided to assist with satisfying the requirements contained in MPR 7123.1.

Tasks	Steps
Define verification/validation requirements	a. Define the method by which the requirement is to be verified 1) Test

	2) Analysis 3) Inspection 4) Demonstration 5) Validation of Records 6) Similarity b. Define the level at which the verification/validation will occur 1) System 2) Subsystem 3) Component c. Define the phase or purpose of the verification/validation activity to be performed 1) Development 2) Qualification 3) Acceptance 4) Pre-launch 5) Flight/Mission 6) Post-flight 7) Disposal
Manage and maintain the verification/validation requirements	a. Manage and maintain verification/validation requirements b. Update as necessary in accordance with established data management requirement

4.2.2.1.2 Product Verification/Product Validation Planning

The Product Verification/Product Validation requirements are the basis to begin defining the scope and begin the planning effort to describe the Product Verification/Product Validation program. The Product Verification/Product Validation planning information provides a description of the product verification/product validation program and is prepared per DRD STD/SE-VVPLAN, Verification/Validation Planning. Additional guidance on product verification/product validation planning is contained in MSFC-HDBK-2221, Verification Handbook; Volume I, Verification Process, Section 2.1.1.4, Verification Plan. The Product Verification/Product Validation planning information also provides a detailed description of the overall approach and organizational structure for implementing the verification/validation program. The scope of the activities and tasks by verification/validation phase for flight hardware and software needs to be fully described in the Product Verification/Product Validation planning information.

NASA-STD-7009, Standard for Models and Simulations (M&S), provides requirements and recommendations for the development and maintenance of models, the operation of simulations, the analysis of the results, training, recommended practices, the assessment of the M&S credibility, and the reporting of M&S results. Other key features included in this standard include requirements and recommendations for verification, validation, uncertainty quantification, training, credibility assessment, and reporting to decision makers.

Test Like You Fly (TLYF) is a pre-launch verification and validation approach that examines all applicable mission and flight characteristics within the intended operational environment and determines the fullest practical extent to which those characteristics can be applied in testing. The application of this philosophy is intended to avoid experiencing any environmental conditions or operations for the first time on orbit and to discover anomalous behavior under those conditions validate end-to-end operability and performance of the item under test. TLYF criteria is designed to understand the limitation of the ground test program and includes: review of the mission scenario, critical events, their verification and identification of tests in support of those verifications; assessment of flight test configuration traceability to flight design; application (combination) of environments as seen in flight; and test procedure correlation to operational procedures. A TYLF exception is an instance in which testing cannot be performed in a like you fly manner due to physical or programmatic constraints (schedule cost, safety, etc.) that prevent creation of the flight environment/configuration during testing. A TYLF exception mitigation is a mitigation plan is required for risks that impact mission assurance and operational capability as a result of not verifying or validating in a test in a like-you-fly manner. Flight tests may be deemed as acceptable mitigation for TLYF. Development testing is not considered as a TLYF assessment. Four major components of TLYF philosophy are: criticality; mission scenario assessment, definition of critical events and functions and their verifications; configuration; qualification test (or demonstration) hardware and software will be of the same configuration and manufacturer, and be manufactured under the same production processes as the flight hardware and software; environments - application of the natural and induced environments to testing; and operation - integration of test article, as it represents flight Hardware/Software (HW/SW), with the way it is intended to be operated in flight.

The Product Verification/Product Validation planning information is prepared to support the SRR and is baselined after the System CDR.

The following tasks and steps are provided to assist with satisfying the requirements contained in MPR 7123.1.

Tasks	**Steps**
Develop and prepare the Product Verification/Product Validation planning information	a. Define and document the detail description of each verification/validation activity based on the verification/validation requirements b. Define and document the organizational roles and responsibilities for each verification/validation activity c. Define the verification/validation approach, methodology, and organization structure to process and implement the verification/validation program d. Identify and describe modeling and simulation needs and requirements 1) Models required 2) Model development 3) Model verification, validation, and accreditation requirements 4) Scope of simulation activities e. Define and document the verification environment 1) Facilities 2) Ground support equipment 3) Software 4) Tools 5) Simulations 6) Personnel 7) Operational conditions f. Document the timeline for the sequence of verification/validation activities g. Identify the documentation necessary to support the verification/validation effort 1) Requirements matrix

	2) Specifications 3) Interface documents 4) Test plans h. Define and document the compliance data review and approval process i. Define and document safety and reliability assessment derived safety verifications (e.g., hazard reports, FMEA/Critical Items List (CIL), reliability prediction including PRA, as applicable, verification)
Submit the completed Product Verification/Product Validation planning information for approval	a. Obtain approval from the project team that the Product Verification/Product Validation planning information has achieved sufficient maturity to be baselined b. The Product Verification/Product Validation planning information is placed under formal configuration control in accordance with established configuration management procedures
Manage and maintain the Product Verification/Product Validation planning information	a. Manage and maintain the Product Verification/Product Validation planning information in accordance with guidance contained in the Project SEMP b. The Product Verification/Product Validation planning information is placed under formal configuration control in accordance with established configuration management procedures

4.2.2.1.3 Product Verification/Product Validation Success Criteria

The Product Verification/Product Validation success criteria provide the detail and specific criteria, which determine successful accomplishment of the verification/validation planning activities. The Product Verification/Product Validation success criteria are prepared in accordance with DRD STD/SE-VVSC, Verification/Validation Success Criteria.

The Product Verification/Product Validation success criteria are submitted as part of the PDR data package and baselined at least 90 days prior to the start of the verification/validation activity to provide sufficient time to develop and publish the procedures.

The following tasks and steps are provided to assist with satisfying the requirements contained in MPR 7123.1.

Tasks	**Steps**
Define verification/validation success criteria	Develop success criteria based on the following considerations: 1) Performance criteria 2) Environment test limits 3) Tolerances 4) Margins 5) Specifications 6) Constraints 7) Inspection points 8) Effectivity and location
Submit the completed Product Verification/Product Validation Success Criteria for approval	a. Obtain approval from the project team that the Product Verification/Product Validation Success Criteria has achieved sufficient maturity to be baselined b. The Product Verification/Product Validation Success Criteria is placed under formal configuration control in accordance with established configuration management procedures
Manage and maintain the Product Verification/Product Validation Success Criteria	a. Manage and maintain the Product Verification/Product Validation Success Criteria in accordance with guidance contained in the Project SEMP and/or Project Verification/Validation planning information b. The baselined Product Verification/Product Validation Success Criteria is placed under formal configuration control in accordance with established configuration

Tasks	Steps
	management procedures

4.2.2.1.4 Product Verification/Product Validation Procedures

Product Verification and Product Validation procedures outline the instructions for performing verification/validation activities.

The Product Verification/Product Validation procedures are prepared in accordance with DRD STD/SE-VVPROC, Verification/Validation Procedures and Models.

The Product Verification/Product Validation procedures are initially submitted at least 90 days and then baselined at least 30 days prior to the start of the related verification/validation activity.

The following tasks and steps are provided to assist with satisfying the requirements contained in MPR 7123.1.

Tasks	Steps
Prepare and document verification/validation procedures	Provide a description for each of the following areas or items: 1) Identify item/article being subjected to test, demonstration, inspection, or analysis 2) Identify the objectives established for the verification/validation activity 3) Identify the characteristics and criteria to be verified (including values and tolerances) for acceptance or rejection and traceability back to the applicable success criteria, traceability to project safety and reliability verification requirements (e.t., hazard reports, FMEA/ CIL, reliability prediction including PRA (as applicable) 4) Describe the sequence of steps and operations to be performed 5) Identify measuring and recording equipment to be used

Tasks	**Steps**
	a) Type b) Range c) Accuracy d) Operating instructions 6) Confirm that required support equipment has been calibrated and its certification is valid 7) Confirm that support equipment has been verified prior to use 8) Document layouts, schematics, or diagrams that show identification, location, and interconnection of item/article, support equipment, and measuring equipment 9) Document test article configuration and identify software loads, GSE vs. flight 10) Identify hazardous situations and operations 11) Document safety precautions and instructions 12) Document environmental and other conditions to be maintained with tolerances 13) Document data storage and translation requirements 14) Document constraints 15) Document instructions for handling non-conformances and anomalous occurrences 16) Document the roles and responsibilities for executing the verification/validation procedures 17) Document hardware, software, and/or GSE that is reused, refurbished, or reflown for a new particular use, function, or mission.
Submit the completed Product Verification/Product Validation Procedures for approval	a. Obtain approval from the project team that the Product Verification/Product Validation Procedures have achieved sufficient maturity to be baselined b. The Product Verification/Product Validation Procedures are placed under formal configuration control in accordance with established configuration

Tasks	Steps
	management procedures
Manage and maintain the Product Verification/Product Validation Procedures	a. Manage and maintain the Product Verification/Product Validation Procedures in accordance with guidance contained in the Project SEMP and/or Project Verification/Validation planning information b. The baselined Product Verification/Product Validation Procedures are placed under formal configuration control in accordance with established configuration management procedures

4.2.2.1.5 Product Verification/Product Validation Reports and Compliance

Product Verification and Product Validation reports provide a record of the results of the verification/validation activity.

Demonstrating Product Verification and Product Validation compliance involves the evaluation, tracking and statusing of submitted reports against the design input requirements.

The Product Verification/Product Validation reports are prepared in accordance with DRD STD/SE-VVRC, Verification/Validation Reports and Compliance.

The Product Verification/Product Validation reports and compliance information are initially submitted when the first verification/validation report is approved. Subsequent reports and compliance information are continued to be provided throughout the project and submitted as needed until full compliance is achieved.

The following tasks and steps are provided to assist with satisfying the requirements contained in MPR 7123.1.

Tasks	Steps
Document the results of the verification/validation activity in a report	Provide a description for each of the following areas or items: 1) Conclusions 2) Recommendations 3) Deviations/waivers

Tasks	Steps
	4) Plots 5) Pictures 6) As recorded results 7) Procedures that were used 8) Traceability to the verification/validation success criteria 9) Additional independent assessment (i.e., "second set of eyes") of the compliance data on a case by-case basis taking into account the criticality and fidelity of the hardware or software and the verification/validation method
Provide compliance of the verification/validation to the technical requirements	a. Obtain approval of the Product Verification/Product Validation Reports via the verification/validation data approval process outlined in the Project SEMP and/or Product Verification/Product Validation Plan. b. Complete or provide the following information: 1) Traceability to requirements and/or stakeholder expectations 2) Traceability to success criteria 3) Compliance data point of contact (responsible party) 4) Non-conformance tracking 5) Status (i.e., open, closed)
Submit the completed Product Verification/Product Validation Reports and Compliance information for approval	Obtain approval of the Product Verification/Product Reports via the verification/validation data approval process outlined in the Project SEMP and/or Product Verification/Product Validation planning information
Manage and maintain the Product Verification/Product Validation Reports and Compliance	a. Manage and maintain the Product Verification/Product Validation Reports and Compliance in accordance with guidance contained in the Project SEMP and/or Project b. Verification/Validation planning information c. The baselined Product Verification/Product Validation

Tasks	Steps
	Reports and Compliance are placed under formal configuration control in accordance with established configuration management procedures

4.2.2.1.6 Data Requirements Descriptions (DRD)

For any DRDs that are applicable to this process, refer to MPR 7123.1.

4.2.3 Product Transition Process

The Product Transition process is used to transition to the customer at the next level in the system structure a verified and validated end product that has been generated by product implementation or product integration for integration into an end product. For the top-level end product, the transition is to the intended end user. The form of the product transitioned will be a function of the product-line life-cycle phase exit criteria and the location within the system structure of the WBS model in which the end product exists.

Product Transition occurs during all phases of the life-cycle. During the early phases, products are usually in the form of documents, models, studies, and reports. As the project moves through the life-cycle, these products are transformed through implementation and integration processes into hardware and software solutions to meet the stakeholder expectations. The process is the last of the product realization processes and is a bridge from one level of the system to the next higher level.

The following are key inputs and outputs to the Product Transition process.

Inputs and Sources:

a. End product or products to be transitioned (from Product Validation Process).

b. Documentation including manuals, procedures, and processes that are to accompany the end product (from Technical Data Management Process).

c. Product transition enabling products to include packaging materials, containers, handling equipment, and storage, receiving and shipping facilities (from existing resources or Product Transition Process for enabling product realization).

Outputs and Destinations:

a. Delivered end product with applicable documentation including manuals, procedures, and processes in a form consistent with the product-line life-cycle phase and location of the product in the system structure (to end user or Product Integration Process – recursive loop).

b. Product transition work products needed to provide reports, records, and undeliverable outcomes of process activities (to Technical Data Management Process).

c. Realized enabling products from existing enabling products and services or realized products from applying the common technical processes (to Product Implementation, Integration, Verification, Validation and Transition Processes, as appropriate).

4.2.3.1 Product Transition Approach

The planning activity associated with the development of the Product Transition approach is part of the broader technical planning effort. Based on the overall level of technical risk, time-phased resource requirements will need to be compiled to support product transition activities throughout the product life-cycle. These resource requirements are based on the full scope of the product transition process, which applies not just to the final verified end product, but to all deliverables associated with the development and successful delivery of the end product.

A description of the Product Transition approach will normally be incorporated into the project SEMP. For smaller projects, the project SEMP may fully describe how the end product will be transitioned in lieu of a more detailed Packaging, Handling, Storage and Transportation (PHS&T) Plan.

When applicable, the development of the product transition approach coincides and supports the development of the ILSP which will ensure the product is supported during development (Phase D) and operations (Phase E) in a cost-effective manner. The Integrated Logistics Support approach will likely identify design considerations for the specific end product or enabling products that will be needed to develop, deliver, maintain, and operate an integrated, verified, and validated system.

The following tasks and steps are provided to assist with satisfying the requirements contained in MPR 7123.1.

Tasks	Steps
Analyze the scope of developing, preparing, and maintaining the Product Transition Approach	a. Assemble and review the list of work products required to support the product transition approach b. Review Stakeholder NGOs 1) FAD 2) PCA 3) Project Plan c. DRL and corresponding DRDs d. Obtain information on availability and skills of personnel needed to conduct transition e. Obtain information on availability of any raw materials, enabling products, or special services needed f. Conduct stakeholder interviews 1) Assess roles and their level of involvement during the development of the product transition approach 2) Obtain tailoring guidance, if needed
Develop a schedule for preparing the Product Transition Approach	a. Annotate due dates for draft and final inputs from planning team and other key stakeholders b. Recognize the iterative nature associated with developing a workable approach to product transition c. Identify timelines for development of parallel management plans, if required d. Incorporate resource requirements and update, as required
Conduct Product Transition Approach kick-off meeting	a. Provide an overview on the scope of the project's product transition strategy and approach b. Provide an overview on how the planning team is organized and description of roles and responsibilities c. Provide an overview on the schedule needed to develop the product transition planning information to include

	specific deliverables, major milestones and due dates
Conduct specialized training for personnel supporting the product transition approach	a. Identify specialized training and level of proficiency needs by personnel job category b. Prepare and obtain approval of the specialized training c. Conduct the specialized training d. Upon successful completion of the specialized training, evaluate the level of proficiency of trained personnel
Co-develop and capture IMS inputs and updates	Support concurrent effort of developing technical schedule inputs based on the product transition strategy and approach
Review the draft Product Transition Approach	Conduct review of draft Product Transition planning information with the planning team and corresponding project stakeholders
Submit for concurrence and/or approval	Submit the final product transition planning information for concurrence and/or approval to the proper designated governing authority
Maintain the Product Transition Approach	Update the product transition strategy and approach, as required, based on: 1) Major program milestone review 2) Major technical reviews

4.2.3.2 Support required acceptance and pre-ship reviews

MPR 7123.1 establishes the SAR as a mandatory technical review for human Flight Systems and Ground Support (FS&GS) projects. The preparation and execution of the SAR is conducted using the recommended activities contained in the Process Assessment (PA) Manual.

The purpose of an Acceptance Review is the final review conducted for product delivery and NASA acceptance. Meanwhile, a Pre-Ship Review is similar to an AR, but is normally conducted to ensure that subsystems/system(s) that have been developed are ready for shipment. Whereas, the AR may be a mandatory, one-time review to establish the "as-built" configuration, the Pre-Ship Review may be a recurring review against a producible configuration that is required before each major end product is authorized for shipment.

4.2.3.3 Coordinate the Handling, Shipping, Packaging, Preservation, and Delivery of Product ; when designated or assigned as the Marshall Lead Representative (MLR)

The purpose of MPR 6410.1 is to ensure that products are handled, stored, packaged, preserved, and delivered in a manner that prevents damage to the product. When designated or assigned as the Marshall Lead Representative (MLR), the MLR is responsible for working with the Customer Support Representative (CSR) to develop a procedure to handle, store, package, preserve, and deliver the product in accordance with the requirements contained in MPR 6410.1.

4.2.3.4 Data Requirements Description (DRD)

For DRDs that are applicable to this process, refer to MPR 7123.1.

4.3 <u>Technical Management Processes</u>

4.3.1 Technical Planning

The Technical Planning process establishes a plan for applying and managing the technical processes that will be used to drive the development of the system. The Technical Planning process also establishes a plan for identifying and defining the technical effort required to satisfy the project objectives and life-cycle phase success criteria within the cost, schedule, and risk constraints of the project.

The SEMP is generated during the Technical Planning process. The SEMP is a subordinate document to the project plan. The SEMP defines how the technical effort will be managed within the constraints established by the project and how the project will be managed to achieve its goals and objectives within defined programmatic constraints. The SEMP also communicates how the systems engineering management techniques will be applied throughout the project life-cycle.

Technical Planning is tightly integrated with the Technical Risk Management process and the Technical Assessment process to ensure corrective action for future activities will be incorporated based on current issues identified within the project. Technical risks will be identified as part of the technical planning process. Technical risks may stem from relying on immature technology to be available to support the development effort; availability of test facilities and ranges, and other challenges associated with producing, manufacturing, and integrating the components of the system. A series of mandatory technical reviews will be performed to evaluate the actual versus planned technical progress and provide management direction and additional resources, if required, to ensure progress on the technical effort is maintained. Appendix E of MPR 7123.1 lists recommended levels of work product maturity for different life-cycle phase transition technical reviews.

Technical Data Management is a critical component of the technical planning effort. As more work products are developed, maintained, and delivered electronically, the Technical Data Management process will ensure the means and infrastructure is in place to support the volumes of data that will be generated to support the product throughout its life-cycle.

Technical Planning addresses the scope of the technical effort required to develop the system products. The technical team identifies, defines, and develops plans for performing decomposition, definition, integration, verification, and validation of the system while orchestrating and incorporating the appropriate concurrent engineering. Additional planning includes defining and planning for the appropriate technical reviews, audits, assessments, and status reports and determining any specialty engineering and/or design verification requirements.

Initial technical planning establishes the technical team, their roles and responsibilities, and the tools, processes, and resources that will be utilized in the technical effort. The expected activities the team will perform and the products it will produce are identified, defined, and scheduled. Technical planning evolves as data from completed tasks are received and details of near-term and future activities are known.

As part of the technical planning/risk identification and mitigation process, component or material development and proof of concept testing is considered in cases where new technology (e.g. components or materials) is required. The TRL, of the components and materials is identified, and successive test programs may be required to select the best option. Design of the experiment, test article fabrication, test planning, and data analysis may be a significant effort, but can result in reduced technical and project risk. This testing activity may be required to support PDR.

The following are key inputs and outputs to the Technical Planning process.

<u>Inputs and Sources</u>:

a. Project technical effort requirements and project resource constraints (from the project).

b. Agreements, capability needs and applicable product-line life-cycle phase(s) (from the project).

c. Applicable policies, procedures, standards, and organizational processes (from the project).

d. Prior product-line life-cycle phase or baseline plans (from Technical Data Management Process).

e. Replanning needs (from Technical Assessment and Technical Risk Management Processes).

Outputs and Destinations:

a. Technical work cost estimates, schedules, and resource needs, e.g., funds, workforce, facilities, and equipment (to project).

b. Product and process measures needed to assess progress of the technical effort and the effectiveness of processes (to Technical Assessment Process).

c. The SEMP and other technical plans that support implementation of the technical effort (to all processes; applicable plans to Technical Processes).

d. Technical work directives, e.g., work packages or task orders with work authorization (to applicable technical teams).

e. Technical planning work products needed to provide reports, records, and undeliverable outcomes of process activities (to Technical Data Management Process).

4.3.1.1 ***(SEMP)***

The SEMP is the primary, top-level technical management document for the project and is developed early in the Formulation phase and updated throughout the project life-cycle. The SEMP is driven by the size and type of project, the phase in the project life-cycle, and the technical development risks.

The technical team develops and updates the SEMP as necessary. The technical team coordinates with the project manager to determine how proposed technical activities would impact the programmatic, cost, and schedule aspects of the project. The SEMP provides the specifics of the technical effort and describes what processes will be used, how the processes will be applied using appropriate activities, how the project will be organized to accomplish the activities, and the cost and schedule associated with accomplishing the activities.

The systems engineer and project manager identify additional required technical plans based on the project scope and type. If plans are not included in the SEMP, they are referenced and coordinated in the development of the SEMP. Other plans, such as system safety and the probabilistic risk assessment, also need to be planned for and coordinated with the SEMP. If a technical plan is a stand-alone, reference if in referenced the SEMP. Depending on the size and complexity of the project, these may be separate, individual plans or may be included within the SEMP. Once identified, the plans can be developed, training on these plans can be established, and the plans implemented.

The best utilization of resources will be to ensure the SEMP is developed and updated to align with the project plan. There is a strong correlation on the description of the technical management effort and the identification of tasks and resource requirements that are used to establish the baseline project plan. The technical approach to the project and the technical aspect of the project life-cycle is developed. This determines the project's length and cost. The development of the programmatic and technical management approaches requires that the key project personnel develop an understanding of the work to be performed.

The level of detail contained in the SEMP is life-cycle dependent and will vary from project to project. The SEMP is likely to have significantly more detail during the design and development of the product than during the later phases of the product life-cycle. Likewise, the SEMP is project dependent. Even though a project may be a small effort, there may be a significant amount of collaboration involved and a high level of dependency on technology development. Therefore, the plan needs to be adequate to address the technical needs of a specific project. The SEMP is a living document that is updated as new information becomes available and as the project develops through the life-cycle.

The SEMP needs to identify what technical product and process measures will be employed to proactively monitor and control product quality and while concurrently ensuring proper process implementation. The INCOSE Measurement Primer and INCOSE Leading Indicators Guide provide additional guidance on technical measures.

Once a SEMP is approved, any changes to the SEMP are formally managed. If the SEMP contains too much content, then it will be difficult to manage and maintain. Using hyperlinks to source information within the SEMP is probably more practical and will help to minimize the need to make changes in order to keep the SEMP up-to-date.

As a general rule, the SEMP is a management plan describing how SE will be performed and conducted and does not contain “shall” requirements.

The following tasks and steps are provided to assist with satisfying the requirements contained in MPR 7123.1.

Tasks	Steps
Analyze the scope of the SEMP writing effort	a. Stakeholder NGOs 1) FAD 2) PCA 3) Project Plan b. SEMP stakeholder interviews 1) Gauge level of involvement during SEMP development 2) Tailoring guidance
Prepare SEMP development schedule	a. Due dates for draft and final inputs b. Recognize iterative nature of SEMP development c. Identify timelines for development of parallel management plans, if required d. Incorporate resource requirements and update, as required
Conduct SEMP kick-off meeting	a. Provide an overview on the scope of the SEMP development effort b. Provide an overview on the SEMP Development Team Organization c. Provide an overview on the SEMP Development

	Schedule to include major milestones and due dates d. Discuss specific responsibilities and tasks for each role of the SEMP Development Team
Co-develop and capture IMS inputs and updates	Support concurrent effort of developing technical schedule inputs based on the technical management approach
Review the draft SEMP	Conduct review of draft SEMP
Submit for approval	Submit the final SEMP for approval to the proper designated governing authority
Maintain the SEMP	Update the SEMP, as required 1) Major program milestone review 2) Major technical reviews Major program milestone review 3) Major technical reviews

Examples

MPR 7123.1, MSFC Systems Engineering Processes and Requirements	Appendix A: SEMP outline
NASA Systems Engineering Handbook NASA/SP-2007-6105	Appendix J: SEMP Content Outline

4.3.1.2 *Integrated Master Schedule Input*

The technical team will work in cooperation with the project team and provide input to the IMS. The project manager tasks the project team with the responsibility for developing and baselining the project schedule. The technical team will organize the technical tasks according to project WBS in a logical sequence of events while considering the major project milestones, phasing of available funding, and availability of supporting resources.

To support the implementation of EVM requirements contained in MPR 7120.5, the technical team becomes familiar with the information contained in the NASA WBS Handbook, NASA Scheduling Handbook, and NASA Systems Engineering Handbook 6105. In order for EVM to be effective, a properly resourced and executable project plan needs to be baselined with the support of the technical team. The following table provides specific references to assist the technical team with the development of the IMS.

MPR 7120.5	**NASA WBS Handbook**	**NASA Scheduling Handbook**	**NASA SE Handbook 6105**
3.1 Organization			
3.1.1 Product Structure			
3.1.1.1 Create a WBS	3.4 WBS Development Techniques	4.4 Project WBS	6.1.2.1 Work Breakdown Structure
3.1.2 Organization Structure			
3.1.2.1 Create an Organization Breakdown Structure (OBS)		4.5 Project OBS	
3.1.3 Control Accounts			
3.1.4.1 Create a Responsibility Assignment Matrix (RAM)		4.5 Project OBS	
3.2 Work Authorization			
3.2.1 Create a Work Authorization Document (WAD)			6.1.1.2 [Technical Planning] Process Activities
3.3 Planning and Scheduling			
3.3.1 Planning Work		4.7 Project Documentation	6.1.1.2 [Technical Planning] Process Activities
3.3.2 Scheduling Work		5.0 Schedule Development	6.1.1.2 [Technical Planning] Process Activities
3.3.3 Project IMS		5.0 Schedule Development	6.1.1.2 [Technical Planning] Process Activities
3.3.4 Performance Measurement Baseline (PMB)	4.5 Performance Measurement	5.8 Establishing the IMS Baseline	

Scheduling is an essential component of planning and managing the activities of a project. The process of creating a network schedule provides a standard method for defining and communicating what needs to be done, how long it will take, and how each element of the project WBS might affect other elements. A network schedule may be used to calculate how long it will take to complete a project.

Scheduling management tools provide the capability to show resource requirements over time and to make adjustments so that the schedule is executable with respect to resource availability and constraints. The objective is to move the start dates of tasks to points where the resource profile is feasible. If that is not sufficient, then the assumed task durations for resource-intensive activities are reexamined and the resource levels changed.

Budgeting and resource planning involve the establishment of a reasonable project baseline budget and the capability to analyze changes to that baseline resulting from technical and/or schedule changes. The project's WBS, baseline schedule, and budget are mutually dependent, reflecting the technical content, time, and cost of meeting the project's goals and objectives. The budgeting process needs to take into account whether a fixed cost cap or cost profile exists. When no such cap or profile exists, a baseline budget is developed from the WBS and network schedule. This specifically involves combining the project's workforce and other resource needs with the appropriate workforce rates and other financial and programmatic factors to obtain cost element estimates.

The following tasks and steps are provided to assist with satisfying the requirements contained in MPR 7123.1.

Tasks	Steps
Develop WBS	a. Identify hardware, software, services, and other deliverables required to achieve an end project objective b. Subdivide the work content into manageable segments to facilitate planning and control of cost, schedule, and technical content c. Establish WBS element codes
Develop Network Schedule	a. Identify activities and dependencies needed to complete each WBS element b. Identify and negotiate external dependencies

	c. Estimate durations of all activities d. Enter the data for each WBS element into a scheduling program to obtain a network schedule and an estimate of the critical path for that element e. Integrate schedules of lower level WBS elements so that all dependencies among elements are included in the project network f. Review the workforce level and funding profile over time and make adjustments to logic and durations so that workforce levels and funding levels are within project constraints
Define Resource Needs	Define resource needs for: 1) Workforce level 2) Funding profile 3) Facilities 4) etc.
Estimate Cost	a. Direct labor costs b. Overhead costs c. Other direct costs (travel, data processing, etc.) d. Subcontract costs e. Material costs f. General and administrative costs g. Cost of money (i.e., interest payments) h. Fees i. Contingencies
Provide completed technical work products to the project team to support IMS development	a. Collaborate with the project team to support the baselining of the IMS b. Capture any technical planning work products via the Technical Data Management process

Examples

NPR 7120.5, NASA Space Flight Program and Project Management Requirements	Appendix G: WBS Template
NPR 7120.8, NASA Research and	Appendix K: WBS Template

Technology Program and Project Management Requirements	
NASA Systems Engineering Handbook NASA/SP-2007-6105	Figure 6.1-2, Activity-on-arrow and precedence diagrams for network schedules
NASA Systems Engineering Handbook NASA/SP-2007-6105	Figure 6.1-3, Gantt chart
NASA Systems Engineering Handbook NASA/SP-2007-6105	Figure 6.1-4, Relationship between a system, PBS, and WBS

4.3.1.3 ***Issue Technical Work Directives***

The technical team supports the project team to ensure work is properly authorized in order to meet the EVM requirements contained in MPR 7120.5. Once the project Integrated Master Schedule has been approved and baselined, the Cost Account Manager (CAM) will work with the technical team to negotiate and authorize the work that needs to be performed. As part of the negotiations with the CAM, the technical team will provide the necessary technical work directives so that this information can be incorporated into a WAD.

With the release of the WAD, the technical team will need to provide regular updates and status on the work being performed. The reporting requirements will support EVM analysis against the baseline plan and provide the project and technical management teams with the necessary insight to make management decisions to ensure the project is able to stay within and meet its overall cost and schedule constraints.

The following tasks and steps are provided to assist with satisfying the requirements contained in MPR 7123.1.

Tasks	Steps
When requested, meet with a CAM to discuss a task that needs to be performed	a. Document and agree on the description and scope of the task to be negotiated b. Understand what and how the technical work directives are prepared
Provide the completed technical work directives to the CAM	Review and respond to any questions the CAM may have regarding the submitted technical work directives
Negotiate with the CAM to	Negotiate with the CAM to reach an agreement on the

define the work to be performed	scope and terms associated with the work to be performed
Properly receive authorization to begin performing the negotiated work	When properly authorized, begin performing the work Provide regular updates and status on work being performed

4.3.1.4 *Data Requirements Description (DRD)*

For any DRDs that are applicable to this process, refer to MPR 7123.1.

4.3.2 Technical Control Processes

4.3.2.1 Requirements Management

The RM is the process of establishing the project requirements and then providing the management control over those requirements to ensure that as project implementation proceeds, the stakeholder expectations and technical requirements are achieved.

Requirement management activities apply to the management of all stakeholder expectations and technical product requirements down to the lowest level product component requirements. The Requirements Management Process is used to:

a. Manage the product requirements identified, baselined, and used in the definition of the WBS model products during system design;

b. Provide bidirectional traceability back to the top WBS model requirements; and

c. Manage the changes to established requirement baselines over the life-cycle of the system products.

Once projects have been through the formal Project Requirements Review (PRR) and/or SRR and the project requirements are formally established by Configuration Control Board (CCB) approval (baselined), management of the requirements through the configuration management function becomes the primary control mechanism to ensure that project implementation adheres to the established requirements. As project implementation proceeds through design, the design reviews provide the opportunities to ensure that system design meets the intent of the requirements. It may become necessary to modify the baseline requirements as project design, fabrication, and testing are implemented.

Requirements flow-down and resource allocation are accomplished where higher level functional and performance requirements and system resources are allocated to end items or functional subsystems that make up the system. To ensure traceability of requirements from the highest level requirement to the lowest level requirement, the requirements flow-down is normally documented in a requirements traceability matrix that defines the parent/child relationship of each requirement.

The following are key inputs and outputs to the Requirements Management Process.

Key Inputs:

a. Expectations and requirements to be managed (from System Design Processes).

b. Requirement change requests (from the project and Technical Assessment Process).

c. TPM estimation/evaluation results (from Technical Assessment Process).

d. Product verification and product validation results (from Product Verification and Validation Processes).

Key Outputs:

a. Requirements Management Plan (RMP) (to Configuration Management Process).

b. Requirements Traceability (to Technical Data Management Process).

c. Approved changes to requirement baselines (to Configuration Management Process).

4.3.2.1.1 Requirements Management Plan

A requirements management process isdeveloped to specify the information and control mechanisms that will be collected and used for measuring, reporting, and controlling changes to the product requirements. The SEMP normally documents the management approach to implementing the requirements management process. However large programs may elect to have a separate stand-alone plan.

The following tasks and steps are provided to assist with satisfying the requirements contained in MPR 7123.1.

Tasks	Steps
Prepare RMP	a. Identify the relevant stakeholders who will be involved in the Requirements Management Process (e.g., those who may be affected by, or may affect, the product as well as the processes) b. Provide a schedule for performing the requirements management procedures and activities c. Assign responsibility, authority, and adequate resources for performing the requirements management activities, developing the requirements management work products, and providing the requirements management services defined in the activities (e.g., staff, requirements management database tool, etc.) d. Define the level of configuration management/data management control for all requirements management work products e. Identify the training for those who will be performing requirements management activities
Manage and maintain RMP	The baselined RMP is placed under formal configuration control in accordance with established configuration management procedures

Examples

CxP 70016	Constellation Program Requirements Engineering Management Plan (REMP)

Requirements Engineering Management Plan (REMP) Outline

a. Section 1: Introduction

b. Section 2: Documents

c. Section 3: Requirements Management Structure

d. Section 4: The Requirements Engineering and Management Process

e. Section 5: Tools and Training

f. Section 6: Milestones

g. Appendices

4.3.2.1.2 Requirements Traceability

When a requirement is documented, its bidirectional traceability is recorded. It is traced back to a parent/source requirement or expectation in a baselined document or be identified as self-derived. Examples of self-derived requirements are requirements that are locally adopted as good practices or are the result of design decisions made while performing the activities of the Logical Decomposition and Design Solution Processes.

The requirements are evaluated to ensure that the requirements trace is correct and that it fully addresses its parent requirements. If it does not, some other requirement(s) has to complete fulfillment of the parent requirement and be included in the traceability matrix. All top-level requirements are allocated to lower level requirements. If a particular requirement does not have a parent and is not a self-derived requirement, there is likely a decomposition/allocation or “gold plating” issue. Duplication between levels also is to be resolved. Requirements traceability is usually recorded in a requirements matrix.

The following tasks and steps are provided to assist with satisfying the requirements contained in MPR 7123.1.

Tasks	Steps
Perform requirements traceability	a. Create parent-child relationships b. Ensure trace is correct 1) One parent 2) Check for decomposition or allocation issues 3) Gold plating 4) Duplication, redundancy c. Requirements matrix

Manage and maintain requirements traceability	Maintain requirements traceability throughout the life-cycle

Examples

NASA Systems Engineering Handbook, NASA/SP-2007-6105, Figure F-5	Requirements Allocation Matrix

4.3.2.1.3 Requirements Changes

Changes to baselined technical requirements occur throughout the system life-cycle. In conjunction with the Configuration Management Process, the Requirements Management Process establishes a formal change management process to specifically manage changes to baselined technical requirements. Changes are evaluated to determine the impacts on the architecture, design, interfaces, ConOps, and higher and lower level requirements. Performing functional and sensitivity analyses will ensure that the requirements are realistic and evenly allocated. Verification and validation ensure that the requirements can be satisfied and conform to mission objectives. All changes are reviewed through an approval cycle to maintain traceability and to ensure that the impacts are fully assessed across the entire system.

Once the requirements have been validated and reviewed in the SRR they are placed under formal configuration control. Thereafter, any changes to the requirements are approved by the CCB. The systems engineer, project manager, and other key engineers typically participate in the CCB approval processes to assess the impact of the change including cost, performance, programmatic, quality, and safety.

The following tasks and steps are provided to assist with satisfying the requirements contained in MPR 7123.1.

Tasks	Steps
Prepare and process change requests	a. Document requested requirement(s) change with rationale b. Communicate the requested change to all relevant stakeholders c. Evaluate the impact (i.e., cost, schedule, technical, etc.) of the requested change d. Approve or disapprove change

	e. Distribute change
Manage and maintain requirements documentation	a. Update requirements documentation b. Maintain requirements change history

Examples

MSFC Form 2327	MSFC Engineering Change Request (ECR)

4.3.2.1.4 Data Requirements Description (DRD)

For any DRDs that are applicable to this process, refer to MPR 7123.1.

4.3.2.2 Interface Management

Interface management is a process to assist in controlling interface product development. The management and control of interfaces is crucial to successful programs or projects. The interface management process is used to:

a. Establish and use formal interface management to assist in controlling system product development efforts when the efforts are divided between Government programs, contractors, and/or geographically diverse technical teams within the same program or project, and

b. Maintain interface definition and compliance among the end products and enabling products that compose the system as well as with other systems with which the end products and enabling products interoperate.

During project formulation, the ConOps is analyzed to identify internal and external interfaces. Functions are then developed based upon the ConOps and these functions are the source for early identification of interface, particularly external interfaces. The interface management process works closely with the TRD. TRD produces interface requirement inputs into the IM process, as illustrated in NASA SP6015, Figure 6.3-1 Interface Management Process.

During project implementation, as the system architecture is defined, additional interfaces are added and changes to existing interfaces are maintained. Additionally, techniques such as NxN matrices are typically used to capture early content definition of interfaces. Configuration Management (CM) processes are used during this phase of the life-cycle to develop, baseline, and manage interface requirements.

During product integration, interface management activities support the review of integration and assembly procedures to ensure interfaces are properly marked and compatible with specifications and interface control documents. Interface Control Documents (ICDs) are necessary at contractual, element, and potentially NASA Center boundaries. They are not necessary at internal interfaces within a project or element, and are avoided there if possible. Interface control documentation and interface requirement changes are inputs to the Product Verification and Product Validation processes particularly where verification test constraints and interface parameters are needed to set the test objectives and test plans.

Inputs and Sources:

a. Internal and external functional and physical interface requirements for the products of a WBS model (from user or program and Technical Requirements Definition). The interface requirements are typically captured in IRDs, but also SRDs.

b. Interface change requests (from project, and Technical Assessment Processes).

Outputs and Destinations:

a. Interface control documents (to Configuration Management Process). Note: Change to reference Interface control document changes from Design Solution Definition, once the MPR is changed.

b. Approved interface requirement changes (to Configuration Management Process).

c. Interface management work products needed to provide reports, records, and metrics of process activities (to Technical Data Management Process).

4.3.2.2.1 Interface Management Approach

An Interface Management Approach is developed to address the process for controlling identified interfaces and associated interface documentation. Key content for the approach includes the list of interfaces by category, the interface owner and the configuration control mechanism to implement the change process for the documents. Typically, the SEMP documents and describes the implementation of the interface management process. *In some more complex programs the systems engineer may choose to define the interface management approach in an Interface Control Plan (ICP). In this case the ICP is a subordinate document to the SEMP. The primary criteria for choosing the development an ICP is the complexity of the program and the number and variety of interfaces being managed by the program or project. A key component of the content necessary to manage interfaces is the definition of the Preliminary Interface Revision Notice (PIRN)/ Interface Revision Notice (IRN) processes.*

The following tasks and steps are provided to assist with satisfying the requirements contained in MPR 7123.1.

Tasks	Steps
Prepare interface management approach	a. Identify the relevant stakeholders *(CM, LSE, Change Engineer (CE), PM, Subsystem, and/or Element Leads)* who will be responsible for implementing the IM process b. Assemble and compile information to support the development of the interface management approach 1) SOW 2) Project Plan 3) Lessons Learned c. Conduct stakeholder meetings and interviews, as required, to develop the interface management approach and list of deliverables *which may include but are not limited; ICP or SEMP Section(s), Section(s) of the Configuration Management Plan (CMP), PIRN/IRN process guidelines, Interface Metrics, Interface Models, Inputs to Verification Plans, and Inputs to the IMS.* d. Prepare a schedule that captures necessary activities and tasks for producing the identified IM deliverables *noted above. The schedule captures the phasing of IM products with CM planning, in order to support design reviews.* e. Assign responsibility, authority, and adequate resources for performing the IM activities, which

	include: 1) Developing the IM work products and supporting information 2) Performing and supporting IM services (e.g., establishing and maintaining a requirements management database tool for interface requirements *in conjunction with TRD*, processing proposed changes to baselined interface documents *in conjunction with CM/DM*, and maintaining the traceability between interface requirements and interface design (see metrics paragraph), etc.) f. Define the level of configuration management/data management control for all IM work products, and *ensure that PIRN/IRN processing is addressed by and accommodated by CM/DM.* g. Identify the training for those who will be performing IM activities
Manage and maintain interface management approach	The baselined interface management approach is placed under formal configuration control in accordance with established configuration management procedures NOTE: The interface management approach is typically incorporated into the SEMP and baselined in conjunction with the SEMP.

Examples

NASA Systems Engineering Handbook NASA/SP-2007-6105	Appendix J: SEMP Content Outline, Common Technical Processes Implementation

4.3.2.2.2 Control Interface Design Solution(s)

Interface design solutions are in response to the interface requirements defined during the Technical Requirements Definition process, as well as in response to structural design and construction standards, system level requirements, and mission timeline(s), all of which inform the interface design. In most cases interface requirements are captured in IRDs, but in some situations interface requirements are captured in system level requirements documents. It is also important to recognize that Decision Analysis impacts the implementation of interface definition. An example is the design decision to implement helium spin-start for the Ares Upper Stage Engine. The stage hosted the helium tank for the engine, thus defining a high-pressure helium line at the interface.

The subsequent interface design solution(s) are captured via an Interface Control Document or Drawing (ICD) and or an Interface Definition Document or Drawing (IDD).

Developing the Interface Control Document (ICD)

The ICD is a design document that describes the detailed, as-built implementation of the functional requirements contained in the corresponding IRD.

In most cases, the ICD will be based on the interface requirements contained in the IRD that was generated as part of the Technical Requirements Process (TRP). The ICD will be prepared in accordance with DRD STD/SE-ICD, Interface Control Document, DRD. Based on the scope and other factors, the ICD will be developed and described in sufficient detail to ensure the selected interface design solution will comply with all applicable interface requirements contained in the IRD.

The following tasks and steps are provided to assist with satisfying the requirements contained in MPR 7123.1.

Tasks	**Steps**
Assemble and review all inputs that would help define the scope of defining and developing a specific interface design solution	Assemble and review the following: 1) Interface requirements 2) Logical decomposition models and work products 3) Applicable trade studies and engineering reports 4) Commercial industry and International Standards 5) Other specifications 6) Figures, tables, schema, or other applicable and supportive information
Develop an approach to	a. Develop schedule and identify resources needed to

manage the development of the ICD	develop the ICD b. Establish conflict resolution procedures to address potential irreconcilable or irresolvable issues that could impede timely completion of the ICD c. Upon completion of negotiations on the ICD development schedule and resources to be provided, obtain authorization to proceed with the development of the ICD
Develop the interface design solution	a. Conduct interface working group meetings in accordance with Interface Management Plan (may be captured in SEMP) b. Collectively assess and evaluate alternative interface design solutions c. Fully describe the selected interface design solution through drawings, tables, and written text d. Document forward work to finalize ICD definition to include: e. Who is responsible for the content f. Expected completion date g. The work package that covers the required work to develop it
Submit the completed ICD for approval	a. Obtain approval from the project set of stakeholders that the ICD has achieved sufficient maturity to be baselined b. Obtain signature approval to baseline the set of technical requirements from the appropriate TA
Manage and maintain the ICD	a. Manage and maintain the ICD in accordance with the procedures defined in the Interface Management section of this document b. The baselined ICD is placed under formal configuration control in accordance with established configuration management procedures

The ICD details the physical interface between two system elements, including the number and types of connectors, electrical parameters, mechanical properties, and environmental constraints. *Sample interface categories are shown in the table below*[1]*.* ICDs are useful when separate organizations are developing design solutions to be adhered to at a particular interface. *ICDs ensure compatibility and allow each side of the perspective interface to continue with their design without fear of developing designs that are not compatible at the interface. ICDs map their information back to their respective requirements documents (IRDs, Environmental Requirements Documents (ERDs), SRD, Specifications, etc.) to ensure completeness and aid in the verification of interface requirements.*

Categories	***Functions***	***Types/Examples***	***Remarks***
I. Structural/Mechanical	*1. Structural integrity between elements & subsystems & components -Load paths -Stiffness -Strength -Durability 2. Separation of elements as mission timeline dictates*	*1. a. Flanges b. Bolts c. Welds d. Links e. Fasteners f. Adhesiveness 2. a. Pyros b. Springs c. Hydraulics*	*1. Form and fit between interface mating parts very critical and a source of many problems. Verification of form and fit as well as structural capability is a major challenge. 2. Separation systems malfunctions have been the source of many problems. Verification of separation systems a major activity and challenge*
II. Fluid & Hydraulic	*1. Propellant flow between elements2. Air flow between elements*	*1. Duct and flanges 2. Duct and flanges*	*1. Prevention of leaks with ability to separate as required*

	3. Control forces/separation forces	*3. Actuators/ links*	*2. Prevention of leaks with ability to separate as required* *3. Ability to handle point loads and varying dynamics*
III. Electrical	*1. Transmit power between elements* *2. Communications between elements* *3. Information flow between elements*	*1. 2. & 3.* *Pins* *Connectors* *Wires* *Busses* *Transmission* *Waves*	
IV. Environments	*1. Electromagnetic Interference/Electromagnetic Compatibility (EMI/EMC)* *2. Natural Environments* *3. Induced Environments*	*1. Wiring shielding and separation* *2. System ability to function in the surrounding environment* *3. System ability to control, manage and function in the created environment*	*1. Design for electronic/electrical signal integrity* *2. System functions in the environment (example: Temperature, Winds)* *3. System functions in the environment it produces (example: Thruster Plume, Thermal Protection System (TPS) icing)*

There is a need to analyze system level interfaces to determine the types of interfaces that exist for the system. As an example, propulsion and structures IxI matrix could *contain the following; with the same type information generated for each subsystem such as avionics, thermal, and Guidance, Navigation and Control (GN&C).*

A. The propulsion system requirements to structures:	*1. Thrust bearing to transfer thrust load to stage,* *2. Gimbal capability of engine for control authority (Throw angle in degrees)* *3. Fluid propellant input to engine (Flow rate)*
B. Propulsion system description to structures;	*1. Induced environments of engine (thermal, acoustic, vibration, thrust)* *2. Engine dimensions* *3. Mass characteristics* *4. Flow rates*
C. Structural requirements to engine:	*1. Attach mechanism* *2. Induced environments* *3. Propellant Lines attachment* *4. Electrical attachment*
D. Structures description to propulsion:	*1. Propellant line flex bellows* *2. Gimbal joint flange description* *3. Propellant line flange description* *4. Volumetric constraints* *5. Detail drawings of interface mating areas*

<u>Developing the Interface Definition Document (IDD)</u>

The IDD is a unilateral document controlled by the end-item provider, and it provides the details of the interface for a design solution that is already established. This document is sometimes referred to as a “one-sided ICD.” The user of the IDD is provided connectors, electrical parameters, mechanical properties, environmental constraints, etc., of the existing design. The user then designs the interface of the system to be compatible with the already existing design interface. An IDD is used to describe the docking station parameters on the ISS for visiting space vehicles or to interface with GSE.

Interface metrics are captured throughout the life of the program beginning with the Concept of Operation definition for the;

a. number of system external interfaces.

Other interface quality metrics may also include, but are not limited to;

b. number of interface documents and their completion status,

c. number of To Be Determined (TBDs)/To Be Resolved (TBRs) and their corresponding burn down status,

d. number of PIRNs/IRNs for the interface documents and their corresponding burn down status,

e. IRD in compliance with requirements (% yes),

f. ICD compliance with Interface Requirements,

g. number of interfaces discovered after initial release of the ICD.

The following tasks and steps are provided to assist with satisfying the requirements contained in MPR 7123.1.

Tasks	Steps
Prepare Interface Control Document or Drawing	a. Identify design definitions for each side of an interface *b. Evaluate the organizational implications for the interface and determine the need for an ICD versus a controlled drawing to capture the interface design. Criteria for this determination could be whether the interface is within an organization, contract, subsystem, technical discipline, component, etc.* c. Address all requirements necessary to describe the interfaces to be met to ensure project, hardware, and software compatibility and interface design formulated during Design Solution Definition including: 1) Physical interfaces which involve physical mating and spatial relationships between interfacing end items

	2) Functional interfaces which involve the interaction or influence of conditions imposed by one subsystem or component upon another or by external sources (fluids, thermal, electrical, environmental, data, loads, etc.) 3) Procedural interfaces which involve critical sequences of events occurring in assembly, disassembly, alignment, service operations, and computer programs d. Traceable to the requirements in the system specifications and/or the Interface Requirements Document. A trace table can be employed here to link interface requirements to interface design, with corresponding metrics reported on the linkages.
Manage and maintain Interface Control Document	The baselined ICD is placed under formal configuration control in accordance with established configuration management procedures and is maintained per the steps discussed above.
Prepare Interface Definition Document or Drawing	*a. Interface documentation can be developed and managed using Interface Control Working Groups (ICWG) and is sometimes managed using an Interface Control Plan. The need for interface documentation is typically driven by the size and complexity of the program or project.* *b. Analysis and trade studies can drive the need for interfaces, and the type of interface.* c. Provide details of the interface for an established design solution to include: 1) Priority assigned to the interface by interfacing entities 2) Type of interface 3) Specification of individual data elements, format, and data content 4) Specification of data element assemblies, format, and data content 5) Specification of communication methods and

	protocols 6) Other specifications, such as physical compatibility (connectors, electrical parameters, mechanical properties, environmental constraints, etc.) d. Traceable to the requirements in the system specifications and/or the Interface Requirements Document. A trace table can be employed here to link interface requirements to interface design, with corresponding metrics reported on the linkages.
Manage and maintain Interface Definition Document	The baselined IDD is placed under formal configuration control in accordance with established configuration management procedures and is maintained per the steps discussed above.

The following example interface documents are provided for reference. The examples represent several types of interfaces for; a) hardware interfaces for major element interfaces for the ISS Pump Module Assembly (PMA)-1 to Russian Functional Cargo Block [sic] (Functionalui Germaticheskii Block) (FGB), both IRD and ICD, b) the ISS IDD for the standard ISS interface, c) SSP 44178 for software interfaces between computer, both IRD and ICD, and d) Standard Component or box level interfaces in the form of Standard ICDs or IDDs.

SSP 42121, Part 1 (IRD)	U.S. On-Orbit Segment Pressurized Mating Adapter – 1 to Russian Segment FGB Interface Control Document
SSP 42121, Part 2 (ICD)	U.S. On-Orbit Segment Pressurized Mating Adapter – 1 to Russian Segment FGB Interface Control Document
NSTS-21000-IDD-ISS	International Space Station Interface Definition Document
SSP 41178-25 Part 1 (IRD)	Software Interface Control Document, Internal Multiplexer De-Multiplexer to International Space Station Book 25, Node 2-2 Multiplexer De-Multiplexer Interface
SSP 41178-25 Part 2 (ICD)	Software Interface Control Document, Internal Multiplexer De-Multiplexer to

	International Space Station Book 25, Node 2-2 Multiplexer De-Multiplexer Interface
NSTS 21000-IDD-ISS	International Space Station Interface Definition Document, Revision A
SSP 30261:001	Multiplexer De-Multiplexer (MDM) Standard ICD (IDD)
SSP 30263:002	Remote Power Controller Module Standard ICD (IDD)

4.3.2.2.3 Data Requirements Description (DRD)

For any DRDs that are applicable to this process, refer to MPR 7123.1.

4.3.2.3 Technical Risk Management

The TRM process focuses on project objectives, providing an analytical basis for risk management decisions and the ensuing management activities, and a framework for dealing with uncertainty. TRM is an organized, systematic risk-informed decision-making discipline that proactively identifies, analyzes, plans, tracks, controls, communicates, documents, and manages risk to increase the likelihood of achieving project goals.

Strategies for handling risks include: mitigation (taking actions to reduce the likelihood of realizing the threat or reducing the impact of the consequences); research (studying the risk to better understand the conditions and/or the consequences so that a mitigation or acceptance plan can be developed); watch (waiting to see what develops); transfer the risk (to another organization because they have resources to address it or authority to accept the risk); and accept (where the responsible authority, usually the Project Manager makes the decision to proceed without taking further actions). Technical Authorities are responsible for concurring (not accepting) the risk. Just as important is understanding the "conditions" that are driving each identified risk. A risk condition is the driver for the risk. Risk conditions are stated as a given fact, but can change during the product life-cycle. For example, a specific technical requirement may be the condition for a performance risk. The project could change this requirement (condition) to mitigate or possibly eliminate the risk.

Once a risk strategy is selected, technical risk management ensures its successful implementation through planning and implementation of the risk tracking and controlling activities. TRM focuses on risk that relates to technical performance. However, management of technical risk has an impact on the nontechnical risk by affecting budget, schedule, and other stakeholder expectations.

TRM is an iterative process that considers activity requirements, constraints, and priorities to:

a. Identify and assess the risks associated with the implementation of technical alternatives;

b. Analyze, prioritize, plan, track and control risk and the implementation of the selected alternative

c. Implement contingency action plans as triggered;

d. Communicate, deliberate, and document work products and the risk; and

e. Iterate with previous steps in light of new information throughout the life-cycle.

The TRL of components or materials or the Manufacturing Readiness Level or Software Readiness Level of systems or subsystems are assessed to determine if they present risks to the project. . A MSFC assessment tool is available at https://trl.msfc.nasa.gov.Identification of risks associated with a low TRL provides justification for proof of concept and development testing as early in the project schedule as possible. If the project takes the protoflight approach, the technical risk management process becomes increasingly important for the identification of unproven technology and designs. Likewise, if the project elects to perform analysis instead of testing, or, decides to delay component V&V testing until the systems test, the associated risks are clearly identified and managed.

The following are key inputs and outputs to the Technical Risk Management process.

<u>Inputs and Sources</u>:

a. Project Risk Management Plan (from project).

b. Technical risk issues (from project and other common technical processes).

c. Technical risk status measurements (from Technical Assessment and Decision Analysis Processes).

d. Technical risk reporting requirements (from project and Technical Planning Process).

Outputs and Destinations:

a. Technical risk mitigation and/or contingency actions (to Technical Planning Process for replanning and/or redirection).

b. Technical risk reports (to project and Technical Data Management Process).

c. Work products from technical risk management activities (to Technical Data Management Process).

4.3.2.3.1 Technical Risk Management Approach

The TRM approach, normally captured in the SEMP, provides the baseline approach for planning, management, control, and implementation of risk management for a program or project. The TRM approach may be captured in the project Risk Management Plan (RMP). The work products generated during this activity include the overall RMP, risk list, analyses, tracking reports, and metrics that support the risk management process.

The TRM approach is based on the implementation of the two complementary processes: Risk-Informed Decision Making (RIDM) and Continuous Risk Management (CRM). The implementation of the TRM process will need to consider the additional procedural requirements contained in NPR 8000.4, Risk Management Procedural Requirements Requirements and MWI7120.6, Program, Project, and Institutional Risk Management.. Additional implementation information on RIDM and CRM is contained in Section 4.3.2.3.2.

The following tasks and steps are provided to assist with satisfying the requirements contained in MPR 7123.1.

Tasks	Steps
Analyze the technical risk management activities that will be performed during the system life-cycle	In conjunction with the preparation or revision of the project SEMP and/or Project Risk Management Plan, prepare a list of key top-level decisions that will be made as part of the current, upcoming, and future life-cycle phases Identify supporting decisions that need to be made to

	support key top-level decisions
Establish guidelines and criteria for identifying technical risks for analysis or evaluation	Establish guidelines to support technical risks that may be based on cost and schedule thresholds, risk, time criticality, resource requirements, or issues that require coordination outside of the project's current authority or purview
Assign a responsible role or working group for technical risk management activities	a. Obtain a project organizational chart to support the technical risk management assignments b. Obtain a project working group chart to support the technical risk management assignments c. Assign a primary role or working group and supporting role or working group to each of the key top-level and supporting technical risk management
Identify key work products that will be used to support the risk management process	a. Based on the scope of the project, analyze the entrance criteria for mandatory technical reviews and key decision points to identify and capture corresponding work products needed to satisfy and comply with the entrance criteria b. Identify additional work products needed to support technical risk management that will ultimately support top-level key project decisions 1) RMP 2) Risk List 3) Analyses 4) Tracking Reports 5) Lessons Learned 6) Metrics
Provide output of the risk management process in support of the preparation or revision of the project SEMP and/or Project Risk Management Plan	Provide a listing of work products needed to support the risk management process 1) RMP 2) Risk List 3) Analyses 4) Tracking Reports 5) Lessons Learned 6) Metrics

Examples

NASA Systems Engineering Handbook NASA/SP-2007-6105	Figure 6.4-10, Performance monitoring and control of deviations
NASA Systems Engineering Handbook NASA/SP-2007-6105	Figure 6.4-11, Margin management method

4.3.2.3.2 Technical Risk Management

As noted earlier, RIDM and CRM are integrated into a coherent framework to foster proactive risk management. These processes provide timely risk information to support better decision making and to more effectively manage technical risk once a specific design implementation is selected.

By taking into account applicable risks and uncertainties, RIDM is used to make an informed decision from a set of different decision alternatives. CRM is then used to manage those risks that could impact the technical performance levels that were key drivers to the selection of that particular alternative.

Risk analysis is used by both RIDM and CRM. Several NASA resources are available to support technical risk analyses.

a. *Probabilistic Risk Assessment Procedures Guide for NASA Managers and Practitioners*, Version 1.1; August 2002

b. *Fault Tree Handbook with Aerospace Applications*, Version 1.1; August 2002

c. *Bayesian Inference for NASA Probabilistic Risk and Reliability Analysis*, NASA/SP-2009-569; June 2009

d. *System Engineering "Toolbox" for Design-Oriented Engineers*, NASA Reference Publication 1358; December 1994

RIDM is invoked for key decisions such as architecture and design decisions, make-buy decisions, source selection in major procurements, and budget reallocation (allocation of Unallocated Future Expenses UFEs), which typically involve requirements-setting or rebaselining of requirements. RIDM is invoked in many different venues, based on the management processes of the implementing organizational unit. RIDM is applicable throughout the project life-cycle whenever trade studies are conducted. NPR 8000.4A, Agency Risk Management Procedural Requirements, includes the requirements for the RIDM Process. The NASA Risk Informed Decision Making Handbook NASA/SP-2010-576 provides guidance for implementing the RIDM requirements with a specific focus on programs and projects in the Formulation phase, and applying to each level of the NASA organizational hierarchy as requirements flow down.

CRM is a widely used technique that is performed continuously throughout the program life-cycle to monitor and control risk. It is an iterative and adaptive technique that promotes the successful handling of risk. Each step of CRM builds on the previous step, leading to improved designs and processes through the feedback of information that is generated.

The steps of CRM are identified as follows:

a. Identify: Identify program risk by identifying scenarios having adverse consequences. These risks include risk related to safety, technical performance, cost, schedule, and other risk specific to a program.

b. Analyze: Estimate the likelihood and consequence components of the risk through analysis, including uncertainty in the likelihoods and consequences, and the timeframes in which risk mitigation actions are to be taken.

c. Plan: Plan the track and control actions. Decide what will be tracked, decision thresholds for corrective action, and proposed risk control actions.

d. Track: Track program observables relating to TPMs, measuring how close the program performance is compared to its plan.

e. Control: Given an emergent risk issue, execute the appropriate control action and verify its effectiveness.

f. Communicate, Deliberate, and Document: This is an element of each of the previous steps. Focus on understanding and communicating all risk information throughout each program phase. Document the risk, risk control plans, and closure/acceptance rationale. Deliberate on decisions throughout the CRM process.

TRM metrics provide insight into the overall technical risk profile of the project. Technical or performance risk may be measured by using TPMs. The projected and/or actual variance to performance requirements is a measure of technical risk. At a lower level, metrics for the Risk Management process itself may include:

a. **Total active high risks, total active medium risks over time.** The objective is to provide visibility into risk trends over time.

b. **Percent of risks (medium and high) with approved mitigation plans.** The objective is to measure the effectiveness of handling the risks requiring action.

c. **Average time span of overdue mitigation activities.** The objective is to measure the effectiveness of meeting mitigation plan schedules.

d. **Aging of active risk records.** The objective is to gain insight into the currency of the risk database.

e. **Number of risks past their realization date.** The objective is to provide an indicator of the effectiveness to handle risks in a timely manner.

The reporting on the status of technical risks being tracked may be part of a monthly progress report that is within the scope of DRD STD/MA-MPR, Monthly Progress Report. The status of technical risks is a standard agenda item for recurring management and technical reviews.

The following tasks and steps are provided to assist with satisfying the requirements contained in MPR 7123.1.

Tasks	Steps
Identify sources of technical risk	a. Baseline technical risk database or list b. Identify sources of technical risk 1) Safety 2) Technical performance 3) Cost 4) Schedule 5) Inadequate staffing or skills 6) Uncertain or inadequate contractor or vendor capability 7) Insufficient production capacity 8) Operational hazards 9) Poorly defined requirements 10) No bidirectional traceability of requirements

	11) Infeasible design 12) Inadequate configuration management 13) Unavailable technology 14) Immature technology 15) Inadequate planning 16) Inadequate quality assurance 17) Other Project specific risks c. Write technical risk scenario statements d. Capture context of the technical risk
Analyze and assess technical risk	a. Add new data & “risks” b. Select risk analysis method; such as, 1) Risk matrices 2) Failure Modes and Effects Analysis 3) Fault Trees 4) PRA c. Assess timeframe d. Assess criticality e. Likelihood f. Consequence g. Prioritize h. Scenario development i. Update risk models
Plan and develop a strategy for each technical risk	a. Mitigate 1) Assign technical risk owner 2) Develop or revise mitigation plan (including contingency plan) 3) Re-analyze technical risks with mitigation incorporated 4) Assess cost-effectiveness of candidate mitigation plans (i.e., overall risk reduction per unit cost) 5) Decide among feasible mitigation alternatives 6) Implement mitigation plan b. Watch 1) Assign risk owner

	2) Develop tracking requirements (including contingency plan) c. Research 1) Assign risk owner 2) Develop and implement research plan d. Accept e. Elevate f. Close
Track technical risk	a. Acquire and compile data b. Run models c. Technical risk tracking report
Control technical risk	a. Re-plan b. Invoke contingency plans c. Continue tracking d. Close e. Elevate
Communicate and document technical risk	a. Manage and maintain risk database 1) Performance requirement 2) Performance measure 3) Performance measure threshold 4) Risk statement or scenario 5) Descriptive narrative 6) Risk analysis a) Probability b) Uncertainty c) Timeframe 7) Disposition status and date a) Mitigation plan b) Research plan 8) Tracking report and date 9) Control recommendation and date (including contingency plan) 10) Control decision and date a) Provide basis when a risk strategy decision

	is made to accept a specific technical risk b. Communicate and report risks to applicable organizations 1) Top risks 2) Cross-cutting 3) Elevation
Manage and maintain technical risk management work products	a. Prepare and/or update technical risk management work products 1) Ensure version and/or configuration control of risk management data 2) Publish and make technical risk information available to support stakeholder needs b. Update and submit in accordance with established data management requirements

Examples

NASA Systems Engineering Handbook NASA/SP-2007-6105	Figure 6.4-4, Continuous risk management
NASA Systems Engineering Handbook NASA/SP-2007-6105	Figure 6.4-5, The interface between CRM and risk-informed decision analysis
NASA Systems Engineering Handbook NASA/SP-2007-6105	Figure 6.4-6, Risk analysis of decision alternatives
NASA Systems Engineering Handbook NASA/SP-2007-6105	Figure 6.4-7, Risk matrix
NASA Systems Engineering Handbook NASA/SP-2007-6105	Figure 6.4-8, Example of a fault tree

4.3.2.3.3 <u>Data Requirements Description (DRD)</u>

For any DRDs associated with this process, refer to MPR 7123.1.

4.3.2.4 Configuration Management

Configuration management is a formal and disciplined process for the establishment and control of the requirements and configuration of hardware/software developed for

NASA. This section of the handbook is intended for use by MSFC Programs and Projects to provide the guidance and activities for successful implementation of the CM requirements in MPR 7123.1, MSFC Systems Engineering Processes and Requirements. It is to be used as guidance and does not supersede existing CM governance.

The configuration management activities provide the discipline necessary for the initial establishment and subsequent control of project requirements and design evolution. Such activities consist of generating Center configuration management policies, requirements, and procedures and assisting with the development of project and contractor plans and manuals. In addition, support functions associated with baseline identification, change processing, tracking, accounting, reviews, and audits are provided. To assure consistency across projects a standardized baseline and change status and accounting system is maintained and supported. Co-located configuration management support personnel are provided to projects, and direct configuration management support is maintained for in-house activities. Support includes change control and integration, and provision and maintenance of a comprehensive document release system.

MPR 7123.1, MSFC Systems Engineering Processes and Requirements; MPR 8040.1, *Configuration Management, MSFC Programs/Projects;* DRD STD/CM-CMP, *Configuration Management Plan* and MSFC-STD-555, *MSFC Engineering Documentation Standard*, establish the basic policy for implementation of configuration management at MSFC.

This section identifies activities, tasks and steps for implementing the Configuration Management (CM) process. Implementation of this guidance, along with an effective CM governance structure, will help the project obtain compliance with the requirements contained in Marshall Procedural Requirements MPR 7123.1. The following is the minimum set of products resulting from this process:

a. Configuration Management Plan

b. List of Configuration Items

c. Baselines

d. CCB/Minutes

e. Change Requests, Deviations/Waivers and Directives

f. Change Logs

g. Status of Change Request Implementation

h. Configuration Audit Records

Properly executed products will provide the evidence needed to ensure process compliance as part of a process audit.

These products are derived from the original requirement for the Center Director or designee to establish and maintain a Configuration Management process found in NASA Procedural Requirements NPR 7123.1, "NASA Systems Engineering Processes and Requirements", as shown in Figure 8.

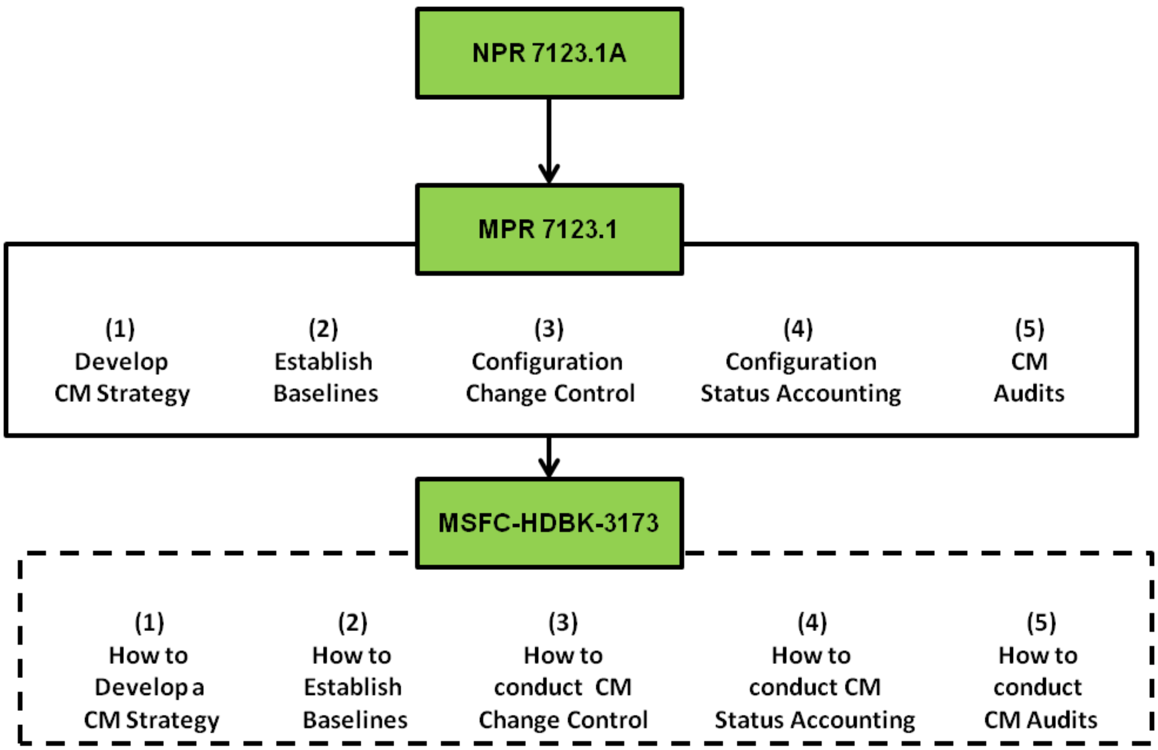


Figure 8. Traceability of Handbook Guidance to CM Requirements

The development of this document was based on the following assumptions:

a. Each project Office needs a minimum number of CM requirements accompanied by proven and accepted guidance used by industry and government.

b. The project requires a Configuration Manager that is very knowledgeable of the CM process and has the ability to guide the Project in the appropriate tailoring for the size, complexity, criticality, and risk of the Project.
Approval of the Configuration Management Plan (and other important guiding documents such as the SEMP) follows a governance process similar to the one outlined in Figure 9.

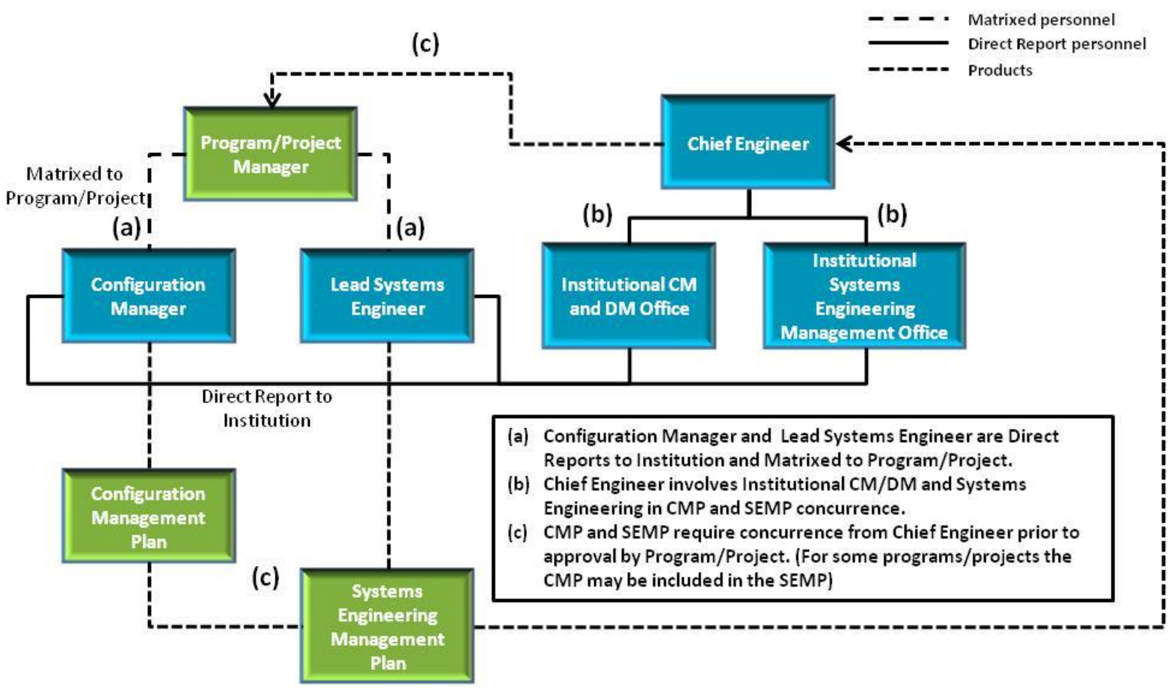


Figure 9. Example of Governance Model to Support an Effective CM Strategy

4.3.2.4.1.2 <u>Developing a Configuration Management Strategy</u>

The Project manager ensures that a CM strategy is developed that meets the requirements for visibility and control of the functional and physical characteristics of a CI over the life-cycle. The Project Manager is satisfied with a Configuration Management Strategy if the following fundamental question can be answered: "Will it allow me to know the end use, pedigree, and history of my Project Configuration Items?"

The strategy has the following elements documented in a CMP:

a. Configuration Identification

b. Establishment of a Configuration Change Control Process

c. Configuration Status Accounting

d. Configuration Audits

e. Defining requirements for CM tools

f. Training the Technical and Project team

This handbook offers the Project Manager the guidance and recommended procedures to accomplish these elements but the process will only be successful if the implementation is facilitated by a well-documented CM process and open communications.

Developing a Configuration Management Plan (CMP)

Configuration Management has five major components: **Configuration Planning**, Configuration Identification, Configuration Change Control, Configuration Status Accounting, and Configuration Audits.

The Configuration Management Strategy is documented in the Project CMP and contains the necessary implementation information. This implementation approach is agreed upon by the Project Manager, the Configuration Manager and the Chief Engineer of the Project. The reason for this agreement is that the manner of implementation can be different for each Project and is a function of the Project organizational structure, operational culture, and the communications approach between the Project office and the performing engineering organizations. NASA SE Handbook 6105, Appendix M, MPR 8040.1, Configuration Management, MSFC Programs/Projects, and STD/CM-CMP provide templates and additional guidance in the development of a Configuration Management Plan.

The CMP is written in close coordination with the Project Plan and the project SEMP. This coordination helps maintain consistency in terminology, major milestones, and products throughout implementation of the CM process. Depending on the size, complexity, criticality, and risk of the Program or Project the CMP can be a stand-alone document or be incorporated into the SEMP or the Project Plan. This decision belongs to the Project Manager.

The following are selected CM guidance gathered from a variety of references and listed here as significant. More specific information related to these and other guidance for developing a Configuration Management Plan will be addressed in further detail in the body of this section.

a. Documents and records are identified by a unique document numbering scheme. For software, the Code is identified by applying labels in the source code folder for storage in the project repository.

b. Projects may tailor this structure according to their specific needs.

c. A baseline is defined as a set of specifications or work products that has been formally reviewed and agreed upon. After formal approval this baseline is the basis for further development, and is only be changed through formal change control procedures.

d. Clearly understand and communicate the roles and responsibilities of CM, Information Technology (IT), Engineering and Project personnel and the interfaces between them.

e. Establish and communicate a CM organizational and functional work flow, and governance.

f. A Baseline Criteria elaborates the conditions and constraints fulfilled prior to establishing/creating a formal baseline. Baseline criteria may vary from baseline to baseline due to the nature of its contents. Specific criteria for each formal baseline are documented in a Configuration Management Plan.

g. All planned baselines in the Configuration Management Plan are reflected as milestones in project schedule in order to avoid them inadvertent omission.

h. For each item of configuration documentation, there is one organization with release authority, only one active release record, and a single point of release at any time in the configuration data item’s life-cycle.

i. The Project minimizes the number of approval signatures and releasing CIs. This ensures aach signatureprovides value to the approval process.

j. When authorized changes are made to configuration documentation, the project baseline is updated to reflect current baseline. The process and criteria for baselining is documented in the Configuration Management Plan.

Tasks	Steps
Develop a Configuration Management Plan	a. Use MPR 8040.1 and STD/CM-CMP as guidance b. Configuration Manager coordinates with Project Manager and Chief Engineer to identify the "Applicable" sections of the guidance template in the above references based on size and complexity of the project c. Deliver to Project Manager and Chief Engineer for coordination and implementation

4.3.2.4.2 Configuration Identification

Identifying Configuration Items and Description Schema

Configuration identification is the definition and establishment of the total technical requirements of a CI or Computer Software Configuration Item (CSCI) and encompasses performance and functional requirements as well as the detailed configuration definition. It is a deliverable product, (hardware, software, or combination), designated for configuration management. The baseline consists of the configuration data which represents the CI and may consist of multiple related work products which describe the attributes or characteristics of the CI (e.g. process descriptions, requirements, design, test plans and procedures, test results, etc.). The selection of CIs is based on criteria established jointly by the Project Manager, Chief Engineer, CM Manager and the responsible design organization during CM planning. It is mandatory that this identification be formally defined and documented throughout the life of the project. The accepted method of documentation includes specifications, engineering drawings, and basic requirements documents (e.g., Military Standards, processes, IRDs, etc.).

At the strategy or planning level, a CI/CSCI is uniquely identified with an identification numbering system (i.e., CI, CSCI, part numbers, serial and lot numbers) so that it can be distinguished from all other Configuration Items. If one changes a specific baseline version of a CI, the change creates a new version of the same configuration item and baseline. NASA has four formal baselines (Functional, Allocated, Product and As-

Deployed), each of which defines a distinct phase in the evolution of the product design (see NASA/SP-2007-6105 for definitions of these baselines). The baseline identifies an agreed-to description of attributes of a CI at a point in time and provides a known configuration to which changes are addressed. Configuration identification is established incrementally and is a product of the various project reviews as discussed in 4.4. The evolution of the configuration baselines are planned and enforced by the project. For a contract, NASA specifies what configuration documentation produced by the contractor will be placed under NASA control and the schedule for these NASA baselines.

When ready for formal release the CI may consist of several configuration items with corresponding interfaces, Figure 10. A complex hardware configuration item may have many levels of configuration items beneath its top level; each configuration item level meets the same fundamental elements of the configuration management system. This is why it is important to establish a configuration item selection criteria prior to generating the project Configuration Items List.

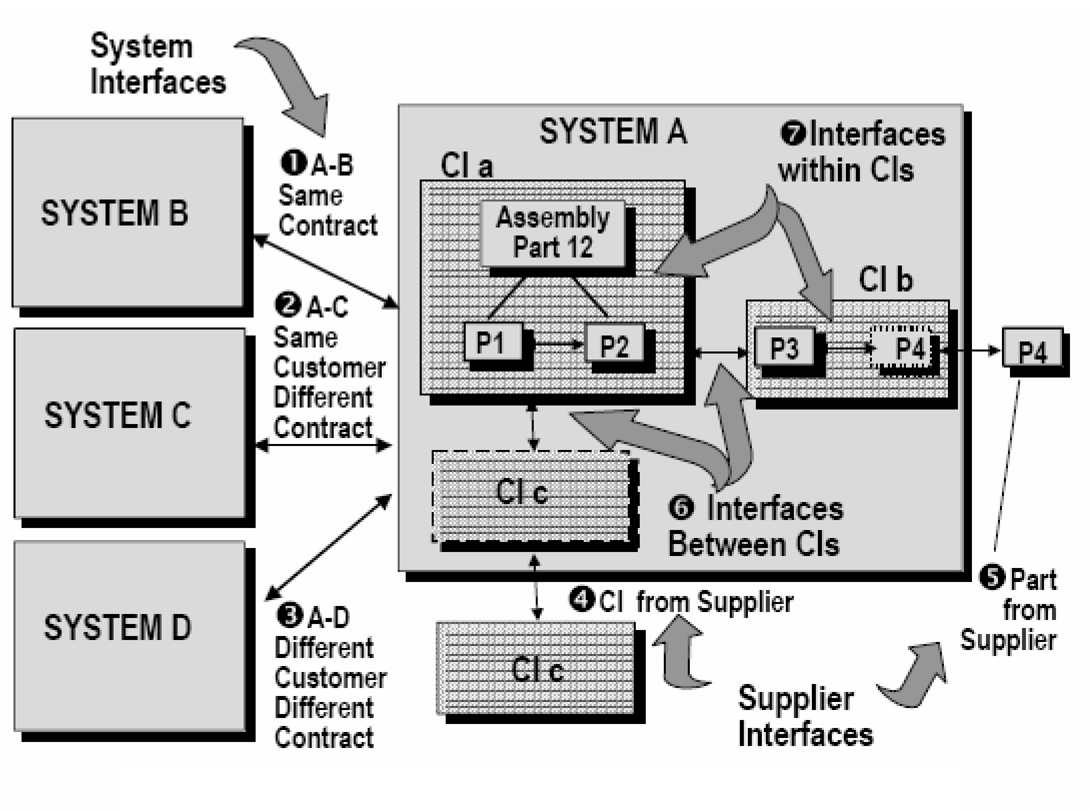


Figure 10. Understanding Interface Levels (Ref: MIL-HDBK-61)

Each configuration item's listing and definition acts as a common vocabulary across all groups connected to the product. It is defined at a level such that an individual involved with product design and an individual in testing the design can agree to a common definition when they use the name of the configuration item. Selection and identification of configuration items for a particular project is the first step in developing an overall architecture of the product from the top down. Each configuration item is treated as a self-contained unit for the purposes of identification and change control.

Tasks	**Steps**
Develop CI Selection Criteria	a. Establish a CI selection checklist b. Identify Project specific guidance for the selection of CIs c. Use MIL-HDBK-61 as a reference for CI selection criteria guidance and selection checklist questions d. This criteria will be used in the development of the CI list
Develop an official Project CI List	a. Establish a unique identifier or numbering system that will be used throughout the life-cycle of each CI b. Configuration Manager coordinates with Project Manager, Chief Engineer and Design Organizations to generate the Project Configuration Items List. c. Develop a Product Structure and a Work Breakdown Structure populated by the CIs
Assign Identifiers to each Configuration Item	a. Identify the elements used by the Project office to assure the unique identity of any CI (See MIL-HDBK-61) b. Describe and implement a method for identifying CI units and CI groups

	(Serial and Lot numbers) c. Provide CI identifiers for development of the product structure
Identify the Configuration Documentation associated with each Configuration Item	a. Configuration Manager, in coordination with the Technical and project personnel, identifies the specification document types (see GEIA-HB-649 or MIL-HDBK-61 for guidance) b. Identify Design Solution and Software document types (see GEIA-HB-649 or MIL-HDBK-61 for guidance) c. Identify Project Specific document types. d. Configuration Items and associated Configuration Documentation populate the Product Structure
Establish and implement an engineering release system	a. Project Manager charters CCBs and authority at each CCB level b. Identify configuration documentation release requirements (For each item of configuration documentation, there is only one organization with release authority, only one active release record, and a single point of release at any time in the configuration data item's life-cycle.) c. Establish CI effectivity and release approval authority d. The Engineering Release System is used as the formal mechanism to publish official Project configuration items.
Identify Configuration Items which are included in Project Baselines	a. Using the CI selection Criteria identified the Configuration Manager coordinates

	with Chief Engineer to categorize and classify CIs and groups of CIs within the product structure that populate the Project baselines (Functional, Allocated, Product, and As-Deployed). b. Official baselines are the primary exit products resulting from successful completion of major reviews (SRR, Product/Preliminary Design Review (PDR), CDR, and ORR)

4.3.2.4.1.3 Configuration Change Control

Managing Change Control

Configuration control is the formal process used to establish and control the baseline. The Change Control process is used by the project to establish, track and control proposed engineering changes to the affected CIs and baselined configuration documentation. Through this process, the proposed change is identified, the justification and impact of the proposed change is reviewed and dispositioned, and the approved changes are incorporated. Implementation of the change is then tracked to determine if changes resulted in the intended outcome. This control is maintained through a hierarchy of formal CCBs that are established at each level of hardware/software management responsibility. The CCB hierarchy normally includes five levels as shown in Figure 11. Level I resides at NASA Headquarters and is responsible for the overall program requirements. Level II is responsible for program requirements allocated from Level I and usually resides at the NASA Center assigned as the Program Office or Lead Center. The program requirements apply to all of the applicable elements, flight, ground, launch sites, test sites, etc., including element to element interfaces. Level III CCBs are established to control the respective element's/project's requirements and interfaces. Each Level III has control of its element's/project's unique requirements and interfaces, but the Level III CCBs may not make final disposition of any change that affects a higher level CCB. The Level IV CCB is the System CCB, and the Project Manager may delegate the chairmanship to the LSE. The Level IV CCB may be the controlling CCB for in-house design, and/or serve as an engineering review board responsible for evaluating and providing technical recommendations pertaining to changes requiring disposition by a higher level CCB. A Level V CCB may reside with the developing contractor or WBS Manager (for in-house activities), and has control for all changes that are not controlled by any of the higher level CCBs. Each board can make decisions within its own authority, so long as it does not violate the cost, schedule, technical, or programmatic authority of higher level CCBs. MPR 8040.1 provides additional guidance on the configuration control process. Figure 12 is a generalized representation of a flow for a typical change.

The primary objectives of formal Configuration Change Control are to:

a. Establish and maintain a systematic change process throughout the life-cycle of the system/CI

b. Efficiently process and implement configuration changes

c. Maintain complete, accurate and timely changes to configuration documentation under configuration control authority

d. Eliminate unnecessary change proliferation.

Figure 13 provides a more simplified overview of the Configuration Control process. Configuration Control begins with the preparation of a request for change, which includes complete justification for the change and any impacts to the design, interfaces, performance, safety factors/margins as well as cost, schedule and safety. Change requests are evaluated and approved or disapproved by the configuration control board based on overall impact to the project. All approved are reviewed and implemented into project requirements and the design. Depending on the size and complexity of the project, additional processes and/or feedback loops may be added, including one for adjudication.

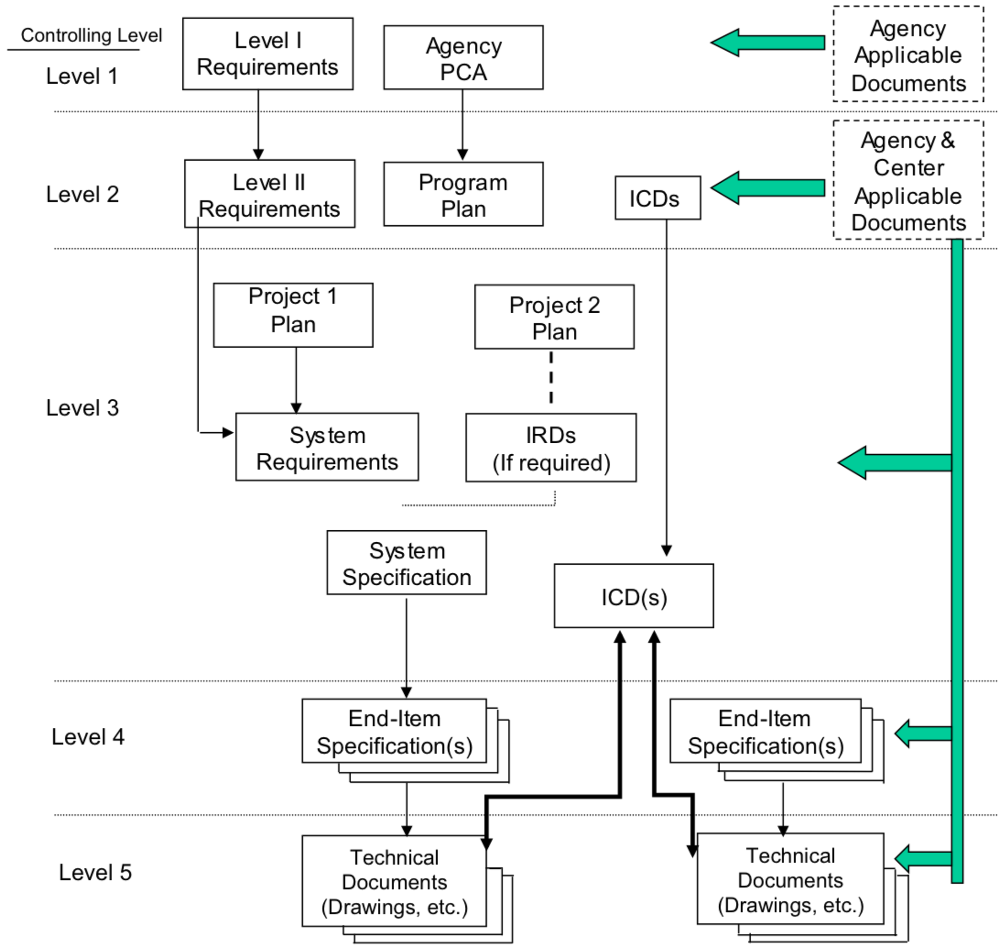


Figure 11. CCB Hierarchy

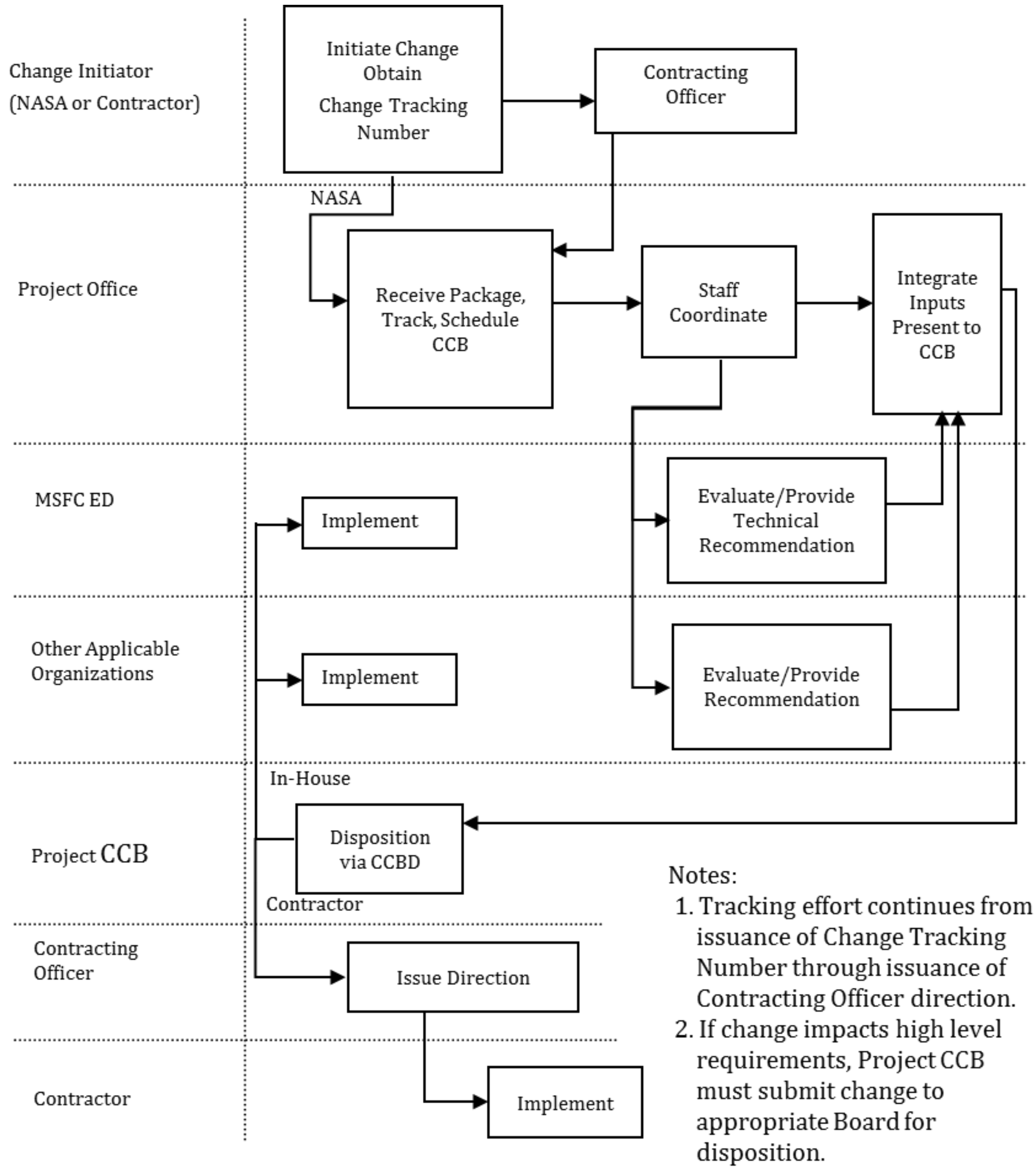


Figure 112. Change Process Flow

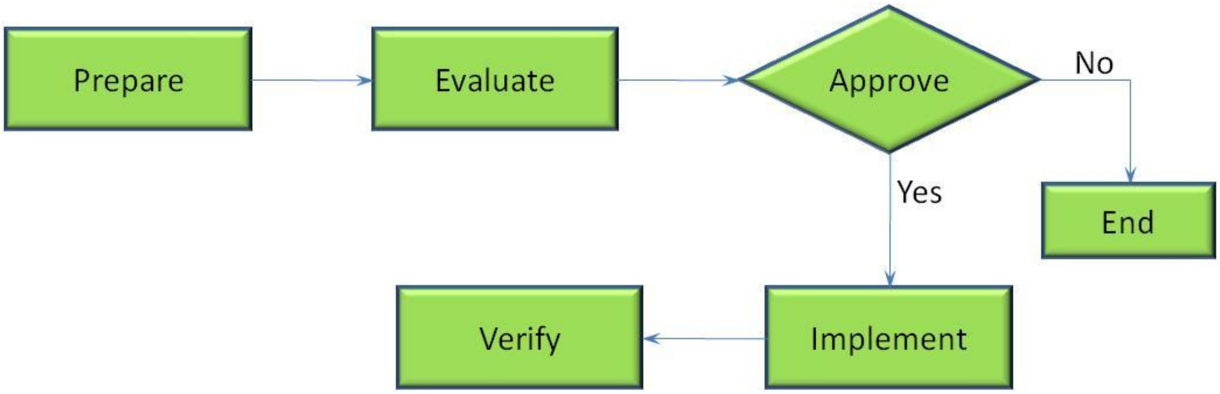


Figure 123. Configuration Management Change Control Overview

The following tasks and steps are provided to assist with satisfying the requirements contained in MPR 7123.1.

Tasks	Steps
Establish Configuration Change Control Boards, Operations and Hierarchy	a. Develop CCB charter, Board Codes, Project Codes, and Effectivity Identifiers MPR 8040.1 b. Project Manager charters CCB and authority at each CCB level c. Identify CI release requirements (assure the existence of only one release desk for the project) d. Establish CI effectivity and release approval authority e. The Engineering Release System is used as the formal mechanism to approve official project configuration items.
Prepare an ECR	a. Develop a configuration change control process and document in the CMP b. Develop a change request classification (see MIL-HDBK-61, section 6.2.2 for activity guidelines) c. If possible develop a checklist to ensure the relevant information is included in the ECR prior to submittal (See MPR 8040.1 and MIL-HDBK-61,

	Table D-4 for guidance) d. Prepare and submit the ECR per the CMP. (Initiation of an ECR is a well-planned and coordinated effort between the design organization and the Project Configuration Manager) e. The ECR is submitted to the project configuration control process per the CMP.
Evaluate the Engineering Change Request	a. Document in the CMP the evaluation flow for the ECRs (including any variations in flow (if any) based on ECR classifications). A possible ECR evaluation flow is found in Figure 12 b. Evaluate the ECR per the CMP. (CMP has configuration control procedures which includes the evaluation process) c. Submit to Configuration Change Control Board d. Document Approved Change e. Implement Approved Change f. Track Change Implementation to Completion
Establish and Implement deviation and waiver process for baselines	a. Establish a criteria for submittal of a request for Deviation or Waiver (i.e., CIs that do not conform to baselined configuration documentation, CI does not meet required performance requirements, the final assembly of the first affected serial-numbered unit of a CI is delivered in a configuration other than that described by the item's baselined documentation) b. Develop a request for Deviation or Waiver classification. Typical classifications are critical, major, and minor. (see MIL-HDBK-61, section 6.3 for additional guidance). c. Identify required information for preparation and submittal of Deviations and Waivers. (see MPR 8040.1, and MIL-HDBK-61, section 6.3 (table 6.9) for guidance)

The configuration control process evolves from a less formal (yet disciplined) version control process in the Pre-Phase A stage of a program to a very formal process during and beyond the Formulation Phase. In the early concept and development of a project, an informal but disciplined version control strategy and process is critical and is utilized in support of SE. This ensures that the correct version of work products (documents, drawings, CAD models, Specifications, etc.) that communicate technical decisions or definitions of pertinent study parameters are disseminated and used by all personnel. In addition, the process increases awareness of affected parties that a change is being developed and enables them to provide pertinent input. The formal CM process is operational at SRR since there will be requirements documents and top level work products that will be formalized in a Functional Baseline at that review. Although version control/revision log is not a formal CM process it "mimics" the formal change control process to enable the users to become familiar with the approach early on in the development. Suggested guidance for an effective version control process follows:

a. There is process to record and communicate messages associated with configuration changes. History or a revision log on a data item is used to track versions. These messages can serve as documentation of the changes.

b. The log messages record who made the change, when it was made and why.

c. The strategy for the distribution of the log messages is decided by the configuration manager but developed with the leadership of the performing organizations.

d. There is a "repository" of changes (whether automated or manual) to track the changes documented by the change messages. This is probably the most important benefit of effective version control. It provides an historic record. It provides the ability to know what changes are associated with a previous version of the item and allows one to compare the two. The ability to compare two versions of one configuration item cannot be underestimated.

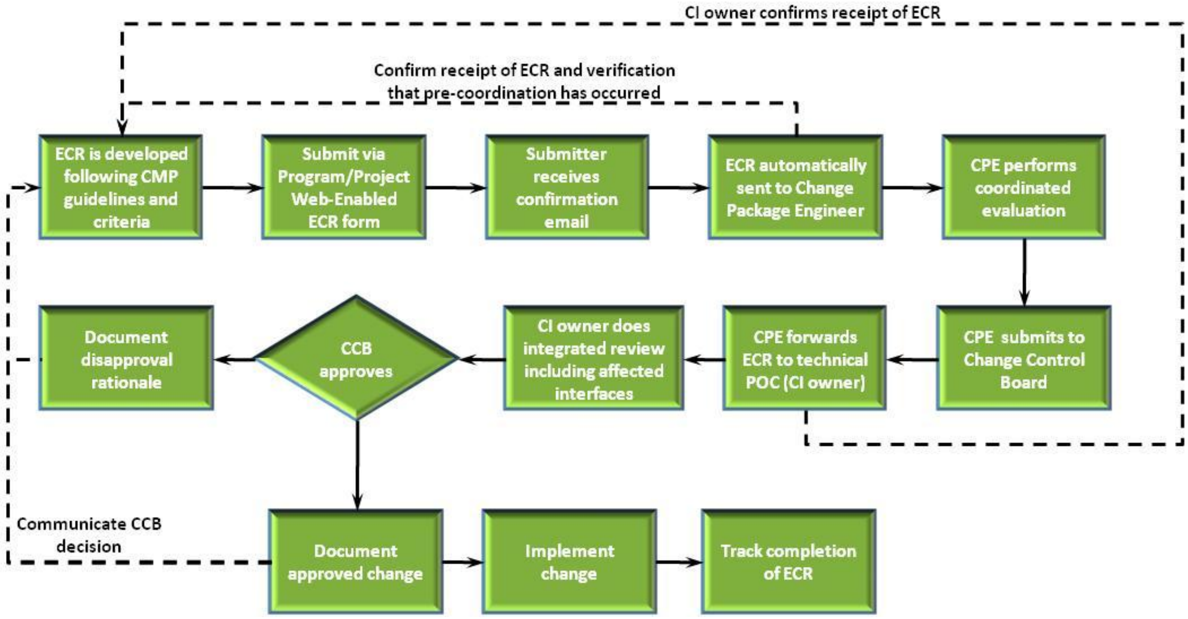


Figure 14. Example of Possible ECR Evaluation Process

4.3.2.4.1.4 Configuration Status Accounting

Maintaining, Dispositioning, and Reporting Change Actions

Configuration Status Accounting (CSA) is the process of creating and organizing the knowledge base necessary to perform configuration management. Once the baseline is formally established, it is imperative that accounting of that baseline and subsequently authorized changes be processed. The accounting, as a minimum, is capable of defining the exact baseline on a continuing basis. It receives information from other CM activities as they are performed (i.e., ECR processing, CCB actions, CI baselining process) and provides performance metrics of the CM process that will provide a clear audit trail from authorization of the baseline/changes into the affected documentation and hardware/software.

The following are recommended activities to create this knowledge base:

a. Track change activity and actions necessary to implement changes.

b. Provide a complete record of approved configuration documentation for each CI.

1) Record configuration management actions in sufficient detail so the content and status of each CI is known and previous versions can be recovered.

c. Record and report the status of proposed engineering changes from initiation to final approval and implementation.

d. Record and report the status of all critical and major requests for deviations and waivers that affect the configuration of a CI.

e. Record and report implementation status of authorized changes to each affected CI or data item.

   1) Ensure that relevant stakeholders have access to and knowledge of the configuration status of configuration items.

f. Provide the traceability of all changes from the original baseline configuration documentation of each CI/ CSCI.

   1) Describe the differences between successive baselines and revise the status and history of each configuration item as necessary.
   2) Specify the latest version of the baselines.
   3) Identify the version of CIs that constitute a particular baseline.

g. Report the effectivity and installation status of configuration changes to all CIs at all locations.

h. Accumulate and format data necessary to provide routine and special configuration accounting reports.

NOTE: See MPR 8040.1for additional guidance on configuration status accounting system data elements. Also, table 7-1 in MIL-HDBK-61contains typical information sources and outputs of the CSA system over the life-cycle of the project.

The following tasks and steps are provided to assist with satisfying the requirements contained in MPR 7123.1.

Tasks	**Steps**
Develop and Implement the CSA system	a. Train Project and user community personnel on the use of the selected CM tool, if any. b. Develop and communicate process for requesting Status of CM work products (i.e., CI status configuration items and related work products). c. Identify Constraints to the CSA (i.e. what and when will information be captured, agreements (provisions) between the project and supporting organizations, identification of the project life-cycle phases, agreements on tasks to be performed and the organization (including contractors) tasked to perform them.) d. Identify inputs to the CSA (i.e., approved configuration documentation, change requests and disposition, configuration verification work products, change verification and validation, action items) e. Using the identified inputs, perform the CSA activities (the activities listed in paragraph 4.3.2.4.4 can be used as the basic CSA system) f. Generate outputs from the CSA system (i.e., status of the CIs, CM information related to every CI, performance measurement of CM processes) g. Provide generated outputs to Project Manager, chief engineer and CM audit team for a specific activity (i.e., status of a CR) or the effectiveness of the CM system. h. Develop and communicate process for requesting Status of configuration items and related work products

4.3.2.4.5.1.5 Configuration Audits and Verification

Configuration audits and verification processes are used to ensure that the CI's design and performance requirements have been met and properly documented and that the CM processes being utilized are documented and in compliance with NASA and Program requirements. There are two types of CM audits, Configuration Item Audits and System Audits, which are described below. There are three phases to the audit process:

Phase 1 - The pre-audit part of the process sets the schedule, agenda, facilities and the rules of conduct and identifies the participants for the audit.

Phase 2 - The actual audit itself is the second phase.

Phase 3 – The post-audit phase is the third phase in which diligent follow-up of the audit action items takes place.

Audit of a CI may include incremental audits of lower-level items to assess the degree of achievement of requirements defined in specifications/documentation.

The two types of CM audits are CM Configuration Item Audits and CM System Audit.

The Configuration Item Audits consist of the FCA and the PCA. The FCA is used to verify that the actual performance of the CI meets the requirements stated in its performance specification and to certify that the CI has met those requirements. The PCA is used to examine the actual configuration of the CI that is representative of the product configuration in order to verify that the related design documentation matches the design of the deliverable CI. MPR 8040.1 has guidance for FCA/PCA and STD/CM-AD, Standard/Functional Configuration/Physical Configuration Audit Documentation, provides a description to support these types of audits.

The CM System audit ensures that the audited organization is compliant with the CM requirements of the project. That is, the configuration baseline is correctly defined, controlled, accounted for and verified, and any required corrective actions resulting from the audit are implemented. MPR 8040.1 has a CM System audit checklist and STD/CM-CMA, Configuration Management Audits Documentation, provides a description to support the conduct of CM system audits when required by the MSFC Project Office for in-house and procured products.

Configuration verification is the task of ensuring that established baselines and subsequent changes have been incorporated and that resulting configuration items meet these established requirements. This requires the involvement and use of the NASA accounting systems and the various contractor systems (e.g., baseline accounting, engineering release, build records, etc.). Progressive configuration verification is accomplished by utilizing the incremental configuration identification baselines established by the formal technical reviews during the implementation phase.

Verification is an ongoing process as the project matures. In each of the aforementioned reviews, the product of the specific review is compared to the baseline requirements, and thus the requirements are verified as being satisfied, or discrepancies are identified and tracked through resolution. Likewise, as engineering changes are authorized, they are verified as being correctly implemented and tested.

The configuration verification process demonstrates that: (1) the required qualification verification has been accomplished and that it substantiated compliance of the "as-verified" design with the original performance and configuration baseline and approved changes thereto; and (2) the required acceptance verification has been accomplished and that it substantiated compliance of the performance and configuration of the article being delivered with the "as-qualified" design. The Design Certification Review or Functional Configuration Audit is used to perform this verification that the configuration item functions in accordance with its requirements. Configuration verification also includes verifying the "as-built" configuration against the "as-designed" configuration to ensure that the design was built to the requirements. The Configuration Inspection or Physical Configuration Audit is the review utilized to perform this verification. For MSFC in-house design and manufacture, the "as-designed" configuration is contained in the Integrated Configuration Management System, and the "as-built" is provided by MSFC Safety and Mission Assurance from the As-Built Configuration Status System.

The following tasks and steps are provided to assist with satisfying the requirements contained in MPR 7123.1.

Tasks	Steps
Conduct an FCA/PCA.	a. Configuration Manager coordinates with Systems Engineer to develop the plan. b. Select CIs for auditing. c. Develop Review Data Package. d. Develop schedule. e. Develop the entrance briefing. f. Present findings and mitigation strategies. g. Sign certificates of completion. h. For additional guidance, MPR 8040.1 and STD/CM-AD.
Conduct a CM System Audit.	a. Project manager coordinates with CM Manager to develop a CM System Audit plan. b. Determine the number and frequency of audits. Audits are planned early in the program life-cycle. c. Perform at least one CM System Audit prior to CDR. d. Document any discrepancies as findings and

	observations. e. Submit an Audit Report. f. For additional guidance, see MPR 8040.1 and STD/CM-CMA.

4.3.2.4.6 Defining Requirements for CM Tools

The most important part of a strategy for determining requirements for CM tools is that a well-defined CM process first exists. It's important to recognize that CM tools do not "do" CM. People "do" CM. Because of inefficiencies in CM processes the tool may simply enable the organization to make bad decisions, or finding the wrong information, quicker.

Automated enabling tools are essential for effective and efficient configuration management. They can automate many aspects of the change management process and deliver a real time platform for managing baseline information. Tools can also provide reports and metrics that are necessary for continuous improvement efforts. Many tools also provide document control and other essential functionality.

When defining requirements for a CM tool, inputs from both the CM practitioner and the CM user community are essential. The roles and responsibilities of the CM user and the CM practitioner are significantly different. Identifying simple user/tool interfaces commensurate with their respective roles will have a significant impact on how well the tool is accepted and utilized.

Table III identifies a list that can be used as criteria for defining CM tool requirements:

Table III. CM Tool Selection Criteria

Tool Selection Criteria	Applicability	
	Yes	No
Integration compatibility with enterprise architecture and IT requirements		
Change management workflow capability (From Request through Implementation)		
On-line forms/ templates		
Automatic number/date generation		

Change tracking		
Multi-user comment and updates during CR evaluation		
Electronic change boards		
Change action item tracking		
Change implementation feedback		
Multi-level CCB Interface functionality		
Custom notifications		
Ability to link information and establish relationships between data elements		
Ability to integrate configuration status accounting with the electronic change control process		
Ability to create and maintain baselines		
Proper product structuring capabilities- documents and parts		
“Where used” capability (Next higher Assembly)		
Baselines flagged with change activity and effectivities		
Ability to create different baseline views depending on user		
Problem reporting functionality		
Version Control capability		
Provide libraries (development, master, archive)		
Requirements management		
Ability to track the configuration status of each CI during the full life-cycle from Development through ops and Sustainability		
The ability to automate implementation of process through work flows		
The ability to customize work flow		
The ability to customize forms		
The ability to customize field names, attributes, data views, etc.		
Automatic metric generation (i.e., outstanding changes, mean time to process changes, etc.)		
Online help		
Control/Access/Security rules		
Customer/Supplier access and compatibility		
Browse access, by a variety of users, at different geographic/physical locations		
Incorporate ITAR, EAR, and other Security restrictions		
Archive and backup		
Can manage administrative as well as technical information		

4.3.2.4.7 Training the Technical and Project Team

A well-trained and knowledgeable project and technical team is the key ingredient to implementing a successful CM Plan. Since each project may have a specific CM process the training is customized accordingly. It is suggested that CM training be role-based to meet the needs of the trainees (i.e., Engineering organizations may need training on processing change requests, while Project leadership may not).

This document can be used as a “How to” training resource on implementing a CM process. However, it is up to the Project Manager and CM Manager to assess and determine any unique training needs. At a minimum it addresses the following three areas tailored to the project:

1. CM Strategy, such as:
    a. Change Control Board Structure
    b. Change Requests Process
    c. Release system
    d. Baselining
2. CM Procedures, such as:
    a. Initiate Change Request
    b. Approval Process
    c. Accessing Baselines
3. Tool usage, such as:
    a. Electronic folder access
    b. Input and access libraries
    c. Search for configuration items and contents

4.3.2.4.8 Data Requirements Descriptions (DRDs)

For any DRDs associated with this process, refer to MPR 7123.1.

4.3.2.5 Data Management

This section of the handbook provides the guidance and activities for successful implementation of the (TDM requirements of MPR 7123.1, MSFC Systems Engineering Processes and Requirements. It is intended for use by MSFC Programs and Projects as guidance and does not supersede existing TDM governance.

Additional data management guidance at MSFC can be found in MPR 7120.3, . At MSFC, Data Management is defined as: *The timely and economical identification/definition, preparation, control, and disposition of documents and data required by a program, project, or activity.* Each Project Manager or Data Manager develops a Data Management Plan during the project formulation phase that describes the specific project implementation of the data management requirements. The Data Management Plan identifies/defines required data, and establishes data preparation requirements, control processes, and disposition processes. For smaller projects and activities, the data management processes may be included as part of the Project Plan or SEMP as long as the requirements identified in MPR 7123.1 are satisfied.

ANSI/GEIA-859, developed as a consensus standard for TDM, identifies a number of principles and activities that enable those principles for effective development of TDM products. However, the following is the minimum set of products for proper TDM implementation:

a. Technical Data storage plan/procedures

b. Technical Data distribution procedures

c. Technical Data security plans/instructions/audits

d. Records retention plans/procedures

e. Technical Data request logs

f. Technical Data Requirements List

g. Technical Data Requirements Description

h. Technical Data Procurement Documents

i. Technical Data Master List

These products are intended to provide the evidence needed to ensure process compliance as part of a process audit. They are derived from the original requirement for the Center Director or designee to establish and maintain a Technical Data Management process found in NASA Procedural Requirements NPR 7123.1, NASA Systems Engineering Processes and Requirements (see Figure 15).

Lead Systems Engineers, Data Managers and Chief Engineers use this document to support the estimating and scheduling of the work that will be required to produce the TDM process work products for the project supported. The data management practitioner is encouraged to seek detailed guidance and best practices to supplement the guidance in this document from the following selected resources: ANSI/ GEIA-859, "Data Management;" MPR 7120.3, MSFC Data Management, and NASA SE/SP-2007-6105, "NASA Systems Engineering Handbook."

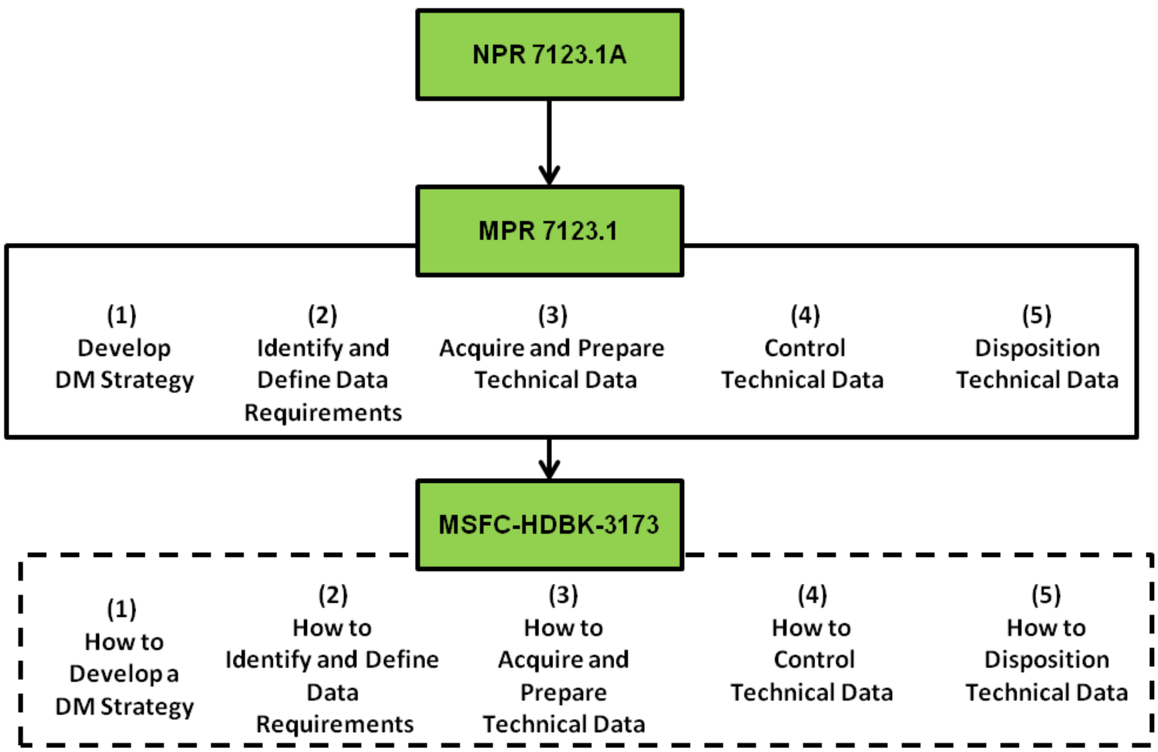


Figure 13. Traceability of Guidance to TDM Requirements

The development of this section of the handbook was based on the following assumptions:

a. Each project office needs a minimum number of TDM requirements accompanied by proven and accepted guidance used by industry and government.

b. The project utilizes a Data Manager knowledgeable of the TDM process with proven ability to guide the project in the appropriate tailoring and customizing for the size and complexity of the project.

c. Approval of the Technical Data Management Plan (and other important guiding documents such as the SEMP) follows a governance process similar to the one outlined in Figure 16.

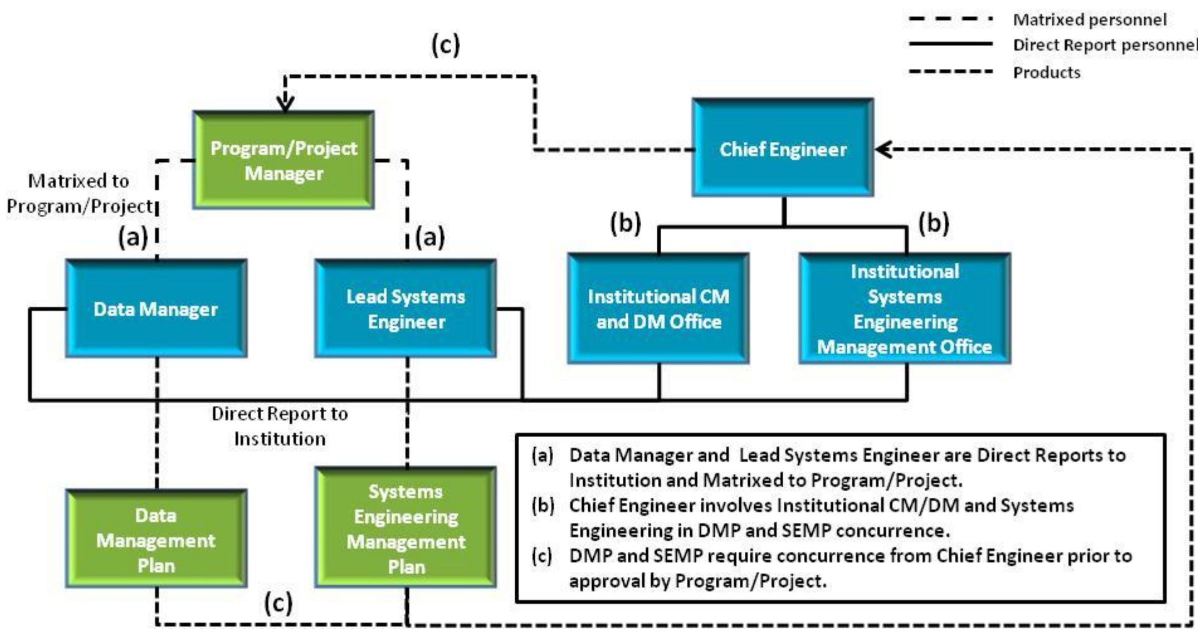


Figure16. Example of Governance Model to Support an Effective TDM Strategy

4.3.2.5.1 <u>Developing a Technical Data Management Strategy</u>

The intent of the Technical Data management strategy is to define how Technical Data management will be implemented for any given Project. This strategy is documented in the Technical Data Management Plan (TDMP) and tailored and customized according to the size and complexity of the Project. The implementation approach is agreed upon by the Project Manager, the Data Manager and the Chief Engineer of the Project. The reason for this agreement is that the implementation can be different for each Project based on the Project organizational structure, operational culture, and the communications approach between the Project office and the performing engineering organizations. The template found in MPR 7120.3, MSFC Data Management contains information included in a Data Management Plan. The DRD STD/DM-DMP, Data Management Plan, also contains additional information on TDMP development. Like the CMP, the TDMP may be combined with the Project Plan or the SEMP as determined by the Project Manager.

Traditional Technical Data Management contains the following key execution functions:

a. Identification and Definition of Data Requirements

b. Preparation of Data

c. Control Procedures

d. Disposition of Data

These functions, which form the basis of this section of the document, are associated with TDM execution. However, in addition to TDM execution, new contemporary methods of TDM also include TDM strategy and architecture development, TDM process and infrastructure design, and TDM process and infrastructure maintenance. These have not yet been described in a unified manner in industry but ANSI/GEIA-859 identifies organizations that have had some success in documenting these methods. projects consider an overall data architecture definition as part of the TDM strategy to ensure data interoperability across teaming organizations and contractors. NASA NPR 7120.9, “NASA Product Data and Life-Cycle Management (PDLM) for Flight Programs and Projects,” provides the policy for establishing a Data Architecture that provides a project team with a framework from which to map program and project data throughout its life-cycle.

4.3.2.5.2 <u>Developing a Technical Data Management Plan</u>

The first step in developing and documenting a TDM strategy and process is for the Project Manager to appoint a Data Manager (DM) in the formulation phase of the project life-cycle. During this phase the DM will coordinate with the Project Manager and chief engineer to develop the Technical Data Management Plan (TDMP). The TDMP addresses the same functions as described by the TDM key execution functions above. Sections 4.3.2.5.2 through 4.3.2.5.6 of this document are used as guidance to help populate the sections in the TDMP. The following tasks and steps can be used as guidance for the initial steps during the development of the TDMP:

Tasks	Steps
Appointing a Data Manager Establish General Requirements for Technical Data	a. Project Manager appoints a Data Manager during the project formulation life-cycle phase. b. Data Manager reviews Project Plan to determine general needs for Technical Data delivery and access throughout the Project life-cycle. 1) A practical way to proceed is to review data requirements from similar programs/projects in coordination with NASA and Industry Subject Matter Experts (SMEs) including the Center Data Requirements Manager (CDRM). 2) Consider Technical Data related to design, manufacturing, testing, and operations. 3) Consider documentation needed for legal, historical, audits, or other valid purposes (Include data views that may be needed through the Project life-cycle.) 4) Identify a process to perform periodic audits of generated technical data to ensure correctness and completeness of all Technical Data quality (Technical Data quality attributes include, precision, date/time, accuracy, completeness, consistency, and others based on project needs.) 5) Include a process for managing the security and access control of technical data. 6) Data views include presentation of Technical Data by technologies such as digital images, geographical information systems, graphical user interfaces, multi-dimensional tables and graphs, virtual reality, 3-D presentations, and

Develop a Technical Data Management Plan	animation. c. Anticipate the form in which the Technical Data will be required and determine if access to Technical Data or delivery of Technical Data is more appropriate. The general requirements will be used to develop inputs to the TDMP. d. The DM is responsible for developing the TDMP. e. Use MPR 7120.3 and DRD STD/DM-DMP as guidance for developing a TDMP. f. Additional guidance is also found in section 2.2 of GEIA-859. g. Data Manager coordinates with Project Manager and Chief Engineer to identify the “Applicable” sections of the MPR 7120.3, template based on size and complexity of the project. h. Deliver to Project Manager and Chief Engineer for coordination and implementation.

4.3.2.5.3 Data Identification/Definition

The identification/definition of data requirements is one of the most important components in the formulation and planning of any project. Data requirements are levied on MSFC contractors and in-house development activities through the use of DPDs, Data Requirements Lists (DRLs) and DRDs. Standard DRDs are provided at MSFC to ensure that mandatory data requirements (e.g. safety, financial reporting, Federal Acquisition Regulation (FAR)/ NASA FAR Supplement (FAR/NFS) reporting requirements) are applied consistently to MSFC contracts and solicitation packages. A Standard DRD is a data requirement that has been identified for repetitive use, either in-house or on contracts. Standard DRDs are maintained by the CDRM and are available on the MSFC Data Requirements Management System at the following location: https://masterlist.msfc.nasa.gov/drm/.

Once the Technical Data needs of the Project life-cycle have been identified in the TDMP then Technical Data types are defined in standard documents. NASA and MSFC directives sometimes specify the content of these documents which are used for in-house Technical Data preparation but the standard description of the Technical Data can be modified based on the Project size, complexity and unique needs. There are different types of Technical Data that can be used in a MSFC project. They types of data applicable to MSFC programs/projects/activities for approval and delivery are documented in STD/DM-DRD,Data Requirements Description. . Section 6.6 of NASA/SP-2007-6105 identifies different types of data that might be utilized within a NASA Project. The following tasks and steps can be used as guidance in identifying and defining Project Technical Data:

Tasks	Steps
Develop and Maintain Standard Data Requirements Descriptions (DRDs)	Data Manager develops the Data Requirements List (DRL) and/or the DPD. MPR7120.3 offers instructions respectively for the development of DRLs and DPDs. It is advisable to coordinate with the CDRM when developing the Project DRL/DPD. At a minimum the DRL/DPD includes the data requirement number, title, Office of Primary Responsibility (OPR), and submission dates (milestones) for each data requirement. Other information in the DRL may be data/document type, document recipients, and number of copies per recipient. In the case of a web-based TDM process, access privileges may take the place of recipients and number of copies. Develop the required DRDs after the DRL is complete (if the DRL format is not sufficient to describe the data requirement a DRD may be attached to the DRL). Figure 2 of MPR 8070.1, identifies guidance for a Standard DRD Development.

4.3.2.5.4 <u>Acquire and Prepare Technical Data</u>

Preparation of Technical Data deals primarily with developing and implementing standardized formats and is critical for technical and administrative accuracy. Technical Data developed for the project is prepared according to the document preparation process identified in the project TDMP. Contractor data is prepared in accordance with contract requirements and the contractor's internal procedures. A key element of preparation is the Office of Primary Responsibility Designee (OPRD) assessment and marking of the data availability limitation (e.g., export controlled, NASA sensitive, proprietary, etc.). The availability limitation marking sets the stage for proper handling, distribution, and access controls during the control phase.

The following tasks and steps can be used as guidance for preparing technical data:

Tasks	Steps
Establish a Standard approach for preparing Technical Data	Data Manager, in coordination with Project Manager and Chief Engineer, defines the technical data preparation requirements and documents them in the TDMP. Instructions and guidance for identifying technical data preparation can be found in MPR 7120.3. Data manager informs the Project of the technical data preparation procedures.

4.3.2.5.5 Data Control

Since data is central to all successful Project processes, proper evaluation, authorization, and protection are critical. The data control process addresses the following elements: receipt, checking to ensure proper preparation and numbering, tracking and accounting, storage, Center Export Representative (CER) approval of availability limitation markings, access/distribution, evaluation, approval authorities (e.g., Project Manager, Document Control Board, Configuration Control Board, Contracting Officers Technical Representative, Office of Primary Responsibility, etc.), release, and records of the data processed and the control process itself. At the end of the control process, the latest approved version of each document is listed (and preferably made available electronically) on the Project Master List(s).

Data Control is essentially the application of Configuration Management principles to project technical data to ensure its integrity and timeliness. Change control is the primary function of this process. However, not all data requires formal change control or even the same level of control. It is important to identify the body of data that requires some level of control, when the data is ready to be placed under formal data management control, and the process for transferring control from the data originator to the data management control process. It is also important to know the state of maturity of the technical data that makes control meaningful and productive. ANSI-GEIA-859, Section 5.0 provides guidance for establishing a control process for technical data. A list of items that can be used as a checklist for planning a Data Control Process addresses the following data control process basic elements:

1. Develop General Data Control Process Requirements

2. Identify the responsibilities of the OPRD. The OPRD is assigned based on the Technical Data (or document) developed.

3. Identify a Technical Data Review Process

4. Identify Technical Data to be placed under configuration control

5. Establish and implement a consistent change control process

    a. Identify a formal change control approval process

    b. Identify a Technical Data authorization and capture process

6. Establish a process for control of contractor-produced Technical Data

The Configuration Management section of this handbook identifies the guidelines for the configuration change control process. Technical data management control uses the CM control process to assure the integrity and availability of formal project technical data. Figure 17 provides a simplified overview of the Technical Data Change Control process.

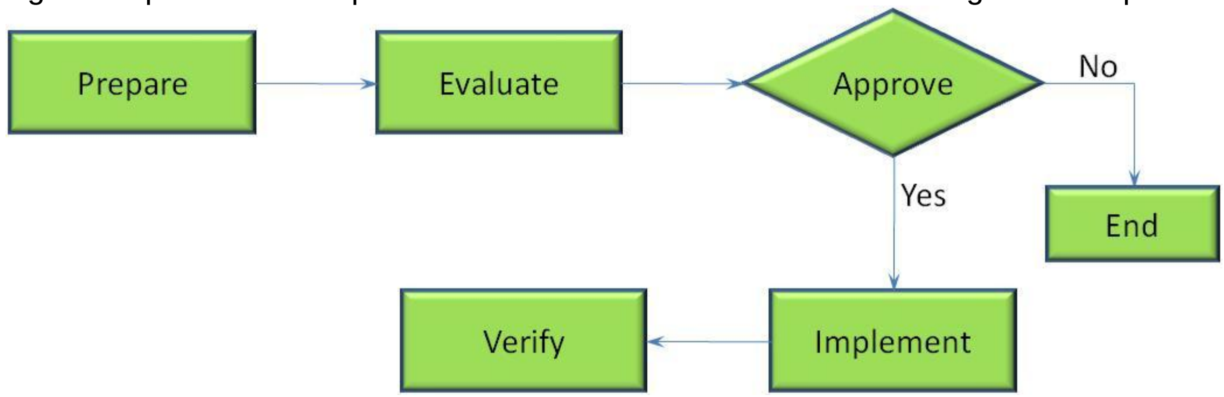


Figure 14. Technical Data Management Change Control Process Overview

The following tasks and steps offer guidance for effective technical data change control:

Tasks	Steps
Establish Technical Data/Document Change Control Boards, Operations and Hierarchy	a. Data Manager, Configuration Manager, Project Manager, and Chief Engineer coordinate to determine the Technical Data and Configuration Change Control Board relationship (some programs/projects may choose to run one change control board for data and configuration). b. Data Manager uses the configuration management process section of this handbook to select appropriate tasks and steps for the Technical Data control process.

4.3.2.5.6 Data Disposition (Access and Records)

Data disposition includes storage, data access, and maintenance of records. NASA records are retained and retired in accordance with NPR 1441.1, *NASA Records Retention Schedules,* and MSFC records management is defined in MPR 1440.2, *MSFC Records Management Program*. Programs/projects identify the records they are producing and ensure they are stored appropriately. Records/data is available for current use, stored so that records may be retrieved and utilized on future Programs/Projects, provided to Government customers (as approved and in accordance with data sensitivity), and retired and retained appropriately to contribute to the knowledge base of the United States and NASA.

The project ensures there is a process to provide adequate retention and preservation of Technical Data assets that are of value to the project and effectively disposing of Technical Data assets that are no longer of value. Once this process has been developed Technical Data is evaluated regularly to assure it is of sustained value to the project. Since projects generally produce both paper and electronic Technical Data a process for electronic conversion of paper Technical Data considered sustained value should be developed and implemented. The project communicates the retention and disposition requirements to all supporting organizations that generate project technical data. This is done to assure the appropriate technology is used at the right time in the project life-cycle and historic Technical Data is accessible and readable. ANSI-GEIA-859, Chapter 7.0 provides guidance for effective preservation and disposition of data.

Tasks	Steps

Establish Technical Data/Document Disposition Process	a. Data Manager coordinates with Project Manager to define a records plan and records management requirements, including a records/retention schedule for the project. See NPR 1441.1 for typical retention schedules and MPR 1440.2 for typical records management requirements. b. Data Manager coordinates with Project Manager and Chief Engineer to identify a process for long-term temporary and permanent Technical Data Management within the MSFC repository. The process includes indexing of archives. c. Data Manager coordinates with Program/Manager and Chief Engineer to establish a process for dissemination (publication and making available) of technical data produced by the project. (see MPR 2220.1, “Scientific and Technical Publications”) d. All Technical Data disposition processes are documented in the project TDMP.

4.3.2.5.7 Training the Technical and Project Team

A well-trained and knowledgeable project and technical team is the key ingredient to implementing a successful TDM Plan. Since each Project may have a specific TDM process the training is customized accordingly. It is suggested that TDM training be role-based to meet the needs of the trainees (i.e., Engineering organizations may need training on Technical Data preparation, while project leadership may not).

This section of the handbook can be used as a “How to” training resource on implementing a TDM process. However, it is up to the Project manager and DM Manager to assess and determine any unique training needs. At a minimum it addresses the following three areas tailored to the project:

1. TDM Strategy, such as:

    a. Technical Data access process

    b. Technical Data classification

   c. Change Control Process

   d. Baselining

2. TDM Procedures, such as:

   a. Technical Data Review Process

   b. Technical Data Approval Process

   c. Control of Contractor-Produced Technical Data

3. Tool usage, such as:

   a. Electronic folder access

   b. Input and access libraries

   c. Search for configuration items and contents

4.3.2.5.8 Defining Requirements for TDM Tools

In today's environment automated tools are essential for effective and efficient Technical Data management. They can automate many aspects of the change management process, provide reports and metrics, and provide document control and other essential functionality.

When defining requirements for a TDM tool, inputs from both the TDM practitioner and the developers of Technical Data are essential. The roles and responsibilities of the Technical Data developer and the TDM practitioner are significantly different. Identifying simple user/tool interfaces commensurate with their respective roles will have a significant impact on how well the tool is accepted and utilized.

Table IV identifies a list that can be used as criteria for defining DM tool requirements:

Table IV. TDM Tool Selection Criteria

TDM Tool Selection Criteria Which of the following capabilities are necessary for the Project?	Applicability	
	Yes	No

Provide TDM training module and On-Line Help		
Integration compatibility with enterprise architecture and IT requirements		
Provides record retention data, and supports data archiving/transfer/destruction per NPR 1441.1		
Capability to attach any number of files to a given document object		
Capability to track and record contractual direction (i.e., DRD deliverable dates, responsibilities, etc.)		
Capability to generate reports that may be viewed on screen, printed, and/or saved to a file		
Capability to track the version history of data that are modified after creation or entry in the system		
Provide a mechanism to record, track, and report on received vs. planned deliverables for each DRL		
Manage administrative and technical data, including configuration documentation		
Provide secure transfer of all information between the client and server		
Incorporate ITAR, EAR, and other Security restrictions		
Provide traceability associated with any creation or change of selected work products		
Supports a combined search of both metadata and file content.		
Intuitive Windows GUI (Graphic User Interface)		
Provide a Workspace Oriented Environment		
Capability to enforce the uniqueness of document numbers		
Capability to customize On-line forms/ templates (field names, attributes, data views, etc.)		
Provide access to authorized users located both on-site (MSFC) and off-site (other NASA centers, Partners, or Contractors).		
Automatic number/date generation		
Custom notifications		
Ability to link information and establish relationships between Technical Data elements		
Problem reporting functionality		
Ability to find duplicate requirements across DRDs		

Version Control capability		
Hyperlink Capability to DRD/DPD from DRL		
Provide libraries (development, master, archive)		

4.3.2.5.9 Data Requirements Description (DRD)

For any DRDs associated with this process, refer to MPR 7123.1.

4.3.3 Technical Assessment

The Technical Assessment process is used to help monitor progress of the technical effort and provide status information for support of the system design, product realization, and technical management processes.

NASA SE Handbook 6105 notes technical plans (e.g., SEMP, review plans) provide the initial inputs into the Technical Assessment process. These plans outline the technical review approach and identify the technical measures that will be tracked and assessed to determine technical progress, particularly at major milestone reviews. Typical activities in determining progress against the identified technical measures include status reporting and assessing metadata. Status reporting identifies where the project stands in regard to a particular technical measure. Assessing metadata means converting the output of status reporting into a more useful form from which trends can be determined and variances from expected results can be understood. Technical Assessment does not encompass the complete decision making process of managing the technical work. Technical Assessment only provides the evaluation and summary of the work. The decision to pursue a course of action based on a technical assessment is the decision maker's prerogative. Results of the assessment activity may prompt initiation of a Decision Analysis process where potential if corrective action is deemed necessary. Data from the technical assessment would then be used to support decision problem definition and Decision Analysis work activity rationale.

For systems engineers and/or chief engineers who are engaged in the day-to-day development of an integrated system solution, Technical Assessment encompasses additional levels of work progress monitoring and technical decision making. The work progress and technical measures assessment mentioned in the above paragraph provide a very top-level view of highly filtered and summarized status metrics. Typically, they are presented at major milestone reviews to support key decision points. Such metrics suffer from the aggregated uncertainty of the metadata metrics involved in these assessments, combined with invalidated analysis methods. Uncertainty and immature analysis methods render such metrics inadequate for assessing the validity and certainty of design solution and work activity performance in the periods between major life-cycle reviews. More frequent formal and informal technical assessment processes are conducted to evaluate work products and work processes relative to system level requirements, analyses, and integration. Identifying, monitoring, and directing integrated system technical decision making on a daily and weekly basis is more likely to identify issues early that could have substantial impacts on other life-cycle phase events.

The three levels of system technical assessment are: 1) Top level (Big SE) status reporting, metadata assessment, and top-level technical readiness; 2) intermediate level formal technical assessment, including designated governing authority boards, working groups, and discipline teams; and 3) ongoing daily technical assessment of the progress, validity, adequacy, goal alignment, and integration of the knowledge work appropriate for the specific system-level domain (little se). The top level is primarily focused on managing the Systems Engineering functions and providing upper management with summarized data for their decision-making processes. The concept is that with informed upper level guidance and decision making, all other levels will remain aligned in their efforts to realize a balanced system meeting stakeholder's needs. The other two levels of technical assessment are focused on the engineering of the system and maintaining alignment in decision making on a continuous basis to realize a valid integrated engineered system. Appendix E provides more detail and guidance on technical assessment for all three levels.

The planning and status reporting feedback loop takes place on a continual basis throughout the life-cycle. This loop is applicable at each level of the project hierarchy. Planning data, status reporting data, and assessments flow up the hierarchy with appropriate actions taken at each level. At each level, managers determine how and when reporting data and assessments are made.

Regular, periodic tracking of the technical measures is recommended, although some measures are tracked more often when there is rapid change or cause for concern. Key reviews, such as PDR and CDR, are points at which technical measures and their trends are carefully scrutinized for early warning signs of potential problems. If existing trends forecast an unfavorable outcome, corrective action begins as soon as practical.

Technical measures are predominantly assessed during the program and project technical reviews. Typical activities performed for technical reviews include:

a. Identifying, planning, and conducting phase-to-phase technical reviews

b. Establishing each review’s purpose, objective, and entry and success criteria

c. Establishing the makeup of the review team

d. Identifying and resolving action items resulting from the review

The Technical Assessment process is closely related to other processes such as Technical Risk Management, Decision Analysis, and Technical Planning. These processes provide input to or receive output from the Technical Assessment process. Other SE engine processes also interact with Technical Assessment. Additional guidance and detail is given in Appendix E.

The following are key inputs and outputs to the Technical Assessment process.

Inputs and Sources:

a. Process and product measures (from Technical Planning Process).

b. Technical plans including the SEMP (from Technical Planning Process).

c. Risk reporting requirements during technical reviews (from project).

d. Technical cost and schedule status reports (from project).

e. Product measurements (from Product Verification and Product Validation Processes).

f. Decision support recommendations and impacts (from Decision Analysis Process).

Outputs and Destinations:

a. Assessment results and findings including technical performance measurement estimates of measures (to Technical Planning, Technical Risk Management, and Requirements Management Processes).

b. Analysis support requests (to Decision Analysis Process).

c. Technical review reports (to project and Technical Data Management Process).

d. Corrective action and requirement change recommendations including actions to correct out-of-tolerance Technical Performance Measures (TPMs) (to Technical Planning, Requirements Management, and Interface Management Processes).

e. Work products from technical assessment activities (to Technical Data Management Process).

4.3.3.1 ***Technical Assessment Approach***

The formulation of the technical assessment approach is done in conjunction with the development of the project's SEMP. Development and subsequent revisions to the project's SEMP are performed as part of the Technical Planning process. The scope of the project will ultimately determine the resources and schedule needed to complete the project within its prescribed constraints of cost and schedule. Similarly, the scope of the technical effort will be based on the development, preparation, and approval of the work products needed to support the technical assessment process. If the scope of the technical assessment is significant, then the project may elect to develop a subordinate technical assessment management plan.

The technical assessment planning effort is a concerted effort by the technical team and active stakeholder collaboration.

Preparing the Technical Assessment Approach includes:

a. Identifying the plans against which progress and achievement of the technical effort are to be assessed;

b. Establishing procedures for obtaining cost expenditures against work planned and task completions against schedule;

c. Identifying and obtaining technical requirements against which product development progress and achievement will be assessed and establishing the procedures for conducting the assessments;

d. Establishing events when TPMs, estimation of measurement techniques, and rules for taking action when out-of-tolerance conditions exist will be assessed;

e. Identifying and planning for phase-to-phase technical reviews and WBS model-to-model vertical progress reviews, as well as establishing review entry and success criteria, review board members, and close-out procedures;

f. Establishing review entry and success criteria (see MPR 7123.1 Appendix D for guidance on review entrance and exit success criteria)

g. Identifying review board members and alternates

h. Specifying the review process to be used including management of Review artifacts and Technical Review close-out procedures

The following tasks and steps are provided to assist with satisfying the requirements contained in MPR 7123.1.

Tasks	Steps
Analyze the scope of developing, preparing, and maintaining the Technical Assessment Approach	a. Assemble and review the list of work products required to support the technical assessment approach b. Stakeholder NGOs 1) FAD 2) PCA 3) Project Plan c. DRL and corresponding DRDs d. Stakeholder interviews e. Assess role and their level of involvement during the development of the technical assessment approach 1) Obtain tailoring guidance, if needed
Develop a schedule for preparing the Technical Assessment Approach	a. Annotate due dates for draft and final inputs b. Recognize iterative nature of approach development c. Identify timelines for development of parallel management plans, if required d. Incorporate resource requirements and update, as required
Conduct Technical Assessment Approach kick-off meeting	a. Provide an overview on the scope of the project's technical assessment strategy and approach b. Provide an overview on how the planning team is organized and description of roles and responsibilities c. Provide an overview on the schedule needed to develop the technical assessment planning information to include specific deliverables, major milestones and due dates
Co-develop and capture IMS inputs and updates	Support concurrent effort of developing technical schedule inputs based on the technical assessment

	strategy and approach
Review the draft Technical Assessment Approach	Conduct review of draft Technical Assessment planning information with the planning team and corresponding project stakeholders
Submit for concurrence and/or approval	Submit the final technical assessment planning information for concurrence and/or approval to the proper designated governing authority
Maintain the Technical Assessment Approach	Update the technical assessment strategy and approach, as required, based on: 1) Major program milestone review 2) Major technical reviews

4.3.3.2 ***Assessing Technical Work Productivity***

Technical work productivity emphasizes the need to closely monitor progress and achievements against a baselined plan. The Technical Planning process is used to develop input to the Integrated Master Plan (IMP) and IMS. Once the IMP/IMS is baselined, EVM is used to measure and monitor the work accomplished and the cost of the work accomplished against the baseline plan. This analysis provides management insight into future cost and schedule performance and may provide key stakeholders with timely insight to provide assistance to maintain the actual progress and achievements with the baselined plan.

Regularly scheduled communications with project stakeholders is key to any successful project. These communications may take the form of weekly or monthly status meetings or status reports. The communication of status is most effective when pre-determined measures or metrics are reported along with an accompanying trend analysis. Trend analysis will not only provide both positive and negative trends, but also provide insight into the impact and effectiveness of management direction and decisions.

Several NASA and INCOSE references are available to support technical work productivity to include:

INCOSE--TP-2005-001-03	INCOSE Systems Engineering Leading Indicators Guide, Version 2.0
INCOSE-TP-2010-005-02	INCOSE Systems Engineering Measurement Primer, Version 2.0
NASA/SP-2010-	NASA Schedule Management Handbook

3403

NASA/SP-2010-3404 NASA Work Breakdown Structure (WBS) Handbook

The following tasks and steps are provided to assist with satisfying the requirements contained in MPR 7123.1.

Tasks	Steps
Compile a list of measures or metrics to support the assessment of technical work productivity	a. Based on the life-cycle timeframe, develop an integrated set of progress measures or metrics to support the analysis of progress and achievements against the baseline plan b. Based on the life-cycle timeframe, develop an integrated set of process measures or metrics to support the analysis of process efficiency and effectiveness c. Ensure the compiled set of proposed measures or metrics provides value-added information and is not redundant or superfluous
Obtain concurrence and/or approval of the proposed set of technical work productivity measures or metrics	Submit the proposed set of technical work productivity measures or metrics to key stakeholders for concurrence and the proper designated governing authority for approval
Execute and maintain the technical work productivity measures or metrics activity	a. Collect technical work productivity measures or metrics b. Track technical work productivity measures or metrics c. Analyze and report on a compiled set of technical work productivity measures or metrics d. Current status e. Trending and causal analysis f. Maintain technical work productivity measures or metrics g. Adjust by adding, modifying, or retiring measures or metrics as necessary to meet current and evolving stakeholder needs and requirements h. Adjust reporting and analysis requirements by adding, modifying, or retiring measures or metrics due to current and evolving product life-cycle needs and requirements

4.3.3.3 ***Assessing Product Quality***

Product quality needs to be assessed in order to ensure progress and achievements are aligned and keeping pace with technical requirements.

The TPMs traditionally provide the insight into the technical progress being made with the proposed design concept. Other measures or metrics are needed to corroborate the information being provided by TPM reporting, tracking, and assessment.

As noted in the previous section, a set of pre-determined measures or metrics is needed to support the reporting of status on the progress being made against a baseline plan. A fully integrated set of measures or metrics will provide additional insight into the quality of the work being performed and work products being produced. The, INCOSE Systems Engineering Leading Indicators Guide, INCOSE--TP-2005-001-03, Version 2.0, is an excellent resource for developing product quality measures or metrics.

In order for product quality metrics to be of value, the product quality criteria need to be established and agreed to up-front. These product quality criteria need to specify measureable progress and intermediate quality checks to ensure a quality product is on track to meet cost, schedule, and technical requirements for the final deliverable.

Several NASA and INCOSE references are available to assess product quality to include:

INCOSE-TP-2010-005-02	INCOSE Systems Engineering Measurement Primer, Version 2.0
INCOSE-TP-2005-001-03	INCOSE Systems Engineering Leading Indicators Guide, Version 2.0
MSFC-HDBK-3599	Space Flight Project Management Handbook of “Best Practices”
NASA 7120.5	NASA Space Flight Program and Project Management Handbook
NASA/SP-2007-6105, Rev. 1	NASA Systems Engineering Handbook
NASA/SP-2010-3403	NASA Schedule Management Handbook

NASA/SP-2010-3404	NASA Work Breakdown Structure (WBS) Handbook
	NASA Standing Review Board Handbook, SRB HB for NPR 7120.5D

The following tasks and steps are provided to assist with satisfying the requirements contained in MPR 7123.1.

Tasks	Steps
Compile a list of measures or metrics to support the assessment of product quality	a. Based on the life-cycle timeframe, develop an integrated set of quality measures or metrics to support the analysis of progress and achievements against the technical requirements b. Ensure the compiled set of proposed measures or metrics provides value-added information and is not redundant or superfluous
Obtain concurrence and/or approval of the proposed set of product quality measures or metrics	Submit the proposed set of product quality measures or metrics to key stakeholders for concurrence and the proper designated governing authority for approval
Execute and maintain the product quality measures or metrics activity	a. Collect product quality measures or metrics b. Track product quality measures or metrics c. Analyze and report on a compiled set of product quality measures or metrics d. Current status e. Trending and causal analysis f. Maintain product quality measures or metrics g. Adjust by adding, modifying, or retiring measures or metrics as necessary to meet current and evolving stakeholder needs and requirements h. Adjust reporting and analysis requirements by adding, modifying, or retiring measures or metrics due to current and evolving product life-cycle needs and requirements

4.3.3.4 ***Conducting Technical Reviews***

Planning and preparation for a technical review is critical. Significant time and effort is needed to logistically prepare and pre-coordinate with key stakeholders and their staffs.

A well-developed and thought-out technical review plan will help to ensure expectations are established early, all aspects and details are addressed, and contingency plans and resources are in place in advance to keep things on track while dealing with challenges that inevitably arise.

Each technical review serves a specific purpose and a series of technical reviews are conducted to ensure adequate progress is being made to develop and deploy a system that meets the baselined technical requirements and stakeholder expectations.

There is a “day by day” systems engineering and integration activity in the planning and preparation for each review that involves:

1) Definition the technical products required and the required maturity level for the review data package

2) Near daily integration of the various engineering disciplines that provide inputs for each data package product with the objective that all engineering/technical products are synced to the SAME TECHNICAL BASELINE at review start.

Technical reviews act as decision gates where key stakeholders decide and certify adequate progress has made to proceed to the next project phase. If sufficient progress has not been made, NASA SE Handbook 6105 provides additional outcomes to include (1) approval for continuation to the next Key Decision Point (KDP), pending resolution of actions; (2) disapproval for continuation to the next KDP. Follow-up actions for disapproval for continuation decisions may include a request for more information and/or a delta independent review; a request for a Termination Review for the program or project (Phases B, C, D, and E only); direction to continue in the current phase; or redirection of the Project.

Several NASA references are available to support the conduct of technical reviews to include:

NASA 7120.5	NASA Space Flight Program and Project Management Handbook
NASA/SP-2007-6105, Rev. 1	NASA Systems Engineering Handbook

NASA S Standing Review Board Handbook, SRB HB for NPR 7120.5D

The following tasks and steps are provided to assist with satisfying the requirements contained in MPR 7123.1.

Tasks	Steps
Prepare the Technical Review Plan	a. Obtain the necessary resources to prepare the Technical Review Plan b. Assemble the Technical Review Planning Team and assign specific responsibilities and actions needed to prepare and complete the plan. Each participating organization is represented and actively engaged with planning and preparing for the technical review. c. Complete the final draft after gaining concurrence from the Technical Review Planning Team
Obtain approval of the Technical Review Plan	Submit the Technical Review Plan to the proper designated governing authority for approval
Conduct the Technical Review	a. Pre-coordinate by communicating regularly on the status of technical review preparations with key stakeholders and staffs b. Execute the technical review in accordance with the approved Technical Review Plan
Prepare the Technical Review minutes	a. Compile the minutes of the technical review to include the decisions, direction, and assigned action items b. Obtain concurrence from key stakeholder staffs
Obtain approval of the Technical Review minutes	Forward the Technical Review minutes to the proper designated authority for approval
Track the timely closure of Technical Review action items	a. Monitor and track the status of action item closures b. Monitor and track the status of RIDs c. Communicating regularly on the status of action item closures, RID closures, and request for assistance, if required, with key stakeholders and staffs

4.3.3.5 ***Data requirements deliverable***

For any DRDs that are applicable to this process, refer to MPR 7123.1.

4.3.4 Technical Decision Analysis

The Decision Analysis process is used iteratively throughout the life-cycle to evaluate the impact of decisions on performance, cost, schedule, and technical risk. It is used to evaluate technical decision issues, technical alternatives, and their uncertainties to support decision-making. Decision problems are structured by identifying alternatives, possible events, and possible outcomes.

Decision Analysis offers a methodology for collecting, analyzing and documenting information for presentation to decision-makers. It also offers techniques for modeling and solving decision problems mathematically. Decision models can take the form of paper-and-pencil procedures or complex computer programs. The methodology of developing a model is broad and adapted to the issue under consideration.

An important aspect of Decision Analysis is to understand when a decision is needed. It is important to understand why a decision is required, how long a decision can be delayed, the impact of delaying a decision, whether the necessary information is available to make a decision, and other drivers or dependent factors and criteria to be in place prior to a decision.

The outputs of Decision Analysis allow the decision maker to decide among competing alternatives without complete knowledge. It is important to understand and document the assumptions and limitations of any tool or methodology along with other factors when deciding among alternatives.

Not all decisions need a formal process but it is important to understand the methodology for decisions that require a formal process due to their complexity. Important decisions as well as supporting information, tools, and models are completely documented so that new information can be incorporated and assessed and past decisions can be understood in context.

Decision Analysis is performed throughout the life-cycle and can be applied to many different activities. Examples of typical activities that use decision analysis are:

a. Determining how to allocate limited resources (e.g., budget, mass, power) among competing subsystem interests to favor the overall outcome of the project;

b. Selecting and testing evaluation methods and tools against sample data;
c. Configuration management processes for major change requests or problem reports;

d. Design processes for making major design decisions and selecting design approaches;

e. Key decision point reviews or technical review decisions (e.g., PDR, CDR) as defined in MPR 7120.1E and MPR 7123.1;

f. Go or No-Go decisions (e.g., FRR);

g. Project management of major issues, schedule delays, or budget increases;

h. Procurement of major items;

i. Risk management of major risks (e.g., red or yellow);

j. SMA decisions; and

k. Miscellaneous decisions (e.g., whether to intervene in the project to address an emergent performance issue).

The following are key inputs and outputs to the Decision Analysis process.

Inputs and Sources:

a. Decisions needed, alternatives, issues, or problems and supporting data (from all Technical Processes).

b. Analysis support requests (from Technical Assessment Process).

Outputs and Destinations:

a. Alternative selection recommendations and impacts (to all Technical Processes).

b. Decision support recommendations and impacts (to Technical Assessment Process).

c. Work products of decision analysis activities (to Technical Data Management Process).

4.3.4.1 ***Decision Analysis Approach***

Decisions are made at all levels of the project and throughout a system's life-cycle. The Project SEMP will describe the importance of a thorough, rigorous, and disciplined decision analysis process because decisions can have far reaching impacts to a project's cost, schedule, and risk profile.

An assessment on the work products and resource requirements to support key decisions needs to be conducted as part of the technical planning process. As part of the SEMP preparation activity, an understanding of all the work products that will be used to make key decisions needs to be captured in addition to delineating decision-making authority to avoid overlap and confusion about who is responsible for making timely and effective decisions.

Decisions that could impact other organizations either negatively or positively are best coordinated and negotiated with those organizations in order to preclude any misunderstandings or repercussions that could adversely impact the project.

Authority to make decisions can be delegated to specific organizations or single representatives of those organizations, taking into account the roles and responsibilities of those organizations. Decision authority will also be delegated and assigned to specific Engineering/Technical Review Boards and Teams, based on their charters. In conjunction with this authority to make decisions, the types of decisions and bounds of these decisions are to be clearly delineated. Examples of these tasks include:

a. Those functions required to integrate hardware/software and mission profile timeline into an integrated vehicle (which requires data from hardware providers as well as integrators) ready for launch.

b. Integrated Hazard Analysis, including verification

c. Interim Human Rating Certification

d. Integrated verification requirements closure

e. Integrated Risk including Verification

f. Develop and integrated engineering drawing set
   1) Integrate drawing/parts list and CAD models from Orion and Ares and ground operations for each flight.
   2) Generate the necessary assembly drawing to integrate with necessary assembly and installation instructions

a) Sequence of A&I, in process test and verification, in process inspections (including mandatory inspections)
b) Outer Mode Line (OML) verification per drawings.

g. Ensure physical mating clearances and other compatibility requirements.
   1) Static and dynamic envelopes and other “stay out zones” are maintained.
   2) Interface compatibility – physical and functional

h. Integrated avionics schematics
   1) Develop an integrated set of avionics drawings
   2) Perform an integrated analysis of the avionics subsystems for physical and functional compatibility

i. Integrated loads

j. Integrated thermal

k. Integrated GN&C

l. Integrated aborts

m. Integrated plume and aero environments

n. Induced environments

o. Integrated mission timelines

p. Trajectory

q. Monitoring/assessing/reporting of all resource margin

r. Power, Mass Properties, CPU usage, bandwidth, thru put, data buss loading, thermal, etc. for each mission phase

For very complex decisions or risky decisions, the NASA RIDM Handbook, NASA/SP-2010-576, provides a description of the RIDM process and highlights key areas of the process.

Complying with stakeholder communication needs will prescribe the frequency, means, and format required to communicate the outcome of required or time critical decisions.

The effectiveness and consequences of decisions that are made will need to be tracked and evaluated. Unlike status reports that provide a snapshot on a project's current state, a decision analysis approach needs to ensure that there are mechanisms in place to understand if the desired outcomes of decisions were achieved.

As noted in NASA SE Handbook 6105, the following items are taken into consideration when establishing guidelines to determine which technical issues are subject to a formal analysis/evaluation process:

a. When to use a formal decision-making procedure;

b. What needs to be documented;

c. Who will be the decision-makers and their responsibilities and decision authorities; and

d. How decisions will be handled that do not require a formal evaluation procedure.

Tasks	Steps
Analyze the key decisions that will be made during a particular system life-cycle phase	a. In conjunction with the preparation or revision of the project SEMP, prepare a list of key top-level decisions that will be made as part of the current, upcoming, and future life-cycle phases b. Identify supporting decisions that need to be made to support key top-level decisions
Establish guidelines and criteria for selecting technical issues that require formal analysis or evaluation	a. Establish guidelines to support decision analysis that may be based on cost and schedule thresholds, risk, time criticality, resource requirements, or issues that require coordination outside of the project's current authority or purview b. Develop a table or matrix to support the implementation of the parameters associated with the established decision analysis guidelines
Prepare a decision assignment matrix assigning a responsible role or working group	a. Obtain an project organizational chart to support the decision making assignments b. Obtain a project working group chart to support the decision making assignments c. Assign a primary role or working group and supporting role or working group to each of the key top-level and

	supporting decisions
Identify key work products that will be used to support the decision making process	a. Based on the scope of the project, analyze the entrance criteria for mandatory technical reviews and key decision points to identify and capture corresponding work products needed to satisfy and comply with the entrance criteria b. Identify additional work products needed to support decisions that will ultimately support top-level key project decisions
Provide output of the decision analysis process in support of the preparation or revision of the project SEMP	a. Provide the decision assignment matrix b. Provide a listing of work products needed to support the decision making process

Decisions are based on facts, qualitative and quantitative data, engineering judgment, and open communications to facilitate the flow of information throughout the hierarchy of forums where technical analyses and evaluations are presented and assessed and where decisions are made. The extent of technical analysis and evaluation needed is commensurate with the consequences of the issue requiring a decision. The work required to conduct a formal evaluation is not insignificant and applicability is based on the nature of the problem to be resolved. Guidelines for use can be determined by the magnitude of the possible consequences of the decision to be made.

The following tasks and steps are provided to assist with satisfying the requirements contained in MPR 7123.1.

4.3.4.2 *Decision Analysis*

Performing decision analysis involves defining decision criteria, identifying alternative solutions, selecting methods and tools, evaluating alternative solutions, and selecting recommended alternative solutions.

Decision criteria are requirements for individually assessing the alternatives being considered. Typical decision criteria include technical, cost, schedule, risk, safety, mission success, and supportability. Objective and measurable criteria permit distinguishing among alternatives. Criteria is identified as either mandatory (i.e., “must have”) versus other criteria (i.e., “nice to have”). Criteria is prioritized by assigning weights to each.

Most decisions will have alternatives to choose from. Alternatives are to be brainstormed and documented. For complex decisions, a literature search may be performed to identify alternatives.

Evaluation methods and tools/techniques are selected based on the purpose for analyzing a decision and on the availability of the information used to support the method and/or tool. Typical evaluation methods are included in the table below.

Alternative solutions are evaluated with the established criteria and selected method. This evaluation is often performed by using a decision matrix. The recommended solution(s) are selected from the alternatives based on the evaluation criteria. Justification for the recommended solutions is documented, including the assumptions and limitations of the evaluation methods used.

Typically a technical team of SMEs makes a recommendation to a decision-maker (e.g., a NASA board, forum, or panel). The technical team produces a technical report, in conjunction with a decision matrix, to document the major recommendations. Decisions are formally disseminated via directive or memorandum.

The following tasks and steps are provided to assist with satisfying the requirements contained in MPR 7123.1.

Tasks	Steps
Define decision criteria	a. Define the type of criteria, such as: 1) Stakeholder expectations and requirements 2) Technology limitations 3) Environmental impact 4) Safety 5) Risk 6) Supportability 7) Total ownership and life-cycle costs 8) Schedule impact b. Define the acceptable range and scale of the criteria c. Apply weight to each criterion by its importance and rank criteria d. Document criteria
Identify alternative solutions	a. Brainstorm alternatives b. Literature search c. Document alternatives
Select methods and tools/techniques	Select methods, tools, and techniques 1) Systems analysis, simulation and performance

	2) Weighted tradeoff matrices 3) Engineering, manufacturing, cost, and technical opportunity trade studies 4) Cost-benefit analysis 5) Decision matrix 6) Decision trees 7) Influence diagram 8) Multi-criteria decision analysis 9) Risk-informed decision analysis process
Evaluate alternative solutions	Utilize selected methods and tools to evaluate identified alternatives against decision criteria
Select recommended solutions from alternatives	a. Select recommended alternative solutions b. Document recommendation with supporting rationale 1) Assumptions 2) Limitations of the evaluation methods used
Generate Decision Report	a. Summary of analysis b. Problem statement c. Choice of analysis technique d. Critical input data used e. Scoring, rating, evaluation summary f. Risks/Benefits g. Recommendations h. Dissent i. References and Resources

Examples

NASA Systems Engineering Handbook NASA/SP-2007-6105	Figure 6.8-2, Decision matrix
NASA Systems Engineering Handbook NASA/SP-2007-6105	Table 6.8-2, Typical Information to Capture in a Decision Report
NASA Systems Engineering Handbook NASA/SP-2007-6105	Figure 6.8-3, Systems analysis across the life-cycle
NASA Systems Engineering Handbook NASA/SP-2007-6105	Figure 6.8-4, Simulation model analysis techniques
NASA Systems Engineering Handbook NASA/SP-2007-6105	Figure 6.8-5, Trade study process
NASA Systems Engineering Handbook NASA/SP-2007-6105	Figure 6.8-6, Influence diagram
NASA Systems Engineering Handbook NASA/SP-2007-6105	Figure 6.8-7, Decision tree

NASA Systems Engineering Handbook NASA/SP-2007-6105	Figure 6.8-9, Risk-informed Decision Analysis Process

4.3.4.3 ***Data requirements deliverable***

For any applicable DRDs associated with this process, refer to MPR 7123.1.

4.4 Lessons Learned

Lessons learned/best practices are important sources of information that permeate organizational boundaries and can have a significant impact upon institutional practices as well as project implementation, system design, development, and operations. Throughout project development, existing lessons learned/best practices are reviewed. Reviewing lessons learned from past projects is critically important during the early phases of system development when the basic structure of the system is being defined. The NASA Lessons Learned Information System (LLIS) provides an electronic reference database for lessons learned/best practices from past projects. The LLIS can be accessed at http://llis.nasa.gov/. In addition to the LLIS, the NASA Technical Standards Program website**,** http://standards.nasa.gov/**,** provides access to lessons learned related to technical standards.

APPENDIX A ACRONYMS

AD^2	Advancement Degree of Difficulty
ADP	Acceptance Data Package
ALERT	Acute Launch Emergency Restraint Tip
ANSI	American National Standards Institute
AO	Announcement of Opportunity
AR	Acceptance Review
ASM	Acquisition Strategy Meeting
ASP	Acquisition Strategic Planning
ATD	Advanced Technology Development
ATP	Authority To Proceed
BAR	Basic and Applied Research
CAM	Cost Account Manager
CCB	Configuration Control Board
CAD	Computer Aided Design
CADRe	Parts A, B, and C
CDR	Critical Design Review
CDRM	Center Data Requirements Manager
CE	Chief Engineer and Change Engineer
CEI	Contract End Item
CERR	Critical Events Readiness Review
CER	Critical Events Readiness and Center Export Representative
CI	Configuration Item
CI	Configuration Inspection
CIL	Critical Items List
CLR	Customer Lead Representative
CM	Configuration Management
CMC	Center Management Council
CMP	Configuration Management Plan
CO	Contracting Officer
CofF	Construction of Facilities
COFR	Certification of Flight Readiness
ConOps	Concept of Operations
COTR	Contracting Officer's Technical Representative
CPU	Computer Processing Unit
CPR	Cost Performance Report
CR	Change Request

CRM	Continuous Risk Management
CSA	Configuration Status Accounting
CSCI	Computer Software Configuration Item
CSO	Chief S&MA Officer
CSP	Customer-Supplied Product
CSR	Customer Support Representative
CWC	Collaborative Workforce Commitment
DA	Decision Authority and Decision Analysis
DAC	Decision Analysis Cycle
DAS	Decision Analysis System
DAU	Defense Acquisition University
DCR	Design Certification Review
DFI	Developmental Flight Instrumentation
DGA	Designated Governing Authority
DID	Data Item Description
DM	Data Management and Data Manager
DoD	Department of Defense
DPD	Data Procurement Document
DR	Decommissioning Review
DRD	Data Requirements Descriptions
DRL	Data Requirements List
DRM	Design Reference Mission
DSD	Design Solution Definition
EAA	Enterprise Associate Administrator
EAC	Estimate at Completion
EAR	Export Administration Regulations
ECR	Engineering Change Request
EEE	Electrical, Electronic, and Electromechanical
EMC	Electromagnetic Compatibility
EMC	Engineering Management Council
EMI	Electromagnetic Interference
EO	Engineering Order
EOM	End of Mission
EOMP	End of Mission Plan
EPA	Environmental Protection Agency
EPO	Engineering Process Outsourcing
ERD	Environmental Requirements Documents
EVM	Earned Value Management
EVMS	Earned Value Management System
FAD	Formulation Authorization Document

FAR	Federal Acquisition Regulation
FCA	Functional Configuration Audit
FEO	Floor Engineering Orders
FEPL	Floor Engineering Parts Lists
FDF	Flight Data File
FFBD	Functional Flow Block Diagrams
FFP	Firm Fixed Price
FGB	Functional Cargo Block
FMEA	Failure Mode and Effects Analyses
FRR	Flight Readiness Review
FS&GS	Flight Systems and Ground Support
FTO	Flight Test Objectives
FTA	Fault Tree Analysis
GEIA	Government Electronics & Information Technology Association
GOR	Ground Operations Review
GPMC	Governing Project Management Council
GSE	Ground Support Equipment
GN&C	Ground Navigation & Control
HQ	Headquarters
HW/SW	Hardware/Software
IA	Independent Assessment
IBR	Integrated Baseline Review
ICD	Interface Control Document and Interface Control Drawing
ICP	Integrated Control Plan
ICWG	Interface Control Working Group
ID	Identifier
IDD	Integrated Definition Document and Integrated Definition Drawing
ILS	Integrated Logistics Support
ILSP	Integrated Logistics Support Plan
IM	Interface Management
IMP	Integrated Master Plan
IMS	Integrated Master Schedule
IMSB	Integrated Management Systems Board
INCOSE	International Council on Systems Engineering
IPCL	Instrumentation Program and Command List
IPT	Integrated Product Team
IRD	Interface Requirements Document
IRN	Interface Revision Notice
ISO	International Organization for Standardization

ISS	International Space Station
IT	Information Technology
ITAR	International Traffic in Arms Regulations
I&T	Integration and Test
IV&V	Independent Verification and Validation
JCL	Joint Confidence Level
KDP	Key Decision Point
KPP	Key Performance Parameter
KSC	Kennedy Space Center
LCC	Life-cycle Cost
LD	Logical Decomposition
LEO	Low Earth Orbit
LLIS	Lessons Learned Informaton System
LSE	Lead System Engineer
LSSM	Launch Site Support Manager
MAP	Manufacturing and Assembly Plan
MCR	Mission Concept Review
MD	Mission Directorate
MDAA	Mission Directorate Associate Administrator
MDM	Multiplexer De-Multiplexer
MDR	Mission Definition Review
MLR	Marshall Lead Representative
MOE	Measures of Effectiveness
MOP	Measures of Performance
MOP	Mission Operations Plan
MP	Materials and Processes
MPR	Marshall Procedural Requirements
M&S	Models and Simulations
MSFC	Marshall Space Flight Center
MWI	Marshall Work Instruction
N^2	N-squared diagrams
NxN	N-squared diagrams
NAR	Non-Advocate Review
NASA	National Aeronautics and Space Administration
NFAR	NASA Federal Acquisition Regulation
NFS	NASA FAR Supplement
NGO	Needs, Goals, and Objectives
NPD	NASA Policy Directive
NRA	NASA Research Announcement
NTIA	National Telecommunications and Information Administration

OBS	Organizational Breakdown Structure
OCC	Operations Control Center
OCD	Operation Concept Document
OER	Office of External Relations
OMB	Office of Management and Budget
OML	Outer Mode Line
OPR	Office of Primary Responsibility
OPRD	Office of Primary Responsibility Designated
ORR	Operational Readiness Review
ORU	Orbital Replaceable Unit
OSAC	Office of Strategic Analysis and Communications
PA	Process Assessment
PAR	Program Approval Review
PBS	Product Breakdown Structure
PCA	Program Commitment Agreement
PCA	Physical Configuration Audit
PCH	Program Critical Hardware
PDD	Product Definition Data
PDLM	Product Data and Life-cycle Management
PDR	Preliminary Design Review and Product /Preliminary Design Review
PFAR	Post-Flight Assessment Review
PFD	Power Flux Density
PHA	Preliminary Hazard Analysis
PHS&T	Packaging, Handling, Storage and Transportation
PI	Principal Investigator
PIRN	Preliminary Interface Revision Notification
PLAR	Post-Launch Assessment Review
PM	Project Manager
PMA	Pump Module Assembly
PMB	Performance Measurement Baseline
PMC	Project Management Council
PNAR	Preliminary Non-Advocate Review
POC	Point of Contact
POP	Project Operating Plan
PPBE	Planning, Programming, Budgeting and Execution
PP&C	Program/Planning and Control
PRA	Probabilistic Risk Assessment
Pre-RID	Preliminary Review Item Discrepancy
PRR	Project Requirements Review

PRSD	Preliminary Requirements Specification Document
P/SDR	Program/System Definition Review
PSR	Pre-Ship Review
P/SRR	Program/System Requirements Review
PSM	Procurement Strategy Meeting
QA	Quality Assurance
RAM	Responsibility Assignment Matrix
REMP	Requirements Engineering Management Plan
REQSPEC	Requirement Specification
RF	Radio Frequency
RFP	Request for Proposal
RID	Review Item Discrepancy
RIDM	Risk-Informed Decision Making
RM	Requirements Management
RMP	Requirements Management Plan and Risk Management Plan
ROM	Rough Order Magnitude
R&M	Reliability and Maintainability
S&MA	Safety and Mission Assurance
SAR	System Acceptance Review
SBIR	Small Business Innovation Research
SBU	Sensitive But Unclassified
SDP	Software Development Plan
SDR	System Definition Review
SE	Systems Engineering
SEB	Source Evaluation Board
SEC	Source Evaluation Committee
SED	Stakeholders Expectations Definition
SEG	Systems Engineering Guide (http://seg.msfc.nasa.gov)
SEMP	Systems Engineering Management Plan
SIR	System Integration Review
SLE	Subsystem Lead Engineer
S&MA	Safety and Mission Assurance
SMD	Science Mission Directorate
SME	Subject Matter Expert
SOW	Statement of Work
SRB	Standing Review Board
SRD	System Requirements Document
SRR	System Requirements Review
STD	Standard

STI	Science and Technical Information
TAS	Technical Analysis System
TBD	To Be Determined
TDM	Technical Data Management
TDMP	Technical Data Management Plan
TIC	Total Investment Cost
TLYF	Test Like You Fly
TMC	Technical Management and Cost
TPM	Technical Performance Metric and Technical Performance Measures
TRD	Technical Requirements Definition
TRL	Technology Readiness Level
TRM	Technical Requirements Management
TRP	Technical Requirements Planning
TRR	Test Readiness Review
T/V	Thermal/Vacuum
UFE	Unallocated Future Expenses
V&V	Verification and Validation
WAD	Work Authorization Document
WBS	Work Breakdown Structure

APPENDIX B GLOSSARY

Agency. Term referring to NASA.

Baseline. An agreed-to set of requirements, designs, or documents that will have changes controlled through a formal approval and monitoring process.

Bidirectional Traceability. An association between two or more logical entities that is discernible in either direction.

Center Management Councail (CMC). The council at a Center that performs oversight of the programs and projects by evaluating all program and project work executed at that Center.

Change Request (CR). The format used to document a proposed engineering change. It is used to submit documentation for initial baselining or to process changes to the baseline for evaluation and disposition by the Configuration Control Board (CCB).

Concept of Operations (ConOps). The ConOps describes how the system will be operated during the life-cycle phases to meet stakeholder expectations. It describes the system characteristics from an operational perspective and helps facilitate an understanding of the system goals. It stimulates the development of the requirements and architecture related to the user elements of the system. It serves as the basis for subsequent definition documents and provides the foundation for the long-range operational planning activities.

Configuration Control Board (CCB). A board composed of technical and Project representatives who recommend approval or disapproval of proposed engineering changes to, and proposed deviations/waivers from, a CI's, or a baseline's, current approved configuration documentation.

Configuration Documentation. The program/project-specific technical documentation (i.e., drawings, parts lists, specifications, standards, interface control documents/drawings (ICDs), software version descriptions (SVDs), and documents invoked therein) that identify and define a configuration item's functional and physical characteristics."

Configuration Items (CI). A Configuration Item is any hardware, software, or combination of both that satisfies an end use function and is designated for separate configuration management. Configuration items are typically referred to by an alphanumeric identifier which also serves as the unchanging base for the assignment of serial numbers to uniquely identify individual units of the CI.

Configuration End Item Part I Specification. The Part I CEI specification is used to specify technical requirements peculiar to the performance, design, and verification of a CEI that are flowed down from the higher level specification and allocated to the CEI. "Part I is a product of the early design effort; and when completed and approved, establishes the design requirements baseline for the CEI."

Configuration End Item Part II Specification. The Part II CEI specification is used to specify exact configuration requirements peculiar to the production, quality control, acceptance verification, and preparation for delivery of the CEI. "Part II is a product of development and operations; and when completed and approved, establishes the product configuration baseline."

Cost Risk. The risk associated with the ability of the Project to achieve its life-cycle cost objectives and secure appropriate funding. Two risk areas bearing on cost are (1) the risks that the cost estimates and objectives are not accurate and reasonable and (2) the risk that the program execution will not meet the cost objectives as a result of a failure to handle cost, schedule, development or performance risks.

Cost-Benefit Analysis. A methodology to determine the advantage of one alternative over another in terms of equivalent cost or benefits. It relies on totaling positive factors and subtracting negative factors to determine a net result.

Customer Service Representative (CSR). Contractor personnel responsible for maintaining interface with the organizational element and other property personnel for user supply or equipment requirements and related actions.

Customer-Supplied Product (CSP). Any hardware, equipment, or materials supplied by a customer (for the purpose of fabrication; testing; storage; Electrical, Electronic, and Electromechanical (EEE) parts screening; analysis; and/or refurbishment) that are returned to the customer upon completion of services at MSFC.
Customer. The organization or individual that has requested a product and will receive the product to be delivered. The customer may be an end user of the product, the acquiring agent for the end user, or the requestor of the work products from a technical effort. Each product within the system hierarchy has a customer.

Customization. Removal of a best practice or guidance by a program/project/activity.

Data Interoperability. The ability for two or more systems to exchange data and use the data that has been exchanged.

Data Procurement Document. A compilation of all data deliverables required from a contractor for a particular activity or project.

Data Requirements Description. A detailed description of a required data item, including purpose, contents, format, maintenance requirements, and submittal requirements.

Data Requirements List. A list of required data items applicable to a specific NASA activity or contract. DRLs may contain both NASA-produced and contracted data or may be limited to contracted data only (DPD/DRL).

Data. Any electronic or written information/statement which represents policies, procedures, instructions, instructional material, drawings, plans, specifications, requirements, handbooks, manuals, reports, standards, or other correspondence. Data becomes information when it is processed in some manner to develop general useful, actionable information. (These may be stored in a variety of media such as magnetic tapes, computer disks, data sheets, log books, strip charts, thumb drives, hard drives, photographs, and video.)

Data Management. The timely and economical identification/definition, preparation, control, and disposition of documents and data required by a program, project, or activity.

Decision Analysis Process. A process that is a methodology for collecting, analyzing and documenting information for presentation to decision-makers. It also offers techniques for modeling decision problems mathematically and finding optimal decisions numerically. The methodology entails identifying alternatives, one of which is decided upon; possible events, one of which occurs thereafter; and outcomes, each of which results from a combination of decision and event.

Decision Authority. The Agency's responsible individual who authorizes the transition of a Project to the next life-cycle phase.

Decision Matrix. A methodology for evaluating alternatives in which valuation criteria typically are displayed in rows on the left side of the matrix, and alternatives are the column headings of the matrix. Criteria "weights" are typically assigned to each criterion.

Decision Trees. A portrayal of a decision model that displays the expected consequences of all decision alternatives by making discreet all "chance" nodes, and, based on this, calculating and appropriately weighting the possible consequences of all alternatives.

Design Solution Definition Process. The process by which high-level requirements derived from stakeholder expectations and outputs of the Logical Decomposition Process are translated into a design solution.

Deviation. A specific written authorization prior to manufacture of a CI to depart from a particular requirement(s) of a CI's current approved configuration documentation for a specific number of units or a specified period of time. It differs from an engineering change since a deviation does not effect a change to a configuration document.

Enabling Products. The life-cycle support products and services (e.g., production, test, deployment, training, maintenance, and disposal) that facilitate the progression and use of the operational end product through its life-cycle. Since the end product and its enabling products are interdependent, they are viewed as a system. Project responsibility thus extends to responsibility for acquiring services from the relevant enabling products in each life-cycle phase. When a suitable enabling product does not already exist, the project that is responsible for the end product may also be responsible for creating and using the enabling product.

End Item. Final combination of products that is ready for its intended use, e.g. launch vehicle, tank, engine, software code, microgravity furnace, etc.

Engineering Change Request (ECR). A proposed engineering change used by MSFC personnel to submit documentation for initial baselining or to process changes to the baseline for evaluation and disposition by the appropriate CCB.

External Interface. The boundaries between a system end product and another external system end product or a human and the operating environment in which the system products will be used or operated.

Formulation Authorization Document (FAD). The document issued by the MDAA (or MSOD) to authorize the formulation of a program whose goals will fulfill part of the Agency's Strategic Plan, Mission Directorate Strategies, or Mission Support Office Functional Leadership Plans. In addition, a FAD or equivalent is used to authorize the formulation of a project.
Gantt Chart. Bar chart depicting start and finish dates of activities and products in the WBS.

Integrated Master Schedule. An integrated set of schedule data that reflects the total project scope of work as discrete and measurable tasks/milestones that are time-phased through the use of task durations, interdependencies, and date constraints and is traceable to the WBS.

Interface Control Document (ICD). Details the physical interface between two system elements, including the number and types of connectors, electrical parameters, mechanical properties, and environmental constraints. The ICD is a bilateral document with two or more approval signatories.

Interface Definition Document (IDD). A unilateral document controlled by the end-item provider, and it provides the details of the interface for a design solution that is already established.

Interface Management. A process to assist in controlling product development when efforts are divided among parties.

Interface. The functional and physical characteristics required to exist at a common boundary between two or more systems, end products, enabling products or subsystems.

Internal Interfaces. The boundaries between products that are controlled by a developer or NASA technical effort.

Key Decision Point (KDP). The event at which the Decision Authority determines the readiness of a Project to progress to the next phase of the life-cycle (or to the next KDP).

Marshall Lead Representative. The senior MSFC person, who by assignment or by virture of position, has responsibility for the use and control of MSFC product and/or CSP (MPR 6410.1).

Master List. Controlled list(s) of data/documents that identify the correct version authorized for use.

Measure of Effectiveness (MOE). A measure by which a stakeholder’s expectations will be judged in assessing satisfaction with products or systems produced and delivered in accordance with the associated technical effort. The MOE is deemed to be critical to not only the acceptability of the product by the stakeholder but also critical to operational/mission usage. An MOE is typically qualitative in nature or not able to be used directly as a design-to requirement.

Measure of Performance (MOP). A quantitative measure that, when met by the design solution, will help ensure that an MOE for a product or system will be satisfied. These MOPs are given special attention during design to ensure that the MOEs to which they are associated are met. There are generally two or more measures of performance for each MOE.

Metadata. Metadata is structured information that describes, explains, locates, or otherwise makes it easy to retrieve, use, or manage the actual data sought by the user. Metadata is often called “data about data” or “information about information.” As an example it could be thought of as the data used in a library card catalogue to describe the relevant information about a particular book (author, subject matter, synopsis and identification system to locate the book on the library shelf, etc.).

Precedence Diagram. Workflow diagram that places activities in boxes, connected by dependency arrows; typical of a Gantt chart.

Probabilistic Risk Assessment (PRA). PRA is a scenario-based risk assessment technique that quantifies the likelihoods of various possible undesired scenarios and their consequences, as well as the uncertainties in the likelihoods and consequences. Traditionally, design organizations have relied on surrogate criteria such as system redundancy or system-level reliability measures, partly because the difficulties of directly quantifying actual safety impacts, as opposed to simpler surrogates, seemed insurmountable. Depending on the detailed formulation of the objectives hierarchy, PRA can be applied to quantify Technical Performance Measures (TPMs) that are very closely related to fundamental objectives (e.g., Probability of Loss of Crew (P(LOC))). PRA focuses on the development of a comprehensive scenario set, which has immediate application to identify key and candidate contributors to risk. In all but the simplest systems, this requires the use of models to capture the important scenarios, to assess consequences, and to systematically quantify scenario likelihoods. These models include reliability models, system safety models, simulation models, performance models, and logic models.

Product Breakdown Structure (PBS). A hierarchical breakdown of the hardware and software products of the Project.

Product Integration Process. One of the SE engine product realization processes that make up the system structure. In this process, lower level products are assembled into higher level products and checked to make sure that the integrated product functions properly. It is the first element of the processes that lead from realized products from a level below to realized end products at a level above, between the Product Implementation, Verification, and Validation Processes.

Product Realization. The act of making, buying, or reusing a product, or the assembly and integration of lower level realized products into a new product, as well as the verification and validation that the product satisfies its appropriate set of requirements and the transition of the product to its customer.

Product Transition Process. A process used to transition a verified and validated end product that has been generated by product implementation or product integration to the customer at the next level in the system structure for integration into an end product or, for the top-level end product, transitioned to the intended end user.

Product Validation Process (PVa). The second of the verification and validation processes that is conducted on a realized end product. While verification proves whether "the system was done right," validation proves whether "the right system was done." In other words, verification provides objective evidence that every "shall" was met, whereas validation is performed for the benefit of the customers and users to ensure that the system functions in the expected manner when placed in the intended environment. This is achieved by examining the products of the system at every level of the structure.

Product Verification Process (PVe). The first of the verification and validation processes conducted on a realized end product. As used in the context of systems engineering common technical processes, a realized product is one provided by either the Product Implementation Process or the Product Integration Process in a form suitable for meeting applicable life-cycle phase success criteria.

Product. A Work Product which is intended for delivery to a customer or end user.

Program. A strategic investment by a Mission Directorate or Mission Support Office that has a defined architecture and/or technical approach, requirements, funding level, and a management structure that initiates and directs one or more projects. A program defines a strategic direction that the Agency has identified as critical.

Program Commitment Agreement (PCA). The contract between the Associate Administrator and the cognizant MDAA that authorizes transition from formulation to implementation of a program.

Program Plan. The document that establishes the Programs' baseline for implementation, signed by the MDAA, Center Director(s), and Program Manager.

Programmatic Risk. The risk associated with action or inaction from outside the project, over which the project manager has no control, but which may have significant impact on the project. These impacts may manifest themselves in terms of technical, cost, and/or schedule. This includes such activities as: International Traffic in Arms Requirements (ITAR), import/export control, partner agreements with other domestic or foreign organizations, congressional direction or earmarks, Office of Management and Budget (OMB) direction, industrial contractor restructuring, external organizational changes, etc.

Project. A specific investment identified in a *Program Plan* having defined requirements, a life-cycle cost, a beginning, and an end. A project yields new or revised products that directly address NASA's strategic needs.

Review Item Discrepancy. A formal documentation of an item found during a formal review that is in conflict with the references for the review; e.g., documenting a conflict between a design and the design’s performance requirements.

Risk. The combination of the probability that a program or project will experience an undesired event (some examples include a cost overrun, schedule slippage, safety mishap, health problem, malicious activities, environmental impact, or failure to achieve a needed scientific or technological breakthrough or mission success criteria) and the consequences, impact, or severity of the undesired event, were it to occur. Both the probability and consequences may have associated uncertainties.

Risk Assessment. An evaluation of a risk item that determines (1) what can go wrong, (2) how likely is it to occur, (3) what the consequences are, and (4) what are the uncertainties associated with the likelihood and consequences.

Risk Management. An organized, systematic decision-making process that efficiently identifies, analyzes, plans, tracks, controls, communicates, and documents risk and establishes mitigation approaches and plans to increase the likelihood of achieving Project goals.

Risk-Informed Decision Analysis Process. A five-step process focusing first on objectives and next on developing decision alternatives with those objectives clearly in mind and/or using decision alternatives that have been developed under other systems engineering processes. The later steps of the process interrelate heavily with the Technical Risk Management Process.

Risk-Informed Decision Making. A risk-informed decision-making process uses a diverse set of performance measures (some of which are model-based risk metrics) along with other considerations within a deliberative process to inform decision making.

Note: A decision-making process relying primarily on a narrow set of model-based risk metrics would be considered "risk-based." [Ref: NPR 8000.4A, Appendix A.14]

Schedule Risk. Schedule risks are those associated with the adequacy of the time estimated and allocated for the development, production, implementation, and operation of the system. Two risk areas bearing on schedule risk are (1) the risk that the schedule estimates and objectives are not realistic and reasonable and (2) the risk that program execution will fall short of the schedule objectives as a result of failure to handle cost, schedule, or performance risks.

Stakeholders. Are defined as Customers or Other Interested Parties.

Customer – The organization or individual that has requested a product and will receive the product to be delivered. The customer may be an end user of the product, the acquiring agent for the end user, or the requestor of the work products from a technical effort. Each product within the system hierarchy has a customer. Examples of customers include Congress, NASA Headquarters, NASA Centers, NASA advisory committees, the National Academy of Sciences, the National Space Council, scientists, project managers, and subsystems engineers and many other groups in the science and space communities.

Other Interested Parties – Other interested parties are groups or individuals who are not customers of a planned technical effort but may be affected by the resulting product, the manner in which the product is realized or used, or have a responsibility for providing life-cycle support services. Other interested parties are defined as those who will be impacted by or will impact the development and use of the system. Examples of other interested parties include the Project Manager, Engineering, Safety and Mission Assurance, Facilities, Logistics, Test, Operations, Procurement, Contractors, Vendors, etc.

Systems Analysis. The analytical process applied to a system by which a need is transformed into a realized, definitive product, able to support compatibility with all physical and functional requirements and support the operational scenarios in terms of reliability, maintainability, supportability, serviceability, and disposability, while maintaining performance and affordability. Systems analysis is responsive to the needs of the customer at every phase of the life-cycle, from pre-Phase A to realizing the final product and beyond.

System. The combination of elements that function together to produce the capability required to meet a need. The elements include all hardware, software, equipment, facilities, personnel, processes, and procedures needed for this purpose.

Systems Engineering. A disciplined approach for the definition, implementation, integration, and operation of a system (product or service). The emphasis is on achieving stakeholder functional, physical, and operational performance requirements in the intended use environments over its planned life within cost and schedule constraints. Systems engineering includes the engineering processes and technical management processes that consider the interface relationships across all elements of the system, other systems, or as a part of a larger system.

Systems Engineering Management Plan (SEMP). The SEMP identifies the roles and responsibilities interfaces of the technical effort and how those interfaces will be managed. The SEMP is the vehicle that documents and communicates the technical approach, including the application of the common technical processes; resources to be used; and key technical tasks, activities, and events along with their metrics and success criteria.

Tailor. Removal of a requirement/shall by a program/project/activity.

Technical Assessment Process. The crosscutting process used to help monitor technical progress of a project through periodic technical reviews. It also provides status information in support of assessing system design, product realization, and technical management decisions.

Technical Data. Scientific or technical information recorded in any form or presented in any manner, but excluding financial and management data. Examples of Technical Data are computer software documentation or any representation of facts, numbers or data of any nature that can be communicated, stored, and processed to form information required by a contract or agreement to be delivered to, or accessed by, the Project. Technical data does not include data related to general workforce operations, communications information, financial transactions, personal data, transactional data, and other data of a purely business nature.

Technical Information. Engineering, evaluation, and research and development (R&D) information associated with design, production, operation, use, and/or maintenance of an equipment, machine, process, or system.

Technical Performance Measurement (TPM). The set of critical or key performance parameters that are monitored by comparing the current actual achievement of the parameters with that anticipated at the current time and on future dates. Used to confirm progress and identify deficiencies that might jeopardize meeting a system requirement.

Assessed parameter values that fall outside an expected range around the anticipated values indicate a need for evaluation and corrective action. Technical performance measures are typically selected from the defined set of MOPs.

Technical Planning Process. The first of eight technical management processes contained in the SE engine, the Technical Planning Process establishes a plan for applying and managing each of the common technical processes that will be used to drive the development of system products and associated work products. This process also establishes a plan for identifying and defining the technical effort required to satisfy the project objectives and life-cycle-phase success criteria within the cost, schedule, and risk constraints of the project.

Technical Risk. Risk associated with the achievement of a technical goal, criterion, or objective. It applies to undesired consequences related to technical performance, human safety, mission assets, or environment.

Technical Risk Management Process. The process for measuring or assessing risk and developing strategies to manage it. Critical to this process is the proactive identification and control of departures from the baseline program, project, or activity.

Traceability. A discernible association between two or more logical entities such as requirements, system elements, verifications, or tasks.

Trade Study. A means of evaluating system designs by devising alternative means to meet functional requirements, evaluating these alternatives in terms of the measures of effectiveness and system cost, ranking the alternatives according to appropriate selection criteria, dropping less promising alternatives, and proceeding to the next level of resolution, if needed.

Validation. Proof that the product accomplishes the intended purpose per stakeholders' expectations. Validation may be determined by a combination of test, analysis, and demonstration.

Verification. Proof of compliance with specifications. Verification may be determined by test, analysis, demonstration, or inspection.

Waiver. A written authorization granted after manufacture to accept a CI that does not meet specified requirements for a specific number of units or a specified time period.

Work Breakdown Structure (WBS). A product-oriented hierarchical division of the hardware, software, services, and data required to produce the Project's end product(s) structured according to the way the work will be performed, reflecting the way in which Project costs, schedule, technical, and risk data are to be accumulated, summarized, and reported.

Work Product. A useful result of a process. A work product can include files, documents, configuration documentation, software code, test data, process descriptions, specifications, physical media and physical parts representing organizational products. Work Products encompass all the items (including data) developed during the development of a Project deliverable. However, a work product is not necessarily a deliverable item.

Workflow Diagram. A scheduling chart that shows activities, dependencies among activities, and milestones.

APPENDIX C DEVELOPING QUALITY REQUIREMENTS

C.1 Developing Requirements

The "system of interest" needs, goals, and objectives are often contained in the parent documents. The need is often found in the announcement of opportunity or proposal. The need explains why the project is developing the product from the stakeholders' points of view (What problem do the stakeholders want to solve?). The needs, goals, and objectives are generally found in the Project Plan, proposal, or a Needs, Goals, and Objectives document. The goals define specific items to accomplish that meet the need. The objectives are initiatives with specific criteria that implement the goals. For example:

a. NEED = To explore space and extend human presence.

b. GOAL = Develop and fly Crew Exploration Vehicle.

c. OBJECTIVE = Minimum two lunar missions per year. Higher safety than the Space Shuttle.

The external interfaces form the boundaries between the system of interest and the rest of the world. Create, use, and maintain interface diagrams to depict all of the external interfaces. Collect and document the Standards, Interface Control Documents (ICD), Interface Definition Documents, and others available for the existing interfaces. Remember that the interface requirements are developed and documented in IRD and not in an ICD that is to be developed later and capture the interface design solution to the established interface requirement.

Operational concepts and scenarios are a step-by-step description of how the proposed system operates and interacts with its users and its external interfaces. Imagine the operations of the future product and document, from the stakeholders' perspective, the steps of how the product is to function or be used. During development, consider the following questions: Who uses the product? Why? Where? When? How? Under what conditions and environments?

Prior to writing the actual "shall" requirements, determine and document any risks associated with the requirements development process. Use the following questions to help identify risks:

a. Do we have product boundary issues?

b. Are there poorly defined or incomplete interfaces?

c. Have we missed or been unable to obtain a key stakeholder input?

d. Have we missed a product life-cycle phase in our assessment?

e. Are there areas of strong disagreement between stakeholders?

f. Are there too many unknowns?

g. Are there technical issues?

h. Are there technology issues?

A “YES” answer indicates risk, and is to be addressed and mitigated according to the project’s Risk Management process.

Requirements Documents are only to contain requirements relative to the product(s) to be developed. Requirements relative to the project or personnel/contractor actions are to be captured in a Statement of Work (SOW) or Project Plan.

C.1.1 **Guidance for Writing Good Requirements**

C.1.1.1 *Correct Terms*

Correct terminology for NASA/MSFC requirements statements are defined in MPR 1410.2, paragraph CH1.1.2.1.

C.1.1.2 *Editorial Checklist*

The requirement is in the form “product ABC shall XYZ.” A requirement states “The product shall (do, perform, provide, weigh, or other verb followed by a description of what) in the “Who” shall “What” form using active rather than passive voice.
Example Product requirements:

a. The system shall operate at a power level of…

b. The software shall acquire data from the…

c. The structure shall withstand loads of…

d. The hardware shall have a mass of…

The requirement uses consistent terminology to refer to the product and its lower-level entities.

The requirement is grammatically correct.

The requirement is free of typos, misspellings, and punctuation errors.

The requirement complies with the project's template and style rules.

C.1.1.3 *Requirement Quality Checklist*

Is each requirement:

Clear and understandable?

a. Can only be understood one way?

b. Free from indefinite pronouns (this, these)?

c. Expressing only one thought per requirement statement? A standalone statement (as opposed to multiple requirements in a single statement or a paragraph that contains both requirements and rationale)?

d. Stated simply and concisely?

e. Stated positively (as opposed to negatively (for example, "shall not")?

Free of ambiguities (for example, as appropriate, and/or, support, but not limited to, be able to, be capable of)?

Free of unverifiable terms (for example, flexible, easy, sufficient, safe, ad hoc, adequate, accommodate, user-friendly, useable, when required, if required, appropriate, fast, portable, light-weight, small, large, maximize, minimize, sufficient, robust, quickly, easily, clearly, other "-ly" words, other "-ize" words)?

Free of implementation? (Requirements are to state WHAT is needed, NOT HOW to provide it. State the problem not the solution. Ask, "Why do you need the requirement?" The answer may point to the real requirement.)

Free of descriptions of operations? (Don’t mix operation with requirements; update the operational concept instead. To distinguish between operations and requirements ask the questions: “Does the developer have control over this? Is this a need for the product to satisfy or an activity involving the product?” Sentences like “The operator shall…” are almost always operational statements not requirements.)

Free of “To Be Determined” (TBD) values? (A best guess, marked “To Be Resolved” (TBR) with the rationale are to replace these.)

Complete with tolerances for qualitative/performance values (less than, greater than or equal to, plus or minus, 3 sigma root sum squares)?

Accompanied by intelligible rationale, including any assumptions? Can you validate (Do I concur with) the assumptions? Assumptions are to be confirmed before baselining.

Traceable to requirements (or to Scope, for the top-level requirements) in the level above it?

Identified with a verification method(s) (test, demonstration, analysis, inspection or a combination of these)? What quantitative entity can be used to measure its accomplishment? Can you state the criteria required for verification? Can compliance be verified?

Located in the proper section of the document?

Defined at the correct level?

Unique (as opposed to redundant)?

Consistent with other requirements (as opposed to conflicting)?

C.1.1.4 *Content Review/Inspection Checklist*

C.1.1.4.1 Clarity

a. Are the requirements clear and unambiguous? (That is, are there aspects of the requirement that are not understood; can the requirement be misinterpreted?)

b. Are the requirements concise and simple?

C.1.1.4.2 Completeness

a. Are requirements stated as completely as possible? Have all incomplete requirements been captured?

b. Are any requirements missing? For example have any of the following requirements areas been overlooked: functional, performance, interface, environment development, manufacturing, test, transport, storage, operations, manufacturing, test, storage, operations, transportation, training, personnel, operability, safety, security, appearance and physical characteristics, and design.

c. Have all assumptions been explicitly stated?

C.1.1.4.3 Compliance

a. Are all requirements at the correct level (that is, system, segment, element, subsystem)?

b. Are requirements specified in an implementation-free way so as not to obscure the original requirements (do the requirements state "what" and not "how")?

c. Are requirements specified in an operations-free way? Is this a requirement the developer has control over, something the product can do, or a quality it is to have, rather than an activity involving the product?

C.1.1.4.4 Consistency

a. Are the requirements stated consistently without contradicting themselves or the requirements of related systems?

b. Is the terminology consistent with the user and sponsor's terminology? Is the terminology consistent with the project glossary?

c. Is the terminology consistently used through out the document?

d. Are the key terms included in the project's glossary?

C.1.1.4.5 Traceability

a. Are all requirements needed? Is each requirement necessary to meet the parent requirement? Is each requirement a needed function or characteristic? Distinguish between needs and wants. If it is not necessary, it is not a requirement. Ask, "What is the worst that could happen if the requirement was not included?"

b. Are all requirements (functions, structures, and constraints) traced to mission or system-of-interest-scope (that is, needs, goals, objectives, constraints, or operational concept)?

c. Is each requirement stated in such a manner that it can be uniquely referenced in subordinate documents?

d. Is allocation to the next lower level documented?

C.1.1.4.6 Correctness

a. Is each requirement correct?

b. Is each stated assumption correct? Assumptions are confirmed before the document can be baselined.

c. Are the requirements technically feasible?

C.1.1.4.7 Functionality

Are all described functions necessary and together sufficient to meet mission and system goals and objectives?

C.1.1.4.8 Performance

a. Are all required performance specifications and margins listed (for example, consider timing, throughput, storage size, latency, accuracy and precision)?

b. Is each performance requirement realistic?

c. Are the tolerances overly tight? Are the tolerances defendable and cost-effective? Ask, “What is the worst thing that could happen if the tolerance was doubled or tripled?”

C.1.1.4.9 Interfaces

a. Are all external interfaces clearly defined?

b. Are all internal interfaces clearly defined?

c. Are all interfaces necessary, sufficient, and consistent with each other?

C.1.1.4.10 Maintainability

a. Have the requirements for system maintainability been specified in a measurable, verifiable manner?

b. Are requirements written to be as weakly coupled as possible so that ripple effects from changes are minimized?

C.1.1.4.11 Reliability

a. Are clearly defined, measurable, and verifiable reliability requirements specified?

b. Are there error detection, reporting, handling, and recovery requirements?

c. Are undesired events (for example, single event upset, data loss or scrambling, operator error) considered and their required responses specified?

d. Have assumptions about the intended sequence of functions been stated? Are these sequences required?

e. Do these requirements adequately address the survivability after a software or hardware fault of the system from the point of view of hardware, software, operations personnel and procedures?

C.1.1.4.12 Verifiability/Testability

a. Can the system be tested, demonstrated, inspected, or analyzed to show that it satisfies requirements?

b. Are the requirements stated precisely to facilitate specification of system test success criteria and requirements?

C.1.1.4.13 Data Usage

Where applicable, are “don’t care” conditions truly “don’t care”? (“Don’t care” values identify cases when the value of a condition or flag is irrelevant, even though the value may be important for other cases.) Are “don’t care” conditions values explicitly stated?

The rationale includes the following items:

The reason for the requirement (why requirement exists and the source of the requirement). Often the reason for the requirement is not obvious, and it may be lost if not recorded as the requirement is being documented. The reason may point to a constraint, trade or design study, or operations concept. If there is a "traceability link" from a higher-level requirement that completely explains the reason for the requirement, then simply reference the link.

Assumptions made while developing the requirement. Assumptions are confirmed before the requirements can be baselined.

The relationships with the product's expected operations (for example, expectations about how customers are to use a product). This may be done with a link to the Operational Concept.

High-level design choices that drive low-level requirements (for example, trade study results). If the requirement states a method of implementation, the rationale is to state why the solution is being limited to this one method of implementation.

Use the following checklist to validate the documented traceability:

Are you able to trace each requirement back to requirements (or Scope, for the top-level requirements) in the level above it and vice versa? The requirement is to be evaluated to assure that the requirements trace is correct and that it fully answers the parent requirements. If it does not, some other requirement(s) is needed to complete fulfillment of the parent requirement.

If there is no parent, is the requirement "gold plating" or is there a missing requirement at the higher level?

C.2 <u>Requirements Analysis Metrics</u>

Metrics are measurements that provide a status on progress and insight into the quality of the work being performed, and the efficiency and effectiveness of the process. This information provides management with indicators of deviations and inconsistencies and allow for timely management action or intervention to be taken. Ideally, metrics are collected and the information correlated to ensure a detected anomaly is corroborated by other metrics.

As an example, if the number of requirement TBDs is increasing over time, then the TBD tracking metric in completing a technical requirements document also indicates the scheduled completion date slipping accordingly. Additionally an increase in the project's risk profile Acute Launch Emergency Restraint Tips (alerts) SE management for the need to take appropriate action.

Systems engineers are familiar with the capabilities of the SE tool software. SE tool software are likely to have an embedded metric capability that can be used to generate reports. The ability to generate these reports assumes the information is entered properly and completely. These measurements when looked at over time provide trending information in addition to current status. As an example, if the TBD burndown is actually increasing when it was expected to be decreasing, the SE tool software can generate a report that shows how fast this increase is over a designated period of time.

SEs do not solely rely on SE tool software to establish and maintain metrics. Project specific metrics are identified and implemented to ensure a complete assessment can be made on the project status.

The following short list of metrics that can be used to gauge the progress and completion of a typical requirements analysis activity:

1. Number or percent of requirements defined, allocated, and traced
2. Time to issue draft technical requirements specification
3. Number of meetings held
4. Number and trends of TBD, TBR, and TBS requirements
5. Number of requirement issues identified (e.g., requirements not stated in a verifiable way)
6. Number and frequency of changes (additions, modifications, and deletions).

APPENDIX D MANAGING REVIEWS AND DISCREPANCIES

D.1 Introduction

This appendix addresses description, practices and approaches to conducting formal technical reviews, specifically the identification, tracking, and resolution of Action Items and Discrepancies in items open for review. MSFC has employed a formal Review Item Discrepancy (RID) process in past projects. The RID generation, tracking, and resolution process describes a robust system for managing the primary activities of a technical review. Individual projects have the flexibility to determine what process they will use for managing commentary on reviewable items during major technical reviews as described in MPR 7123.1. MPR 7123.1 provides directive on the type and order of major milestone reviews, and provides descriptions of major milestone life-cycle reviews, recommended review entrance and exit criteria, review products and recommended maturity of review products for each life-cycle phase.

D.2 Reference Documents

Air Force handbook AFI 63-1201, 23 July 2007

CMMI Second Edition Guidelines for Process Integration and Product Improvement

Peresztegy, L. B. (Sam), and Charles E. Connor, Technical Reviews and Audits for Systems, Equipment, and Computer Software, Aerospace Corporation Report No. TOR-2007 (8583)-6414, Vol. 1, Rev. 1, 30 January 2009

D.3 Technical Reviews

D.3.1 Technical Reviews Directives and Guidance

NPR 7123.1 specifically states in section 3.1.1 that “the systems engineering common technical processes are used to drive the development of the system products and associated work products required by management to satisfy the applicable product-line life-cycle phase exit criteria while meeting stakeholder expectations within cost, schedule and risk constraints.” Additionally, the SE common technical processes enable efficient and effective knowledge work and operational execution of the product-line artifacts that meet stakeholder needs within cost, schedule, risk constraints, and especially performance goals.
Technical Assessment is progress management of the technical work.

Requirements for the phasing of programs and projects is specified in MPR 7120.1, and the minimum types of major milestone reviews to support required project phases, key decision points, and phase transitions are further specified in MPR 7123.1. NASA/SP-6105-2007 describes the different major milestone reviews, and provides guidance for developing and specifying entrance and exit criteria for major milestone reviews.

Technical reviews enable project management to determine on a periodic basis how effectively the team is transitioning from stakeholders needs and expectations to requirements, to design, to delivered and operational product, and finally to retired product. Whether reviews are internal, conducted among team members, or external or contractual, with stakeholder participation, they provide a means to observe and communicate technical progress, evaluate the validity of the product and alignment with project objectives, and to obtain approval to proceed to the next level of activity.

D.3.2 Inter-related Technical Assessment and Review Responsibilities

Project Management is responsible for managing the budget, schedule, and satisfaction of predominantly external stakeholders needs, including system performance for the entire project. Project Management control the direction of all work and have ultimate authority for controlling program or project funds. Chief Engineers or Lead Systems Engineers may be delegated responsibility for assessing technical validity, assessing and monitoring progress on technical development, and supporting negotiations regarding cost and schedule alignment with technical/knowledge work progress.

Delegation of responsibility and authority are captured in the Program Plan or SEMP under Designated Governing Authority. It is reiterated that in general, at MSFC, Chief Engineers and Lead Systems Engineers do not have final authority to direct action on project work or to control budget and schedule-impacting major decisions. The role of Chief Engineers and Lead Systems Engineers is to help plan and guide the knowledge/technical work or operations execution to maintain the alignment of work activities with project objectives and execute technical work guidance in compliance with the project plan and SEMP.

The systems engineering process of Technical Assessment is closely linked with the technical planning process and the decision analysis process. During the technical planning process, project management, the lead systems engineer, and the chief engineer evaluated the program objectives captured in the Program Plan, and specified in the SEMP the major milestone review/key decision points to be conducted, and at what maturity the project products are to be at each of the major milestone reviews. Output from Decision Analysis System (DAS) process iterations support Technical

Assessment and may be, on a case-by-case basis, formally included in Technical Review documentation. Also, TAS activities may invoke a DAS activity.

D.3.3 Technical Review Guidelines

D.3.3.1 Recommended Practices

Initiation in the early days of the program, but kept simple to avoid diverting the team from their real purpose (the purpose is not to support reviews, the purpose is to engineer the system)

Technical reviews reflect the progress against established requirements and identify emerging risks, trends, and action plans to mitigate risks or resolve technical challenges

Technical reviews are planned around key events whenever practicable

Less formal subsystem reviews are held prior to major system reviews to ensure completeness of review preparation and to integrate and pre-coordinate technical evaluation of review items so that significant discrepancies or risks can be identified and addressed prior to high level review.

High level review meetings cost a lot of money. Lack of pre-coordination increases risk of failed reviews, reconvening of the Board for follow-up resolution, or repetition of a review due to lack of readiness for the review.

Technical assessment of individual technical issues are conducted as an ongoing activity, with review by discipline teams, panels and boards as appropriate and as frequently as is practicably and logically appropriate.

Action items and review discrepancies or dissenting opinions are recorded and follow-up activities are tracked and resolved as quickly as possible.

D.3.3.2 Project Readiness

Scope, objectives, entrance and success criteria are used to determine readiness for a review, determining validity of identified discrepancies, and determining whether or not the review was successfully completed

Scope is the extent or range of review activity. For instance, a subsystem review would have a scope that encompasses the subsystem and its interfaces with other subsystems, but would not include issues with the design of other subsystems, even if they impact the subsystem under review.

Objectives are the goals and purposes of the review. If the objectives are not met, the review is not considered a success. A follow-on review may be required.

Entrance and success criteria are statements of the maturity of the system under review. They can be considered analogous to success criteria in a verification plan; if certain criteria are met, the verification is acceptable.

For more guidance on entrance and success criteria for specific reviews, refer to Appendix C: Major Milestone Reviews.

Ensuring adequate Project maturity is crucial to the successful completion of the review. Conducting the review before the Project is sufficiently mature most likely results in large numbers of legitimate identified discrepancies and dissenting opinions and/or discrepancies that require lengthy study, analysis, or prerequisite work to resolve.

The PM is encouraged to conduct an internal audit of review documentation prior to scheduling the review to ensure that the requirements and/or design are sufficiently mature for the applicable review, and that the documentation of the data accurately reflects the configuration/system.

To facilitate an effective review process, all individuals actively working on the Project need to be up-to-date on the Project activities and direction, and be proactive in resolving format and content deficiencies well before the review is conducted

The PM may elect to establish a threshold for suspense dates on identified discrepancies, such as 90 days. Discrepancies or action items which are anticipated to exceed the threshold for resolution may need review by the Pre-board and/or Board to determine if the discrepancy or action item is valid for the subject review, and if the Project is mature enough to meet the intent of the review milestone.

The process for identifying and resolving discrepancies and action items is always very resource demanding. Project management needs to have budget and personnel allocated for resolution of these items.

D.4 Preparation for Conducting Major Program Technical Reviews

From NPR 7123.1 Appendix Table 3.1.1, Process Activity Matrix, the Technical Assessment Process encompasses the following activities. Assessment of technical work progress and validity prior to entering a review is essential.

D.4.1 Prepare a Strategy

Prepare a strategy for conducting technical assessments to include:

a. Identifying the plans against which progress and achievement of the technical effort are to be assessed

b. Establishing procedures for obtaining cost expenditures against work planned and task completions against schedule

c. Identifying and obtaining technical requirements against which product development progress and achievement will be assessed and establishing the procedures for conducting the assessments

d. Establishing events when TPMs, estimation or measurement techniques, and rules for taking action when out-of-tolerance conditions exist will be assessed

e. Identifying and planning for phase-to-phase technical reviews and WBS model-to-model vertical progress reviews, as well as establishing review entry and success criteria, review board members, and close out procedures

f. Establishing which technical effort work products will undergo peer review, the team members who will perform the peer reviews, and reporting requirements

g. Training team members, support staff, and managers involved in conducting technical assessment activities.

D.4.2 Assess Technical Work Productivity

Assess technical work productivity (progress and achievement against plans) to include:

a. Identifying, collecting, and analyzing process measures (e.g., earned value measurements for measuring progress against planned cost, schedule, resource use, and technical effort tasks) and identifying and reporting cost-effective changes to correct variances;

b. Monitoring stakeholder involvement according to the SEMP

c. Monitoring technical data management against plans

D.4.3 Assess Product Quality

Assess product quality (progress and achievements against technical requirements) to include:

a. Identifying, collecting, and analyzing the degree of technical requirement and TPM satisfaction;

b. Assessing the maturity of the WBS-model products and services as applicable to the product-line life-cycle phases;

c. Determining any variances from expected values of product performance and identifying and defining cost-effective changes to correct variances.

D.4.4 Conduct Technical Reviews

Conduct technical reviews to include:

a. Identifying the type of technical reviews and each review's purpose and objectives (see MPR 7123.1 section 4.3.1 Technical Planning and Appendix C for types, definitions, requirements, and products, and recommended product maturity at Technical Reviews)

b. Determining progress toward satisfying entry criteria

c. Establishing the makeup of the review team

d. Preparing the review presentation materials

e. Identifying and resolving action items resulting from the review.

D.4.5 Capture Work Products

Capture work products from the conduct of technical assessment activities to include:

a. Identifying variances resulting from technical assessments

b. Identifying and reporting changes to correct variances

c. Recording methods used in doing assessment activities

d. Documenting assumptions made in arriving at the process and product measure outcomes

e. Reporting corrective action recommendations

D.4.6. Review Entrance and Exit Criteria

Each of the Technical Reviews defined in 4.3.1 has an entrance criteria and a success criteria associated with them. The criteria are in narrative form and provide a general description to allow adjustments from oneproject to another. The tables provided in Appendix D of MPR 7123.1 assist the Systems Engineers to focus their attention on the specific pieces of information documented in the review documentation.

D.4.7 Obtaining Review Plan Approval.

The project CE, LSE, and/or Governing Technical Authority approves the review plan.

The project’s Configuration Control Board approves the review plan.

The Review Plan is distributed to all Review Committee, Review Team members, team leads, the RID Screening Committee members, the Pre-board members, and the Board members.

D.5 <u>Conducting Major Program Technical Reviews</u>

D.5.1 Review Kickoff Meeting

A kickoff meeting is conducted to present the Review Committee, Review Team, and any other independent reviewers with the review objectives, scope, organization, ground rules and an overview of the system and/or subsystems under review.

Kick off meeting attendance is mandatory for the Review Committee, Review Team, and review team leads.

The PM or designee invites the Chairman of the EMC/SRB to participate if an EMC/SRB is required.

D.5.1.1 *Purpose*

The purpose of the kickoff meeting is to provide the review Committee and Review Teams with an overview of the objectives, scope, ground rules and processes of the review. Examples of items that are covered in the kick off meeting include:

a. Scope, ground rules, and processes of the review

b. Top-level description of the system and subsystems under review

c. Driving requirements, and how they are implemented

d. Constrained Resources: Estimates of mass, power, volume, crew time requirements and other constrained resources, and the basis for estimates

e. Summaries of Technical work flow and life-cycle phase activities, orientation to life-cycle roadmap or integrated schedule describing work efforts included in review

f. Products to be reviewed, such as plans, design descriptions (drawings, models, specifications), block diagrams, signal flow diagrams, schematics, logic flow diagrams, and results of analyses, models and simulations, requirements or program documents, or other as appropriate

g. Risk Constraints: parts selection, de-rating, radiation hardness, identification of single point failures, high risk and life-limiting aspects of the design

D.5.1.2 ***Agenda***

A typical agenda for a design review kickoff:

Introduction/Welcoming Remarks	PM
Safety Procedures (protected areas/evacuation routes, etc.)	
Project Overview	
Review Scope and Objectives	
Review Teams/Responsibilities	
Review Process/Ground rules	
RID Criteria and other Ground rules	
System Overview	Chief Engineer designee
Requirements/Verification Flow	
Design Overview	
Interfaces, Integration and Test	
Issues/Concerns	

Subsystem A Requirements/Verification Design Overview Interfaces Manufacturing, Integration and Test Issues/Concerns	Chief Engineer designee
Other Subsystems as Applicable	Chief Engineer designee
Operations Requirements/Verification Concept/Planning Overview Training Issues/Concerns	Lead Operations Engineer
Safety and Mission Assurance	Chief S&MA Officer (CSO) or designee
Concluding Remarks	PM

D.6 Review Item Discrepancy (RID) Legacy Process

The following process describes the formal RID process as used in the past at MSFC. This process may be used for future projects as it encompasses best practices and proven techniques for eliciting, evaluating, distilling, tracking, and resolving action items and discrepancies in review items identified during formal project reviews. This process documented here provides guidance on how good reviews are conducted, including identifying, tracking, and resolving action items, discrepancies in review items, and dissenting opinions. Programs and projects may tailor this process to their needs.

D.6.1 Overview

Specific technical reviews for each program and project aredefined in the individual Project Plans and/or in the SEMP for each project.

Narrative statements describe the entrance criteria and success criteria for each review.

In addition to entrance criteria, the NASA Lessons Learned Information System is reviewed for any applicable data.

“Best Practices” associated with the required systems engineering processes are reviewed and considered when assessing review items.

The testing organization may have test or operational readiness reviews at any stage of the development and qualification process, which are independent of project requirements. These organizational reviews are primarily focused on the safety of the test or operation. These organizational reviews may be held in conjunction with the project test or operational readiness reviews detailed below, at the discretion of the project manager.

D.6.2 Conducting Reviews and RID Processing

It is common to identify discrepancies between the submitted products and the expectations, validity, or approaches as contained in product content or maturity during a review. There are several different tools for processing review item discrepancies. MPR 7123.1 does not mandate the use of a specific RID tool and process. For guidance on managing action items and discrepancies resulting from review of major milestone review products, the key factors in RID processing are provided here. The Project Review Plan identifies the RID process and any RID tool that may be used for the specific review. The manual guidance for the MSFC RID Processing Tool for this tool is MSFC-MNL-3317, entitled “Review Item Discrepancy (RID) System User’s Guide.”

D.6.2.1 Planning the Reviews

The PM or designee plans the reviews, which includes:

a. Determining the required formal life-cycle reviews to be conducted.

b. Determining the technical reviews to be conducted and how they support the life-cycle reviews.

c. Documenting the planned reviews in the Project plan and/or the SEMP.

d. Tailoring/waiving reviews, if necessary, and obtaining approval from the DGA (for additional information on the MSFC DGA see MPR 7123.1).

e. Documenting a review plan that includes:

    1) Kickoff meeting date/time and location.

2) Objectives, scope, identification of those things that are RID-able, RID acceptance criteria, review entrance criteria, and review success criteria.

3) The RID process that will be used.

4) PreRID/RID submission deadline (to be no sooner than one week after the Kickoff meeting).

5) PreRID/RID screening meeting(s) dates/times and locations.

6) PreRID/RID dispositions at the team level.

7) Preboard meeting date/time and location.

8) Board meeting date/time and location.

9) Define approach to support the life-cycle reviews.

f. Ensuring that the Project uses this MSFC directive for entrance and success criteria associated with life-cycle and technical reviews. The Agency SE Handbook (NASA/SP-2007- 6105), this document, and the Systems Engineering Guide (SEG) Web site (http://seg.msfc.nasa.gov) provide additional guidance for conducting reviews.

g. Ensuring that the review is not scheduled unless there is reasonable assurance the review data package meets the review entrance criteria.

h. The DGA determines if an SRB is needed and notifies the PM or designee to initiate the selection of a Chairperson for the SRB, as appropriate.

i. The PM or designee screens technical standards to determine if the most current versions of the technical standards have identified any safety issues that are to be addressed, whether included in the package directly or as applicable/reference documents. The current version of NASA and many industry standards can be found in the Standards and Technical Assistance Resource Tool (START) at https://standards.nasa.gov.

D.6.2.2 *Appointing a Review Committee*

The PM or designee appoints a review committee:

a. The review committee membership is based on the review objectives, scope, the amount and complexity of the review data.

b. The review committee includes project personnel, S&MA and independent reviewers to ensure a thorough and independent review.

c. Review committee members are functional/technical experts capable of performing a detailed evaluation of the data package.

d. S&MA and the customers are represented on the review committee.

e. The Review Committee assesses the review documentation for compliance with reference documentation, and evaluates for technical accuracy and completeness and appropriate maturity in accordance with review objectives.

f. The review committee identifies and discusses potential issues with developers, and submits documented discrepancies when issues meet the criteria defined in the review plan.

g. The PM or designee organizes the review committee into teams based on functional areas, disciplines, subsystems, organizations or other categories.

h. If the PM or designee organizes the review committee into teams, review team leads are appointed to manage each team's review:

- Team leads are functional/technical team leads or senior level engineers;
- Team leads cannot serve as pre-board or board members.

i. If the review committee is organized into teams, the team leads provide leadership and direction to their review teams to monitor progress, ensure complete and thorough review of the data package, provide guidance, and facilitate discussions between reviewers and document developers.

j. Members of the review committee examine the review data package and document discrepancies.

k. The MSFC RID processing tool or any other tool allows discrepancies to be documented as Preliminary Review Item Discrepancies (Pre-RIDs) and screened prior to going to a pre-board or board.

l. The RID processing tool includes the ability to identify Lessons Learned in a distinct manner separate from other information.

m. Project document developers provide support and clarification to review committee/team members in order to facilitate an effective review.

D.6.2.5 PreRID Screening

The PM or designee may commission the review committee/teams to provide technical evaluations/assessments of PreRIDs prior to PreRID screening:

If a PreRID does not meet the criteria, it is returned to the initiator;

a. the initiator can modify/rewrite and resubmit it;

b. the initiator can withdraw it; or

c. if it is not modified/resubmitted or withdrawn by the initiator, it proceeds to the PreRID screening process where it is classified (editorial/technical), simplified (one discrepancy per form), and/or consolidated (merged/combined with other PreRIDs), as appropriate.

If a PreRID is considered technically acceptable, it proceeds to the PreRID screening process where it is classified (editorial/technical), simplified (one discrepancy per form), and/or consolidated (merged/combined with other PreRIDs), as appropriate.

Screening is a crucial element of a successful review. PreRIDs may be screened by a Screening Committee to ensure that they meet the criteria/ground rules as defined in the Review Plan. An accepted PreRID becomes a RID and is assigned a RID tracking number and is forwarded to the Review Committee/Teams for disposition.

The project CE or designee appoints a Pre-RID screening lead. The PM or designee appoints a screening committee/team to review and make recommendations on criteria compliance in order to assist the screening lead.

The Pre-RID screening lead has the final authority to rule on the compliance of all Pre-RIDs with the review criteria at the screening level meeting.

If the PM does not give the Pre-RID screening lead authority to reject non-compliant Pre-RIDs, it is specifically stated in the review plan.

The Pre-RID screening activities protect Sensitive But Unclassified (SBU) information.

The Pre-RID screening committee lead/teams classify (editorial/technical), simplify (one discrepancy per form), and consolidate (merge/combine with other Pre-RIDs), as appropriate.

The Pre-RID screening committee lead/teams screen the Pre-RIDs and determine if they meet or fail to meet the review criteria.

Pre-RIDs that fail to meet the review criteria are returned to the initiator with the failure rationale provided.

a. the initiator modifies/rewrites the Pre-RID to comply with the criteria/ground rules and resubmits it.

b. the initiator may withdraw the Pre-RID.

c. the initiator may “reclama” the Pre-RID as defined by the project.

Pre-RIDs that meet the criteria are promoted as RIDs to the Pre-board or Board.

D.6.2.6 *RID System Coordinator*

The CE or designee appoints a RID System Coordinator:

a. The RID System Coordinator establishes a system to track Pre-RID/RID generation, submission, screening, disposition, development, and processing from initiation to closure.

b. The RID processing and tracking system protects SBU information.

c. The RID system tracks the following data set for each discrepancy:

1) Project Name.

2) Type of Review.

3) Pre-RID/RID number.

4) Name and contact information for RID initiator.

5) Description of the discrepancy.

6) Review documentation and location containing the discrepancy.

7) Reference documentation and location of specific area being violated (this can include violation of the Review Plan when required data is not available, or upper level applicable documents not included in the data package when issues are discovered that would prevent the project from meeting its upper level requirements).

8) Screening and disposition classifications

9) Team, Pre-board, and/or Board disposition

10) Document developer's suggested corrective action, associated cost, schedule impacts, and other information associated with implementing/resolving RID disposition.

11) Action, actionee and suspense date, if applicable.

12) Record of closure concurrences and dates, closure approval signature and date, and associated evidence of closure.

d. The RID System Coordinator reports the status and disposition of all Pre-RIDs/RIDs as required by the Pre-board and/or Board.

D.6.2.7 *RID Process*

A RID process includes:

a. RID form and processing flow.

b. RID submission and screening criteria/ground rules that determine whether or not a RID is within the scope of the review.

c. A RID describes and includes: discrepancies between the reference documentation and the review documentation; absence of needed information; data package maturity that is not at the appropriate level based upon the review objectives; noncompliance with entrance criteria and success criteria.

d. RID disposition process by which dispositions of the RIDs are developed and approved.

e. RID disposition classifications that characterize the findings of the Review Committee, Review Teams, Pre-board and Board.

D.6.3 Conducting Pre-Board Meetings

D.6.3.1 *Guidelines for a Pre-Board Meeting*

The Project CE or designee chairs the Pr-eboard.

The RID system coordinator presents a summary of the RID status to the Pre-board.

The summary includes a complete list of all RIDs, the recommended dispositions, and associated cost and schedule impacts, if possible.

A total of the cost impacts for all approved RIDs is presented, if possible.

RIDs forwarded to the Pre-board for review and action are presented individually in sufficient detail to facilitate Pre-board disposition and recommendations.

D.6.3.2 *Pre-board Process*

Typically, the Board Chairperson is the PM, but can be some other designee. The CE serves as the Pre-board Chairperson. Board members are typically managers two levels above review team leads and Pre-board members are managers one level above review team leads. If the Review Plan does not stipulate review teams, Board members are managers two levels above review committee members, and Pre-board members are to be comprised of managers one level above review committee members.

The Pre-board:

a. If the Pre-board finds that a RID lacks information, the RID is returned to the appropriate source for additional information.

b. If the Pre-board finds that RID criteria have not been met, the RID is returned to the initiator with rationale provided.

1) the initiator can modify/rewrite and resubmit the RID.

2) the initiator can withdraw the RID.

3) the initiator may “reclama” the discrepancy as defined by the Project.

4) RIDs areevaluated to see if it is within the scope of the Pre-board to implement.

a. The PM or designee establishes thresholds for cost and schedule impacts, which, if exceeded, require RIDs to be forwarded from the Pre-board to the Board for disposition before implementation.

1) Cost thresholds for Pre-board and Board reviews are established by the PM.

2) Schedule thresholds for Pre-board and Board reviews are based upon the schedule reserve available to the PM.

b. The established cost and schedule thresholds are used by the Pre-board to decide if a RID is within the Pre-board scope.

1) If the cost and schedule impact of the RID resolution is within scope, the Pre-board approves the final “FROM/TO” language and promotes it for implementation.

2) If the cost and schedule impact of the RID resolution is not within scope, the RID is forwarded to the Board for disposition.

c. The CE or designee publishes the Pre-board meeting minutes and distributes to the PM, the Pre-board members and the Board members. The minutes include:

1) A list of Pre-board members.

2) A listing and summation of cost and schedule impacts for RIDs that were within the scope of the Pre-Board and forwarded to the PM for concurrence and implementation.

3) A description of RIDs requiring Board review and disposition.

d. A list and status of all open RIDs from previous reviews.

e. A statement to the Board of whether or not the Pre-board considers the entrance and success criteria to have been met, and their recommendation regarding the readiness of the Project with the next stage of development.

f. If the Pre-board finds that the entrance and success criteria have been met, that the Project is ready to proceed to the next stage of development, and that there are no RIDs requiring Board review, then the Pre-board may recommend not having a formal Board meeting. In this case, the Board chairperson has final authority to determine whether or not to convene the Board.

A review data package contains:

a. A list of reference and review documentation, with their maturity levels (preliminary, baseline, etc.) necessary to satisfy the entrance and success criteria for the particular review.

b. Guidance on data package contents for selected reviews may be found in this MPR, NASA SP-2007-6105, MSFC-HDKB-3173, and SEG Web site. If reference documents are not RID-able, that is clearly stated.

c. The review data package is available to the Review Committee/Review Teams no less than one week prior to the kickoff meeting.

The PM or designee appoints the Pre-board and Board members:

a. A majority of the Pre-board and Board consist of institutional and/or functional managers that are not part of the program or project team.

b. Each organization represented on the review committee is represented on the Pre-board and Board.

c. If non-MSFC organizations participate on the review committee, then the PM or designee states in the Review Plan whether or not the non-MSFC Pre-board and Board members hold voting or non-voting positions.

d. The S&MA Directorate and the Engineering TA are represented on the Board and Pre-board in a voting capacity.

e. The Board has final disposition authority for all RIDs.

D.6.4 Conduct Board Meeting

The PM or designee chairsthe Board.

If a Board meeting is required and a Pre-board was held as part of the review process, the CE or designee presents a summary of:

a. the Pre-board minutes.

b. RIDs forwarded by the Pre-board to the Board for review because they exceeded the scope of Pre-board. These RIDs are presented individually in sufficient detail to facilitate Board disposition.

c. RIDs disapproved by the Pre-board that have not been withdrawn by the initiator. The RID initiator attends the meeting in order to defend these RIDs.

d. Open RIDs from previous reviews.

e. RIDs meeting special criteria established in the Review Plan.

The Board:

a. Determines the final disposition for all RIDs. The Board is the final disposition authority for all RIDs and has the authority to change action items or dispositions previously recommended by the review committee, review teams, or the Pre-board. Discrepancies, issues, and problems that are not resolved by the Board may be appealed to a higher level using another process. RID processing ends at the Board level.

b. Reviews open RIDs from previous reviews submitted by the Pre-board, and assigns any actions, if warranted.

c. If the Board finds that a RID lacks information, the RID is returned to the appropriate source for additional information.

d. If the Board finds that the RID does not meet the necessary criteria, the RID is returned to the initiator (with the “failure to meet criteria” rationale):

1) the initiator can modify/rewrite and resubmit it.

2) the initiator can withdraw it.

3) the initiator can change the discrepancy to another format and process it at the SRB, EMC, CMC, or GPMC level

e. If the Board approves the RID, the RID is evaluated to determine if implementation of the RID is within the scope of the Board:

1) If the RID implementation is within the scope of the Board, the PM or designee approves the final “FROM/TO” language and promotes it for implementation. This information becomes part of the published minutes and findings.

2) If the RID implementation is not within the scope of the Board, the PM or designee assigns actions to allow the unresolved discrepancies, issues, and problems to be appealed to a higher level using another process. RID processing ends at the Board level.

3) Formal closure of a RID is complete when RID actionees complete actions to resolve RIDs and provide documented evidence such as revised drawings or other documentation to the RID coordinator. If required by the Review Plan, RID Initiator concurrence is required prior to RID closure. The PM designates, in the Review Plan, any concurrences required for RID closure. The PM reviews and approves final closure of all RIDs. Closure is based upon documented evidence that the RID has been resolved. RIDs are not closed based upon a plan of action for RID resolution.

f. Determines whether the success criteria, as stated in the Review Plan, hasbeen met, and whether to recommend that the Project proceed to the next stage of development.

1) If the success criteria have not been met, or the Project is not ready to proceed, then the Board documents required corrective actions.

g. The Project does not proceed further until the conditions established by the Board have been fulfilled.

h. Publishes Board meeting minutes and distributes to the PM, the Pre-board members and the Board members. The minutes include:

1) RID dispositions at the board level.

2) A listing and summation of cost and schedule impacts associated with the final dispositions for all RIDs.

i. A description of RIDs reviewed by the Board and any associated actions levied by the Board.

j. A list and status of all open RIDs from previous reviews, and any associated actions levied by the Board.

k. A statement of whether or not the success criteria have been met, and a determination of the readiness of the Project to proceed to the next stage of development. If the stated criteria have not been met, or the Project is not ready to proceed, required corrective actions are included in the minutes.

l. If the Board did not convene, the Board Chairperson publishes a list of all RIDs along with their dispositions, cost and schedule impacts, and confirmation that the entrance and success criteria as stated in the Review Plan have been met, and that the Project is ready to proceed to the next stage of development. A suggested Pre-board/Board certification sheet format is included in Appendix D.6.6.

D.6.4.1 *Documentation of Review Results*

The PM documents results of the Review including copies of the Pre-board and Board minutes.

If the Board Chairperson did not issue a positive finding of Project readiness to proceed, a plan for repeating the review or a portion of the review, or other corrective actions assigned by the Board is included. Formal completion of the Review contains positive Board findings, approved dispositions for all RIDs, and documentation of review results.

Review results become a formal record.

As a minimum, review results include the following:

a. Project identifier and type of review.

b. Scope of review.

c. Review team membership.

d. Findings, issues, action items, and closure plans.

e. Recommendation for progression to next design/development stage.

The review schedule is provided and includes:

a. Kickoff meeting date/time and location.

b. Pre-RID/RID submission deadline (to be no sooner than one week after the Kickoff meeting).

c. Pre-RID/RID screening meeting(s) dates/times and locations.

d. RID dispositioning at team level.

e. Pre-board meeting date/time and location.

f. Board meeting date/time and location.

g. Approach to support the life-cycle reviews. (Per NPR 7120.5.)

D.6.6 Template for Pre-board/Board Certification

Project Name – Name of Review – Pre-board or Board Findings - Date

The Pre-board/Board Chair recommends the following:

______ The Project has demonstrated successful completion of the Entry Criteria defined in the Review Plan.

________ The Project has demonstrated successful completion of the Success Criteria defined in the Review Plan and it is recommended that they proceed to the next major milestone.

________ The Project has not demonstrated successful completion of the defined Criteria. In order to address these issues the following actions are required:

List issues and corrective actions required

________ Rationale/Additional data *as needed…*

Pre-board Member Concurrences:

Board Member Concurrences:

Attach list of all RIDs, disposition classifications (or disposition classification recommendations by Pre-board), and cost/schedule impacts.

D.6.7 RID Tracking

Tracking RID closure is a valuable TPM that PMs are encouraged to utilize as part of the regular Project status. This can be done by using the RID suspense dates for the “planned” performance, and obtaining status from the RID coordinator on “actual” closures. RID closure tracking by Work Breakdown Structure (WBS) is an effective means of determining technical areas that require management attention.

D.6.8 Post-Board, Post-Review Presentations of Results

The PM or designee prepares, delivers, and presents the Review Report to the EMC/SRB, if required.

The summary package includes summary of trades, open requirements, Verification and Validation Plan, cost estimates, schedule, margins, and specific ToR defined for the review.

If generated, the EMC/SRB Review Report becomes a formal record.

All EMC/SRB records, reports, and findings protect SBU information.

The PM, CE and Lead S&MA representatives attend the presentation of the Review Report at the EMC/SRB, if held.

D.6.8.1 *CMC Briefing*

The PM, CE, and S&MA provide a status to the CMC on the results of the review and any EMC/SRB recommendations to be carried forward to the Governing Project Management Council (GPMC) prior to the GPMC meeting.

The CMC Briefing becomes a formal record.

The Review Board Chairperson, the EMC/SRB, and the CMC report their findings to the GPMC.

Any EMC/SRB findings that are not agreed to by the PM are discussed at the CMC Briefing.

The GPMC issues their recommendations/direction. Any technical issues that remain open may have to be carried up through the adjudication path for final resolution.

The GPMC Briefing becomes a formal record.

D.7 RID Criteria and Ground Rules

Clear and effective RID criteria and ground rules are crucial to the success of the review.

Each Review Plan clearly defines the RID criteria and ground rules for RIDs for that specific review.

Ambiguous RID criteria results in a large number of RIDs of limited value to the Project.

Not every issue is worked as a RID. For instance, during a design review, new requirements or design changes to improve the product can be incorporated through the engineering change process, rather than through the RID process.

Editorial comments are not technical discrepancies and therefore not RIDs.

RIDs are not accepted against presentation packages because presentations do not constitute official requirements or design documentation that can be updated per a RID action to correct discrepancies.

Specific RID criteria/ground rules related to each review are developed and defined in the review plan.

D.7.1 Technical Requirements Reviews RID criteria and ground rules

Examples of appropriate RID criteria/ground rules for requirements reviews may include:

a. A requirement is not necessary, achievable, verifiable, clear or consistent with Agency policy or higher-level requirements.

b. Incomplete/incorrect flowdown from or traceability to higher-level requirement.

c. Requirements are inconsistent.

d. Missing, incomplete, or unverifiable requirements.

e. Unclear or confusing requirement.

f. Incorrect allocation or unallocated requirement.

g. Lack of sufficient information (sufficient basis for RID only if the initiator and /or Review Committee has exhausted all reasonable means to obtain information, and the requirement for the information is reasonable based on the Project maturity, review scope, objectives and entrance criteria).

h. Project planning is inadequate or incompatible with Project requirements.

i. Planning is not in compliance with upper level requirements.

j. Identifying 'forward work' is out of scope of the review and not a basis for a RID. 'Forward work' is defined as work that is necessary for successful completion of the element but not required to satisfy the success criteria for that specific review or at that phase of the project.

k. The content of the 'forward work' is forwarded to the appropriate Office of Primary Responsibility (OPR) for information.

l. Identifying product improvements or better techniques are not discrepancies and not a basis for a RID.

D.7.2 Design Reviews RID criteria and ground rules

Examples of appropriate RID criteria/ground rules for design reviews may include:

a. A finding that a deficiency exists in meeting requirements.

b. A finding that an incompatibility/discrepancy exists within the design.

c. Addition of or change in requirements is a basis for a RID only if such action is required for the system to meet its overall safety or performance requirements, and only if the requirements documentation is not baselined. Changes to baselined requirements are incorporated through the Engineering Change Process to ensure proper identification and review of effectivity and impacts.

d. Lack of sufficient information (sufficient basis for RID only if the initiator and/or Review Committee has exhausted all reasonable means to obtain information, and the requirement for the information is reasonable based on the Project maturity, review scope, objectives and entrance criteria).

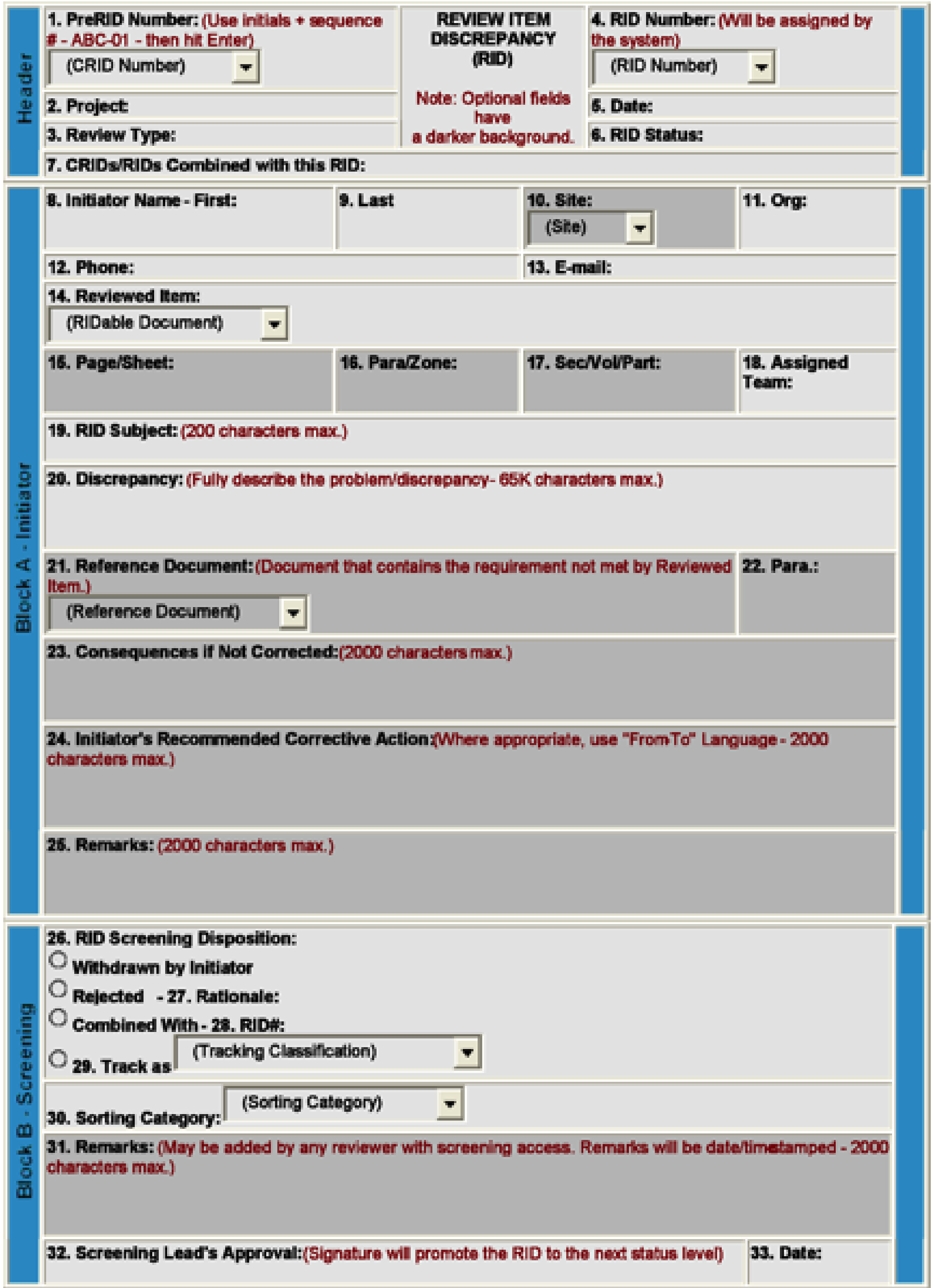
e. Improvements to requirements or design implementation are not discrepancies and not a basis for a RID. Suggestions for improvements are forwarded to the appropriate OPR for information. For baseline requirements or design implementation, suggestions for improvements need to be submitted through the Engineering Change Process. Assigning an official non-RID action item as part of the review, or using the Project action item tracking system to submit an Engineering Change Request (ECR) can accomplish this.

f. The change process provides sufficient review to determine whether or not the change can or needs to be approved.

g. Identifying known ‘forward work’ is out of scope of the review and not a basis for a RID. ‘Forward work’ is defined as work that is necessary for successful completion of the system but not required to satisfy the success criteria for that specific review or at that phase of the project. The content of the ‘forward work’ is forwarded to the appropriate OPR for information.

h. Non-RID action items are formally tracked within a formal action item tracking system. The action item and the closure record and evidence of closure need to be included in the review records. Some Projects may require that the closure data be provided to the non-RID action initiator for concurrence prior to closure. Non-RID action items typically are not presented to the Board or Pre-Board. However, the Board or Pre-Board may require that closure to the actions levied during the Board and/or Pre-board meetings be provided to the Board and Pre-board membership.

D.7.3 Example RID Form



Header

1. PreRID Number: (Use initials + sequence # - ABC-01 - then hit Enter)
(CRID Number)

REVIEW ITEM DISCREPANCY (RID)

Note: Optional fields have a darker background.

4. RID Number: (Will be assigned by the system)
(RID Number)

2. Project:

5. Date:

3. Review Type:

6. RID Status:

7. CRIDs/RIDs Combined with this RID:

Block A - Initiator

8. Initiator Name - First:

9. Last

10. Site:
(Site)

11. Org:

12. Phone:

13. E-mail:

14. Reviewed Item:
(RIDable Document)

15. Page/Sheet:

16. Para/Zone:

17. Sec/Vol/Part:

18. Assigned Team:

19. RID Subject: (200 characters max.)

20. Discrepancy: (Fully describe the problem/discrepancy- 65K characters max.)

21. Reference Document: (Document that contains the requirement not met by Reviewed Item.)
(Reference Document)

22. Para.:

23. Consequences If Not Corrected: (2000 characters max.)

24. Initiator's Recommended Corrective Action: (Where appropriate, use "From-To" Language - 2000 characters max.)

25. Remarks: (2000 characters max.)

Block B - Screening

26. RID Screening Disposition:

- Withdrawn by Initiator
- Rejected - 27. Rationale:
- Combined With - 28. RID#:
- 29. Track as (Tracking Classification)

30. Sorting Category: (Sorting Category)

31. Remarks: (May be added by any reviewer with screening access. Remarks will be date/timestamped - 2000 characters max.)

32. Screening Lead's Approval: (Signature will promote the RID to the next status level)

33. Date:

34. Developer's Recommended Corrective Action: (65K characters max.)

35. Cost Impact ROM:	**36. Schedule Impact ROM:**
37. Other Impact (Specify):	
38. Developer's Approval: (Signature will promote the RID to the next status level)	**39. Date:**

40. Team Recommendation:

Approved	Disapproved
Withdrawn by Initiator	Combined With RID
Approved per Remarks	Recommended Study

42. Present to PreBoard?

Yes No

Disapprove & Recommend Study automatically marked 'Yes'
Withdrawn & Combined automatically marked 'No'
Approved & Approve per Remarks not automatically marked

43. Remarks: (May be added by any reviewer with Team access. Remarks will be date/time-stamped - 2000 characters max.)

Team Level Action Summary (Click Action # to view, update and concur with actions for this RID.)

#	Action	Actionee	Suspense	Recommended/Assigned By	Status

44. Team Lead's Approval: (Signature will promote the RID to the next status level and lock actions from further update)	**45. Date:**

46. PreBoard Recommendation:

Approved	Disapproved
Withdrawn by Initiator	Combined With - RID#:
Approved per Remarks	Recommended Study

48. Present to Board?

Yes No

Disapprove & Recommend Study automatically marked 'Yes'
Withdrawn & Combined automatically marked 'No'
Approved & Approve per Remarks not automatically marked

49. Remarks: (May be added by any reviewer with PreBoard access. Remarks will be date/time-stamped - 2000 characters max.)

PreBoard Level Action Summary (Click Action # to view, update and concur with actions for this RID.)

#	Action	Actionee	Suspense	Recommended/Assigned By	Status

50. PreBoard Chairperson's Approval: (Signature will promote the RID to the next status level and lock actions from further update)	**51. Date:**

52. Board Disposition:

Approved	Disapproved
Withdrawn by Initiator	Combined With - RID#:
Approved per Remarks	Recommended Study

54. Remarks: (May be added by any reviewer with Board access. Remarks will be date/time-stamped - 2000 characters max.)

Board Level Action Summary (Click Action # to view, update and concur with actions for this RID.)

#	Action	Actionee	Suspense	Recommended/Assigned By	Status
#	(Action Description)	(Actionee)	(Suspense Date	(Name of person assigning the Action)	(Action Status)

55. Board Chairperson's Approval: (Signature will promote the RID to the next status level and lock actions from further update)	**56. Date:**

Block G - Implem.

57. RID Implementation Information: (Summarize RID Actions. Where appropriate, use "From-To" language - 65K characters max.)

58. System Engineer's Approval: (Signature will promote the RID to the next status level)	**59. Date:**

60. RID Implementation Concurrence				**61. RID Implementation Closure**	
○ Yes ○ No	**Initiator:**			**Close RID?** ☐ Yes	
○ Yes ○ No	**Reviewer:**			**Proj. Mgr.:**	**Date:**

62. RID Implementation Remarks: (May be added by Implementation reviewers and Approval Authority - 2000 characters max.)

APPENDIX E TECHNICAL ANALYSES AND ASSESSMENT

E.1 Introduction

This appendix addresses the description and practices of assessing technical work for validity, completeness, and alignment with Project technical performance objectives, schedule, budget, and risk constraints. Three levels of technical assessment (TAS) are defined- life-cycle phase transition major milestone key decision point assessment, periodic assessment of technical work through boards, panels, and intermittent peer review, and ongoing technical assessment of evolving work products closely linked with integration of the technical work involved in engineering a system. Technical analyses support the technical assessment activities performed by systems engineers and chief engineers. The different types and levels of analyses have varying levels of importance at the different levels of assessment and review. Guidance is given regarding formal Systems Engineering (SE) metric assessment and analyses, top-level integrated systems engineering technical work and analyses assessment, and technical assessment of engineering analyses supporting integrated product solutions.

E.2 Technical Assessment Overview

E.2.1 Technical Assessment Objective

SE common technical processes enable efficient and effective knowledge work and operational execution of the product-line artifacts that meet stakeholder needs within cost, schedule, risk constraints, and especially performance goals.
Technical Assessment is progress and validation management of the technical work.

E.2.2 Relationships of Technical Assessment With Other SE Engine Processes

The Systems Engineering process of Technical Assessment is closely linked with other SE engine SE processes. Technical Assessment derives activity and schedule structure from plans developed in the Technical Planning process. The Requirements Definition Processes develops Technical Performance Measurements (TPMs) and subsidiary requirements that are used as criteria for assessing the assessed state of the design to the expected completed state and the expected completed state at the specific time of the assessment. Verification and Validation SE Processes develop logical series of measurement activities against which the conceptual and realized systems are assessed for validity, sufficiency, and completeness. The Decision Analysis (DAS) process supports technical assessments at multiple levels. In fact, technical assessment and decision analysis are closely coupled iterative and recursive processes. DAS products may be required deliverables at formal technical reviews.

During the technical planning process, Project management, the lead system engineer, and/or the chief engineer evaluated the program objectives captured in the Program Plan, and specified in the SEMP the major milestone review/key decision points to be conducted, and at what maturity the decisional products need to be at each of the major milestone reviews. TAS activities during major milestone reviews, intermediate peer, board, or panel reviews, and in ongoing evaluation and integration systems engineering is aligned, logical, integrated, necessary, and sufficient to meet expectations of product validity, completeness, and program and resource constraints. The approach for assessing progress on technical work, assessing the validity of the technical work, and delegation of authority and responsibility for directing technical work activities are defined in the SEMP.

Measures or metrics for evaluating product and process fidelity and completeness are specified in the Project Plan, SEMP, and other products of the Technical Planning and System Design processes. Product measures, metrics, logic, and milestones provide essential evidence of product integrity and task completion.

Technical performance measures are derived during Requirements Definition. Formal TPMs become the top-level metrics against which the predicted system performance (from analyses) is compared. The progress of the developing solution relative to the planned system design maturity may help to gage technical work progress, efficiency, effectiveness, and identify trends that might indicate potential cost or schedule impacts. Analyses of parameters associated with measurement of the actual work performed may be conducted periodically or prior to major milestone reviews to summarize project progress. Typically, Program management will monitor the measurement of actual work performed, expected system maturity and cost and schedule as a primary project management responsibility. Technical performance metric assessment by SE's and CE's are focused more on ensuring that the work being performed in developing the system is valid, aligned, and progressing as planned. TAS is closely tied to the complementary SE engine process of Technical Requirements Management (TRM).

Technical Assessment is also closely tied to the Verification, Validation, and Design Solution SE processes. Tasks specified for Design solution activities need to be tracked and monitored at the system level to estimate work progress and efficiency, and to identify trends that might indicate potential technical, schedule, risk, or cost impacts. The project provides risk reports and technical cost and schedule reports that Systems Engineers may utilize in maintaining alignment with technical work activities and project constraints. The logical flow of activities supporting verifying and ensuring the validity of the system being designed and realized evolves from the verification and validation planning activities. V&V plans provide more detailed system performance and design parameters against which the predicted and actual system performance is to be measured. Technical work needs to be integrated and assessed throughout the life-cycle, but especially in the early phases, to ensure the validity of the realized system.

Decision Analysis products provide logical hypotheses, validated evidence, rationale/justification, recommendations and evaluations for potential impacts. The products of Decision Analysis support critical approval decisions accepting the conclusions as valid and directing continuation of work efforts to mature the design. DAS is a very limited set of activities that accepts parameters for a decision, processes the parameters logically, transforming and translating them into a format upon which selection of a solution alternative can be made. DAS products feed into TAS activities, and TAS activities invoke the DAS process as often as needed.

Project Management is responsible for managing the budget, schedule, and satisfaction of predominantly external stakeholders needs, including system performance for the entire project. Project Management control the direction of all work and have ultimate authority for controlling program or project funds. Chief Engineers or Lead Systems Engineers may be delegated responsibility for assessing technical validity, assessing and monitoring progress on technical development, and supporting negotiations regarding cost and schedule alignment with technical/knowledge work progress.

Delegation of responsibility and authority is captured in the Program Plan or SEMP under Designated Governing Authority. It is reiterated here that in general, at MSFC, Chief Engineers and Lead Systems Engineers do not have final authority to direct action on project work or to control budget and schedule-impacting major decisions. The role of Chief Engineers and Lead Systems Engineers is to help plan and guide the knowledge/technical work or operations execution to maintain the alignment of work activities with project objectives and execute technical work guidance in compliance with the project plan and SEMP.

E.2.3 Levels and Types of Technical Assessment

Technical reviews enable project management to determine on a periodic basis how effectively the team is transitioning from stakeholders needs and expectations to requirements, to design, to delivered and operational product, and finally to retired product. Whether reviews are internal, conducted among team members, or external or contractual, with stakeholder participation, they provide a means to observe and communicate technical progress, evaluate the validity of the product and alignment with project objectives, and to obtain approval to proceed to the next level of activity.

Chief Engineers and Lead Systems Engineers are responsible for making lower level decisions that can impact the long-term performance, cost, and schedule. CE/LSEs initiate and conduct the lower level technical reviews to make actionable decisions, primarily to ensure the validity and alignment of the technical effort with the technical objectives. LSEs/CEs may designate these lower level technical reviews as "Boards". LSEs/CEs may be supported by various system level panels and working groups that are charted to assess the validity of technical work within an integrated system discipline, or to evaluate or integrate a discipline's technical analyses across systems. At the lowest level of engineering the system, the LSE or CE may assess, balance, and integrate the product delivery timing, analytical approaches, and performance metric allocations for the different product teams to maintain task progress and meet program objectives.

E.2.4 Top Level "Big SE" Technical Assessment and Meta-Analysis

Lead Systems Engineers generally lead the system architecting activities, including parametric cost model development. Architecture configuration is a primary product of Pre-phase A and Phase A activities. As such, appropriate systems engineering processes, including technical assessment practices are essential to developing a valid, sufficient, performing system that meets stakeholders needs within cost, schedule, and risk constraints.

Top level "Big SE" technical assessment is used to: (1) determine progress of the technical effort against both plans and requirements; (2) review progress during technical reviews; and (3) support control for the engineering of a system. The product and process metrics selected for assessing progress provide information for risk aversion, meaningful financial and non-financial performance, and support of project management.

A common practice for TAS uses metrics produced by an EVM system to track the progress of the processes. Product technical requirements essential to the system being acquired are also tracked. TAS uses metrics to track the progress against the program plans and schedules used to manage the program, while top level "little se" tracks the progress in meeting product-related technical requirements. Technical reviews provide a status of design maturity and requirement satisfaction, identifies risks and issues to be resolved and determines whether the system is ready for the next engineering phase. Cost, schedule and performance variances reflected in the metrics are fed into a risk management system, which produces risk mitigations identified, the effect of which can be observed and adjusted. A program that does not employ a closed loop to feed EVM system variances into the risk management system cannot be effective in making positive changes in the management of the system.

Inputs to the top level TAS include Technical Performance Measurements (TPM), Work Breakdown Structure (WBS), Inputs to Earned Value Management System (EVMS), Program metrics, Process metrics, Integrated Master Schedule (IMS) , SEMP and/or Software Development Plan (SDP), Configuration Management Plan, and Trade-off Analysis Technical Reports.

Tasks to consider include the following:

a. List the appropriate events such as system specification, design reviews, tasks, and process metrics, including capability maturity, for monitoring progress against plans and schedules.

b. Collect and analyze identified process metrics data and results from completion of planned and scheduled tasks and events, which will be used to conduct trend analyses. Assess the program’s schedule performance status by examining data produced by the monitoring and tracking system. Compare the actual or forecast dates and durations to the targeted dates and durations. Collect the number of actual hours worked from the accounting system.

c. Compare process metrics data against plans and schedule using trend analysis to determine technical areas requiring management or team attention. Compare the actual or forecast hours to target hours. Continually identify and manage critical path activities.

d. Determine risk and identify need to correct variances, make changes to plan and schedule, and redirect work because of risk.

Some of the metrics that may be used include Percent EVMS that is not level of effort, accuracy of trend analysis, amount of time between the closing of a reporting period and the reporting of a metric, number of team members that have access to their appropriate metrics, IPT member satisfaction with the metrics. A metric that has recently been added is the Joint Confidence Level (JCL) metric that is a statistically combined measure of the confidence of cost and confidence of schedule compliance.

Tracking discrepancy closures of review items can be a useful TPM that can be utilized as part of the regular Project status. This can be done by using the discrepancy suspense dates for the “planned” performance, and obtaining status from the discrepancy closure coordinator on “actual” closures. Closure tracking by Work Breakdown Structure (WBS) may be used in determining technical areas that require management attention.

Process metrics are identified and used to assess the means of attaining stakeholder satisfaction. Process metrics may include earned value (cost/schedule measure), amount of waste, number of engineering changes, percentage of drawings completed, number of drawing errors, percentage of lines of code completed, rework percentage, idle time (e.g., work in progress), change rate, and turnover in personnel. The criteria for process metric selection are based on how well enhancement in project performance correlates with improvement in potential customer satisfaction.

Some potential outcomes associated with completing these activities provide:
a. An evaluation of the progress toward meeting requirements pertaining to the system being engineered or reengineered;

b. Status information to enable efficient use of resources;

c. Evaluation and tracking of system quality and technology;

d. Faster response time to inquiries from acquirer or other stakeholders;

e. Identification of variances from planned improvements in critical technical parameters as the design evolves;

f. Early identification and resolution of system related problems; and

g. Tracking trade-off analysis and analysis of alternative recommendations, effectiveness analysis results, verification outcomes, and validation results.

Major milestone reviews are a major component of the activity of Big SE Technical Assessment. Major milestone reviews are not intended for problem solving, but but to verify that the problems are being addressed. They are a risk-reduction approach that manages the progress of the technical aspects of a system development or deployment.

Definitions for major milestone reviews, life-cyclelife-cycle timing of reviews, entrance and exit criteria, conducting reviews, and identifying, tracking, and resolution of discrepancies or action items resulting from reviews are captured in MPR 7123.1, appendices to MPR 7123.1, or in this document, or appendices to this document, and will not be reiterated here.

NAS Systems engineering Handbook, Appendix C: Systems Engineering Technical Reviews and Associated Checklists is also a good resource for understanding the expected products and processes of technical reviews.

A checklist of potential questions to answer during major milestone reviews is given in Aerospace Report No. TOR-2005(8617)-4204 by P. G. Cheng of the Aerospace Corporation, El Segundo, CA entitled “100 Questions for a Technical Review”, 30 September 2005. This list was developed for the Air Force Space Command Space and Missile Systems Center.

E.2.5 Top Level “little se” Technical Assessment

Top level “little se” or the traditional functions of leading the engineering of a system include formal and semi-formal technical assessments of the validity and completeness of the technical work. LSE’s and CE’s conduct regular and intermittent review board meetings to assess and direct technical work on the system and subsystem (or element) levels. Some engineering analyses directly support only system level technical assessment, while other engineering analyses are conducted, aggregated, and evaluated in the context of a system issue.

It is essential that the leader of the engineering system design effort have sufficient domain knowledge and system level experience in order to maintain a system perspective while being able to delve deeply into specific analyses that may have significant relevance to the system integrity. LSEs and CEs need to maintain an awareness of higher level requirements, expectations, and schedule/cost/resource constraints and risk postures to appropriately assess technical products. Decisions made by LSEs and CEs in directing technical work approaches are to align with program and project objectives, constraints, and agreements.

Tasks to consider include the following:

a. Identify product metrics, and their expected values, that will affect the quality of the product and provide information of the progress toward satisfying acquirer and other stakeholder requirements, as well as derived requirements. Integrated Product team (IPT) leaders, LSEs, CEs, or functional managers in technical teams identify Key Performance Parameters (KPPs) and Technical Performance Measures (TPMs) to be tracked. TPMs are added or deleted, or parameters adjusted as the program progresses to ensure that an appropriate set of key performance requirements is being monitored (and managed).

b. Collect and analyze product metrics data. This is typically done by the IPT to conduct trend analysis. Examples might include, power, sensitivity, vibration, fuel consumption, weight, balance and software function points. A technical compliance matrix is used to compare actual progress with the requirements baseline (or plan).

c. Chair review boards to assess integrated analyses and system design issues, allocate resources between elements, integrate system and discipline analyses that have system level impacts, ensure the validity and completeness of trade study results and understand, decide and champion trade study conclusions within the scope of authority and purview.

d. Ensure that the rationale for decisions and assumptions made with respect to collected data is recorded correctly.

e. Compare results against requirements to determine degree of technical requirement satisfaction, progress toward maturity of the system (or portion thereof) being engineered, and variations and variances from requirements.

f. Identify deficiencies and discrepancies to specifications and configuration baselines. The process considers revisions to technical approaches, requirements and/or plans in the event that it appears that one or more requirements will not be able to be met as presently defined. It may be necessary to change a technical approach or revise a requirement if the requirements cannot be met.

g. System analyses panels and working groups ensure that analyses assumptions and ground rules are sufficiently explicated and documented, they guide technical analysis processes, integrate technical analysis activities as appropriate, and ensure that the rigor, fidelity, validity, and completeness of analysis are captured in all work products under their purview.

Technology readiness is an important assessment to be made at this level. Verification and Validation plans will be executed and directed at this level, and the results evaluated and validated. It is essential that the logic underlying the verification and validation plans be well understood by the whole team, and that the lead governing technical authority consider the potential risks if a verification or validation process fail to confirm assumptions, expectations, or model predictions. Testing, prototyping, and other subscale tests or analogs need to validate the foundational scientific and engineering approaches to design solution development and formal qualification/certification processes. The true control of technical adequacy and technical work progress hinges on the integrity, domain knowledge, competence, and technical integration skills, both horizontally and vertically, of leaders/DGAs at this level.

Top level “little se” is the level where the review of the technical work and the direction of technical work to progress in concert with the Project plan and SEMP is really controlled. Boards and pre-milestone review preparation at this level is essential to the sufficiently mature a system through key decision points at major milestone reviews.

Integration of technical work and the execution of technical analyses and assessments, done with integrity, competence, and alignment with Project objectives is the key work activity in the realization of a valid system. Pre-milestone reviews of all review products, with integration with all stakeholders prior to milestone reviews greatly increases the liklihood of a truly successful review.

E.2.6 Engineering the system Technical Assessment

Blair, Ryan, Schutzenhofer and Humphries 2001 technical report on the Launch Vehicle Design Process is an excellent resource for describing the subsystem and element level classical engineering of the system technical assessment activities required for daily, ongoing guidance and direction of technical work.

The Naval Systems Engineering Guide provides a good illustration in 33 charts of SE processes in a different context than NASA's, but with basically the same activities and products.

More detailed descriptions of systems, discipline, operations, and program management/project management analyses are contained in the Decision Analysis, Appendix F of this document. The list is not a comprehensive list of analyses conducted at MSFC for the engineering and integration of engineering of systems. Analyses supporting other SE processes from the SE engine are included in the list.

E.3 Commonly Used System Analyses for Engineering at MSFC

For guidance on applying system analyses to system design at MSFC, refer to NASA Technical Paper 3642, Working on the Boundaries: Philosophies and Practices of the Design Process by Robert Ryan, James Blair, John Townsend, and V. Verderaime, July 1996 and NASA/TP-2001-201992, Launch Vehicle Design Process: Characterization, Technical Integration, and Lessons Learned, by James C. Blair, Robert S. Ryan, and Luke A. Schutzenhofer, and W. Randall Humphries, 2001. Other references noted above are applicable.

It is highly recommended that every practitioner of SE and launch vehicle system design at MSFC be familiar with the publications by Blair, Ryan, and Schutzenhofer, et al. The Space Launch and Transportation System (SlaTs) class at MSFC gives an overview of launch vehicle design and is a good starting place for understanding integration of system analyses at MSFC.

There is a wide variety of different types and levels of analyses used in Systems Engineering and the engineering of a system. The list below is a legacy list from an earlier document, and is not comprehensive, but gives a sense of the different types of analyses (not decision analysis methods) that may be used to support a decision analysis process.

E.3.1 System Analyses

System analyses are activities that support both the definition of system requirements and the conduct of system integration. System analysis accepts project objectives and provides system concepts, trade studies, performance analysis, cost analysis, and other analyses necessary to define a preferred system configuration and to assess the performance characteristics of the system as it proceeds through formulation and implementation.

The system analyses activity maintains a close working relationship with the engineering discipline centers of expertise residing in the design organizations. This working relationship is essential for the transfer of practical state-of-the-art knowledge into the systems engineering process, and to ensure validity of analyses performed. System analyses cover a broad spectrum of objectives and products. The following paragraphs synopsize typical system analyses.

E.3.1.1 *System Functional Analyses*

System functional analyses are performed in support of system requirements definition and to assess system capabilities to perform their mission and satisfy project requirements. These analyses analytically confirm design performance in their application. Key analyses common to many projects are described in the following paragraphs.

E.3.1.2 *Functional Decomposition Analyses*

Functional decomposition is performed to determine what the system needs to do from a functional standpoint before development of requirements or design of the system is begun. Functional decomposition begins by defining the top-level functions the system will perform. These functions have a direct influence on the system's design and are described in more detail by taking each top level function and decomposing it to increasingly lower levels until an appropriate level is obtained that defines a functional mission. The functional decomposition represents what an operational system does and the system level of performance.

E.3.1.3 *System Layout and Sizing*

Through coordination with the design organizations, the various subsystem designs are integrated into a total system layout. This system layout is done within allowable system envelopes. These layouts are iterated with the design organization as the subsystem designs mature. This iteration process supports optimization of the designs for sizing to meet maximum allowable envelopes, for providing any required operational envelopes, for providing accessibility for maintenance, and for providing proper interfaces between subsystems.

E.3.1.4 *Trade Studies*

Trade studies are used to compare a number of options. Weighted factors trade studies are performed when each of the options under consideration is well defined and there is good definition of what is important to a specific project. Factors that are important are identified and a weighted factor is assigned to each. A determination is then made as to how well each of the options meets each of the factors. Finally, the weights are taken into account, the scores are totaled and the selection is based on the final score.

Advantages/disadvantages is one type of trade study used when there is not much information about the options under consideration, or it is difficult to quantify how well each option satisfies the criteria selected. In this study, each option is evaluated, identifying the advantages and disadvantages of each. The results are then presented for a subjective decision, based on the information available, as to which option is selected.

E.3.1.5 *System Synthesis*

System synthesis is conducted for all candidate systems to identify the preferred system configuration and feasible performance characteristics. Using knowledge of available technology and feasible subsystems, candidate systems are hypothesized and analytically tested against project requirements. Trade studies are performed to optimize the preferred system configuration and to resolve problems.

E.3.1.6 *System Thermal Analyses*

System thermal analyses are performed to support the definition of system requirements and to determine the capability of the thermal control subsystem to meet the requirements. The system thermal analyses may also provide verification compliance of the thermal control requirements and are utilized to support thermal vacuum testing criteria.

E.3.1.7 *Data Management Analyses*

The data management analyses are performed to assess the Instrumentation Program and Command List (IPCL) database against a mission scenario to determine the real time and data storage requirements. These analyses provide assurance that adequate measurement and command data handling capability exists.

E.3.1.8 *Interface Analyses*

Interface analyses are performed to determine and identify where hardware and/or software elements interact at a common boundary. These analyses identify the physical and functional characteristics that exist at all of the interfaces to facilitate the fit and function compatibility of all hardware and/or software elements. The interface analyses also assesses the system design to ensure the interfaces (internal and external) are compatible with the applicable interface requirements.

E.3.1.9 *Error Budget Analyses*

Error budget analyses are performed to identify sources of error in system performance and attempt to conservatively quantify the effect of each. Statistical or other methods are used to model how individual (subsystem) errors are combined into the total (system) errors. These analyses serve to ensure subsystem requirements and specifications are realistic and compatible with system requirements.

E.3.2 Project Management Analyses

E.3.2.1 *System Safety Analyses*

System safety analyses activities are an integral part of the system analyses efforts. Close coordination between system safety engineering personnel and systems engineering personnel is required to assure timely, effective design solutions that eliminate or properly control hazards. The S&MA and other Center engineering organizations provide supporting technical rationale to aid the Project Manager in the assessment of residual hazards for safety risk acceptance decisions. Key system safety analyses are system hazard analyses and the FMEA/CIL.

E.3.2.2 *Risk Analyses*

Risk analyses are the processes of describing and quantifying the risks that a developing system may encounter and developing alternatives for mitigating or eliminating those risks. Cause, effect, and magnitude of the risk are key outputs of these processes, and these can be documented and tracked through a mitigation plan and a “watch list.” These analyses identify the risks, their consequences, the warning signs or events that will trigger the risk, and risk handling steps. The “watch list” is continually reviewed and revised during the project life-cycle. Risk assessments are conducted continuously to identify the risks to a project due to technology considerations (i.e., new technology, new designs, materials, processes, operating environments), availability of vendors, failure modes, schedule optimism, margin allocation, and requirement stringency. Risk assessments are also necessary to identify any potential risks that arise as a result of design implementation and to incorporate risk mitigation. In the case of technical standards, changes to standards can have major impacts on the safety, performance, reliability, and cost of the Project. Therefore, the Standards Watch List and Alerts Function is in place to mitigate risks by providing notification as requested by the Project when standards products change.

E.3.2.3 *Cost Analyses*

Costs are estimated during the formulation phase of a project. Cost and performance monitoring and tracking is continuous through the implementation phase. The cost estimating activity can be performed with varying degrees of resolution and accuracy depending on the fidelity of the project definition. For example, a cost estimate can be generated using only the estimated weight of the completed system. Other parameters that define the system such as computing requirements, mass storage, and similarity to past projects, etc. can also be used by the cost estimating software. As more information (such as percent new design, performance characteristics, schedules, and better definition of the system) is generated, the cost estimates are refined. Cost analyses are highly iterative processes, and are continuous throughout the project life-cycle.

E.3.2.4 *Performance and Resource Analyses*

Performance and resource analyses support system synthesis, as well as system requirements and system integration functions after the system configuration is baselined. Products of these analyses will include not only performance predictions but also resource budget allocations among system elements. Key analyses are described in the following paragraphs.

E.3.3 Discipline Analyses

E.3.3.1 *Natural Environment Definition Analyses*

Natural environment definition analyses include both space and terrestrial environments. These analyses support the definition of the natural environment requirements for the system. For a particular mission, each natural space environment is defined using specific mission characteristics as inputs to the natural space environment analysis. The natural space environment includes: gravitational field, ionizing radiation, magnetic field, meteoroids/space debris, neutral thermosphere, plasma, solar environment and thermal environment.

The natural terrestrial environment includes near surface, ascent, and descent environmental definitions such as: atmospheric constituents (gasses, sand, dust, sea salt), atmospheric electricity, sea states, severe weather, near-surface thermal radiation, temperature, pressure, density and winds, and wind shear. These analyses require the manipulation of computer model and databases particular to space environment and terrestrial environment. The results of these analyses are documented in a natural space environment definition and requirements document and a natural terrestrial environment definition and requirements document.

E.3.3.2 *Human Engineering Analyses*

Human engineering analyses are performed to define applicable human factor requirements to support the development of system requirements and to assess the capability of the design to satisfy the human factor requirements. These analyses include man-system integration associated with both ground operations and on-orbit operations of the system.

E.3.3.2.1 Life Support and Environmental Control Analyses

Life support and environmental control analyses are performed for manned systems requiring an environment to sustain life. These analyses support the definition of system requirements and assess the system design for meeting the requirements.

E.3.3.2.2 Functional Instrumentation and Command Analyses

Functional instrumentation and command analyses are performed to support the development of the Instrumentation Program and Command List (IPCL) and assess the capability of the system design to provide the defined instrumentation and commands. All telemetry and command data that enter and exit the system are compiled and the resource utilization of communication and telemetry subsystems are determined.

E.3.3.2.3 Electromagnetic Compatibility/Electromagnetic Interference Analyses

Electromagnetic Compatibility (EMC) /Electromagnetic Interference (EMI) analyses are performed to predict system-level performance based on equipment-level EMC test data. Conducted emissions/susceptibilities and turn-on transients are examined and margins are determined.

E.3.3.2.4 Spacecraft Charging Analyses

Spacecraft charging analyses are assessments of a spacecraft's ability to cope with the electrical charge build up resulting from exposure to the ionizing radiation of space. These analyses combine the space environment the spacecraft is predicted to encounter with the materials and protective coating characteristics of the spacecraft, and combined with the conductive paths within the spacecraft. These analyses may result in a choice of different materials or protective coating for the spacecraft.

E.3.3.2.5 Induced Environments Analyses

Induced environments analyses are performed to determine the thermal, pressure, structural loads, vibration, acoustics and shock environments to which the system is exposed during launch, on-orbit operations and landing as applicable. These induced environments analyses support the definition of the system requirements, and provide inputs to establishing induced test criteria.

E.3.3.2.6 Lightning Protection Analyses

Lightning protection analyses are performed to determine the effects on the system electrical circuits if a lightning strike occurs. Both direct and indirect strike effects are examined. These analyses assess the system design to ensure proper lightning protection.

E.3.3.2.7 Contamination Control Analyses

Contamination control analyses are performed to determine and identify contamination sensitive areas that influence the system design, to define contamination control requirements and to assess the system design for providing control to meet the contamination requirements.

E.3.3.2.8 Structural/Coupled Loads Analyses

Structural/coupled loads analyses are performed to examine the loads supported by the structure and the forces applied to the system, especially during phases where there are induced loads.

E.3.3.2.9 Radio Frequency Communication System Analyses

Radio Frequency (RF) Communication System analyses include RF link margin analysis, flux density analysis, coverage analysis, and communication requirements analysis. The link margin analysis supports the system design of a data link and examines the link margin to ensure that the link will maintain signal fidelity and synchronization. The link margin permits the establishment of the feasibility and suitability of a desired communication link before proceeding with design and development. The flux density analysis assesses the Power Flux Density (PFD) generated at the surface of the Earth by the user system to ensure conformance with established limits. The coverage analysis determines the line of sight access times. Communications requirements analysis supports the development of upper level system requirements. This analysis examines the mission and functions the project will perform, the objectives of the project and other support required. Communication needs to support the mission functions and objectives are defined. System communication analyses also support the supplying of RF requirements, and planning information to the NTIA for applying for approval and licensing of the proper RF allocations by the NTIA. (The NTIA requires that projects submit information and applications for licensing in four stages (see 4.1.1.2.). DRD STD/DE-CSAS address the contents of RF Communication System Analyses.

E.3.3.2.10 Attitude Control Analyses

Attitude control is required on any launch vehicle, spacecraft, or experiments that require that stabilization of attitude as part of their mission. Attitude control analyses, associated with the design and assessments of the system**,** require knowledge of and combination of the system’s mass properties, structural dynamics, attitude measuring, system disturbances, and control forces of the system. The effects of local dynamics and/or vibrations are considered in attitude control analyses.

E.3.3.2.11 Dynamic Analyses

System structural dynamics analyses are required for ensuring understanding of the interactions of the system under dynamic conditions. Structural dynamics information is used as an input in attitude analyses as well as determining system integrity under loads. Tether dynamic stability analyses are also performed for projects utilizing tethers.

E.3.3.2.12 Guidance and Navigation Analyses

The normal missions of launch vehicles and spacecraft require that certain orbits be obtained. The ability of a system to be inserted in those orbits requires a navigation system to be aware of where it is with respect to a reference, and what actions the system requires to obtain the desired position. These analyses associated with designing and assessing the ability of a system to successfully achieve guidance and navigation require combining the characteristics of the navigation sensors, the system propulsion characteristics, and the attitude control system.

E.3.3.2.13 Supportability Analyses

Supportability analyses provide an assessment of a system's reliability, availability of components, parts and/or materials that may be required for maintaining the system, maintainability (the ability of the system to be maintained), and logistics requirements and planning. Supportability analyses ensure that sufficient spares (flight hardware and GSE) are available to support a given system throughout the system's operational life. The sparing philosophy results in an optimum mix of Line Replaceable Units (LRUs), shop replaceable units, Orbital Replaceable Units (ORUs) and piece parts.

E.3.3.2.14 Electrical Power Analyses

The electrical power analyses are performed to assess the system electrical power generation, storage, and utilization to determine if adequate power and energy margins exist to support system operations. The electrical power analyses include solar array analysis, voltage drop analysis, fault/fusing analysis and system grounding analysis. In general, normal and worse case subsystem/system interface conditions (voltage, current and power) are used to evaluate the design for proper performance and compatibility. A grounding analysis assures that the grounding configuration of all the elements of the system is consistent with design and performance specifications.

E.3.3.2.15 Mass Properties Analyses

Mass properties analyses are performed on all elements of a flight system to ensure allocated masses are maintained. The total weight of the flight system as specified in the project requirements is allocated to lower management level subsystems and piece parts with a reserve maintained. The mass properties analyses are repetitive activities that occur throughout formulation and implementation. The allocated weights and reserve are used to begin the mass properties process. As subsystems and piece parts are developed and fabricated, actual weights are included in the analyses to refine the results. Maintaining a comprehensive mass properties database allows the Project Manager and SLE to revise allocations as subsystems and piece part designs mature.

The mass properties analyses continue until the flight system is developed and a measure of total mass is performed.

E.3.3.2.16 Data Handling and Software Systems Analyses

Data Handling and Software System Analysis investigates hardware and software measurement, command, and control requirements for data management system resources and provides visibility of resource consumption and margins. Analysis includes data busses, memory, central processing units (CPU) loading, configurable logic device utilization, multiplexers, and error rate assessments. Continuous assessment of resource margins and performance is performed to ensure that adequate resources are available throughout the implementation phase to allow for growth and implementation of Data Handling and Software Systems that may be required as a result of testing. DRD STD/DE-DHSA addresses the contents of a Data Handling and Software System Analysis and NPR 7120.5 requires establishment of computer hardware resource and utilization requirements, and Software Metric Report generation for specified software classifications.

E.3.3.2.17 Attitude Control Propellant/Momentum Analyses

Attitude control propellant and/or momentum utilization analyses are conducted to ensure that the available, or budgeted, attitude control propellant or control moment gyro momentum is adequate to perform the mission of the system. Analysis integrates the mission operations attitude requirements with other factors that may require propellant usage (misalignments, contingencies, mission ground rules) to determine the adequacy of the system performance.

E.3.3.2.18 Pointing and Alignment Error Analyses

The pointing and alignment error analyses are performed to identify sources for error in the system performance and attempts to conservatively quantify the effects of each. Statistical or other methods are used to model how individual (subsystem) errors are combined into total (system) errors.

E.3.3.2.19 Propulsion System Performance Analyses

Propulsion system performance analyses are the assessments required to ensure that the operation of the propulsion system is adequate in terms of efficiency (thrust and specific impulse) and quality and quantity of propellant. The analyses combine the engines/thruster characteristics with the volume, temperature, and pressure of the propellants to predict mission performance. Propellant allowances for flight dispersions, loading uncertainties, and any other contingencies are also estimated and analyzed. Post flight analyses are also performed to compare predictions with flight data, and to account for any differences.

E.3.3.2.20 Orbital and Flight Mechanics Analyses

Orbital and flight mechanics analyses are performed for mission planning purposes. These analyses not only define the orbit parameters required to perform the desired mission, but are also used to predict orbital lifetimes. These analyses also support mission timelines and define orbit pointing and attitude control requirements. Thermal analyses also utilize the results of orbital attitude analyses for generating sun angles, eclipses, and exposure times.

E.3.3.2.21 Materials Analyses

Materials analyses are performed to provide support in the areas of materials selection for the system (including ensuring non-toxic material use for manned systems) and contamination avoidance. The materials analyses also include assessments of the system design to ensure the use of approved materials.

E.3.3.2.22 Orbital Debris Analyses

For flight systems that have the potential to create orbital debris, orbital debris analyses are developed in accordance with the requirements of NPD 8710.3, *NASA Policy for Limiting Orbital Debris Generation.*

E.3.3.2.23 Digital Signal Integrity Analysis

For successful operation of components across all operating and environmental conditions and for the anticipated lifetime of the hardware, establishing and maintaining design margins of internal digital signals is crucial. It is especially critical when upgrading heritage components to accommodate newer hardware and when mixed logic device families within a design are being used. Digital Signal Analysis assures noise margins for the logic thresholds of each device are identified and maintained, and that differences in grounding references are considered. Digital Signal Analysis determines signal criticality, establishes noise margins through simulation and modeling, provides assurance that correct noise margins have been established through analytical methods and tests, and establishes risk mitigation for signals that do not meet pre-defined margin criteria.

E.3.3.2.24 Mission Analyses and Operations

E.3.3.2.24.1 Mission Analyses

Mission analyses are the systems engineering disciplines that develop, analyze and document mission requirements leading to the definition of the most effective and efficient methods of satisfying mission objectives. Mission analyses may be defined as the process of translating the high level project requirements (Level I and II) into a carefully analyzed, detailed mission profile. The activities required to perform mission analyses are divided into three separate analyses as discussed in the following paragraphs:

a. Mission Requirements Analyses are the orderly transformation of mission objectives into detailed mission requirements. This effort includes the identification, interaction, and documentation of overall mission objectives, the breakdown of objectives into detailed mission requirements, the analyses of those requirements, and finally, the development of finely detailed mission requirements and their allocation to individual mission operation system elements. These steps are summarized as follows:

1) Delineate the overall mission objectives.

2) Translate mission objectives into requirements.

3) Analyze and expound mission requirements.

4) Allocate the mission requirements and input to the overall requirement allocation process.

b. Mission Planning and Profile Generation Analyses are the activities accomplished to analyze mission objectives, define system capabilities, and generate a mission profile that maximizes the achievement of mission objectives within hardware, software and mission constraints. Detailed mission requirements provide an input to this activity. The output of this process will be a preliminary mission profile or a detailed DRM. The processes for mission planning and profile generation analyses are as follows:

1) Perform mission/system assessment
    (a) Trade studies – Mission objectives vs. system capabilities
    (b) Define target conditions, data return, and other parameters

2) Conduct preliminary hardware/software assessment
    (a) Launch vehicle size/weight
    (b) Propulsion, guidance, and navigation subsystems

3) Develop trajectory design
   (a) Trajectory analyses
   (b) Guidance, navigation, and maneuver analyses
   (c) Optimization analyses
   (d) Range safety and reentry impact analyses
   (e) Tracking/telemetry coverage study
   (f) Performance capability analyses

4) Generate mission profile and input to the system design processes and the flight operations processes.
   (a) Mission timeline design
   (b) Launch window
   (c) Trajectory event profile
   (d) Ground track generation

The mission of the end item system under study is more clearly defined during project formulation, but still not baselined. The purpose of defining the mission more clearly is to develop performance targets for the design team. Baselining does not occur at this point because there may still be multiple concepts under consideration. Once a single concept is selected, during late formulation and early implementation, the mission will be baselined.

c. Mission Performance Analyses assess the capabilities of the system design to satisfy mission requirements. These analyses define and prioritize specific mission performance parameters and perform feasibility trade studies to determine and evaluate performance versus cost and risk. The scope of this activity can range from straightforward parametric studies to sophisticated system simulation models. The steps in this process are described below:

1) Interpret mission requirements into a set of measurable performance parameters,

2) Identify system design features that affect mission performance,
3) Assess mission performance of system design,

4) Determine sensitivities of mission performance parameters to selected system design parameters and operational constraints,

5) Iterate, process, and provide feedback as design and operations concepts evolve.

E.3.3.2.24.2 Mission Operations

Mission operations activities permeate system organizational boundaries. The results of mission operations trade studies and analysis can have a significant impact upon system hardware and software design. Throughout the system developmental process, from pre-proposal studies through final delivery, mission operations is directly involved in system design, development and decision-making activities. This involvement is critically important during the early phases of system development when the basic structure of the system is being defined and the initial system documentation is drafted. Even though actual system operations may be years in the future, the operational concept is established as early as possible to ensure that system development is based upon valid and comprehensive operations scenarios. This operations concept is maintained as a living document to grow and mature as the total project follows its development course.

The systems engineering contribution to mission operations during the flight covers the following tasks:

a. Providing flight hardware system expertise.

b. Monitoring the health of the hardware and software.

c. Monitoring the engineering performance of the system.

d. Performing the ground analysis/calibration for subsequent uplink.

e. Responding to anomalies that affect system performance.

f. Coordinate software patches for anomaly correction.

g. Providing status information to/from the science operations leads and management as appropriate.

h. Generation of the Flight Data Files (FDFs)

E.3.3.2.24.2.1 *Design Reference Mission*

During the late formulation and early implementation phase, the study team assembles numerous DRMs. The project office chooses the DRMs that have the greatest impact upon the design and performance specifications of the flight article. The DRMs are realistic missions (i.e., not three-sigma excursions). They are determined by cognizant authority (project management) in concert with the user community, usually through a Preliminary Requirements Specification Document (PRSD). These DRMs allow the designers to satisfy the mission objectives with the concepts under active consideration. The shortcomings of the individual concepts are identified and reevaluation takes place. The concepts have to be augmented to satisfy the objectives, or the objectives re-scoped, changed, or eliminated completely. The DRMs are also used to place bounds on the anticipated mission drivers for each subsystem.

Early in a project, specific missions may not be finalized. To allow the design process to proceed, a series of DRMs will bound the various performance requirements. As the project matures and specific missions are baselined, the DRMs are phased out, and FDFs are eventually generated to define the final mission.

E.3.3.2.24.2.2 *Operations Planning*

Operations planning is a critical function that defines the functional requirements for operations, defines and baselines the interfaces between operations facilities and the flight system, and defines the resource and schedule required to prepare and execute the operations. Operations planning is conducted as a joint activity between the organizational elements of the project responsible for systems engineering and for operations implementation (preparation and execution), with final approval by the Project Manager. The specific analysis tasks and products required will be project-dependent, as will the division of responsibilities for producing those products. The following types of products will be generated:

a. Operations Functional Requirements

b. Mission Operations Facility Requirements

c. Interface Definition

d. Project Operations Plan

e. Engineering Support Plans

f. NSTS and ISS Required Integration Documentation

g. Mission Timeline

h. Operations Concepts

i. Operations Sequence Diagrams

j. Software specification requirements for Flight Operations and Ground Control

k. Training Assessments/Training Plans

l. Mockup Definition

m. Human Factors Analysis

n. Mission Flight Rules

o. Crew Procedures

p. Crew Training Materials

q. Crew Aids Definition (for manned flight programs)

r. Ground Support Staff Definition and Requirements

s. Ground Operator Workstation Definition

t. Launch Commit Criteria

E.3.3.2.24.3 Ground Operations

Ground operations planning begins in the mid formulation phase to define the functional requirements for GSE and ground operations activities, to define and document the GSE to flight interfaces, to define and document handling and transportation requirements, and to define the support requirements for pre-launch and launch operations, including servicing and maintenance. If the flight system is to be returned to Earth in a controlled manner after flight, ground operations planning includes assessment and definition of the inverse process for flight system de-integration and handling and transporting to a designated site.

Ground operations planning and analyses continue into the implementation phase with some activities being performed late into the implementation phase. The interfaces between GSE systems and GSE and the flight system are defined and documented. The interface requirements are defined. Physical integration analyses of the interfaces and assessments of interface requirements are performed to ensure the compatibility of all the ground interfaces and compliance to the interface requirements. Assessments of launch site and launch vehicle (for payload launch) requirements are performed to ensure that ground operations and the flight system are in compliance. Responsible personnel on each side of the interface are to be knowledgeable of the interface requirements and definitions to ensure compatibility.

Flow diagrams are developed as an integral part of the ground operations systems engineering. The ground operations flow diagram is a visual representation of the process of a project and shows the relationship between ground operations activities and project milestones and relates the schedule of support and engineering teams to the project. Ground processing analyses are performed to validate the ground processing flow. Ground operations, servicing, and launch site support requirements are defined and documented. Accessibility for performing all integration and ground operation activities is verified.

The elements of ground operations are a mixture of the varied skills, facilities, equipment, and other capabilities necessary to physically transport, functionally integrate, test, and service the flight subsystems/system. Certification of both supporting personnel and applicable support equipment is required to perform many of the activities associated with handling and transportation of flight hardware. MPR 6410.1, *Handling, Storage, Packaging, Preservation, and Delivery*, MWI 6410.1, *Packaging, Handling, and Moving Program Critical Hardware*, and MWI 6430.1, *Lifting Equipment and Operations*, are management guidelines and instructions that apply to project ground operations. The specific ground operation elements applicable to a project are a function of the ground processing flow for that project. The ground operations processing flow for a flight system is dependent upon characteristics of that system.

E.4 Reference Documents

Cheng, P. G., “100 Questions for a Technical Review”, Aerospace Report No. TOR-2005(8617)-4204, The Aerospace Corporation, El Segundo, CA30 September 2005

Naval Systems Engineering Guide, October 2004
[*Excellent source of clear SE processes (in Navy terminology); esp. process charts in Appendix E (33 charts*)]

National Airspace System (NAS) Systems engineering Manual, Version 3.1, 6 June 2006, see Appendix C: SE Technical Reviews and Associated Checklists; and Appendix E: Integrated Technical Planning Details, 25 August 2006 [pgs. E-3 through E-5 list example metrics for TAS]

Blair, James C., Robert S. Ryan, Luke A. Schutzenhofer, and W. Randall Humphries, Launch Vehicle Design Process: Characterizatin, Technical Integration, and Lessons Learned, NASA/TP-2001-210992, May 2001
[*Excellent resource for understanding technical assessment and the intricacies of technical integration and systems engineering in launch vehicle design*]

Air Force Handbook AFI 63-1201, 23 July 2007

INCOSE Metrics Guidebook for Integrated Systems and Product Development, http://www.incose.org/ProductsPubs/products/measurementprimer.aspx, accessed 29 February 2012

INCOSE Technical Measurement Guide, 27 July 2005, Primary Authors: Gary Roedler and Cheryl Jones, http://www.incose.org/ProductsPubs/products/techmeasurementguide.aspx, accessed 29 February 2012

INCOSE Leading Indicators Guide, http://www.incose.org/ProductsPubs/products/seleadingIndicators.aspx, accessed 29 February 2012

Peresztegy, L. B. (Sam), and Charles E. Connor, Technical Reviews and Audits for Systems, Equipment, and Computer Software, Aerospace Corporation Report No. TOR-2007 (8583)-6414, Vol. 1, Rev. 1, 30 January 2009

Sauser, Brian J., Jose E. Ramirez-Marquez, Devanandham Henry, and Donald Di marzio, “A System Maturity Index for the Systems Engineering Life-cycle”, International Journal of Industrial and Systems Engineering, Vol. 13, No. 6, 2008
[ways to measure system technological maturing during the life-cycle using TRL+ Integration Readiness Level (IRL)= System Readiness Level (SRL)]

APPENDIX F DECISION ANALYSIS METHODS

F.1 Introduction

This appendix addresses the definition, approaches, and descriptions of practices and methods for conducting decision analysis. This Appendix further explicates concepts captured in the body of this document, as well as provides additional methods, references, and information regarding Decision Analysis.

Decision analysis is NOT decision making. Decision Analysis supports decision making but is not a prescription for how decision making is done and does not mandate that any recommended or considered course of action be chosen. Decision analysis does not describe how all decisions are made. The decision analysis process starts after a decision problem is sufficiently defined such that the issue and goal of performing the analysis guides the selection and use of appropriate methods or tools. Decision Analysis is a Systems Engineering Process. DAS supports decision-making; it is not be confused with the entire process of making decisions.

Decision analysis includes procedures, methods, and tools that can be documented that support

a. Understanding of the decision problem

b. Organizing information suggesting solutions to the decision problem

c. Translating technical information into formats and terminology to orient and inform the technical team and decision maker

d. Computing through logical methods (models, simulations, procedures, logic, or other algorithm) to translate organized information into technical or managerial terms that can be interpreted within the context of whole decision space

e. Prioritizing, recommending, and justifying attractive solutions (may be more than one) with appropriate rationale, and

f. Sensitivity analysis to illustrate how variation of key variables may impact the attractiveness of specific solutions.

The goal of decision analysis is to provide formal, logical, and explicit information to decision makers to increase the likelihood that the decision made will be valid and that the uncertainty inherent in all decision making is understood as much as possible. Appropriately applied DA procedures can reduce uncertainty and improve prediction by structuring thought and shared mental models. "Decision analysis is used for identifying, representing, and formally assessing prioritized aspects of a decision, prescribing a recommended course of action by applying *[decision theory]* to a well-formed representation of the decision, and for translating the formal representation of a decision and its corresponding recommendation into insight for the decision maker and other stakeholders."[1]

Decision analysis starts after a decision problem and general parameters influencing the potential solution space have been have been identified. Once the decision problem and general parameters have been defined, an appropriate decision analysis method or methods (can be more than one) may be chosen that are likely to produce a recommendation meaningful to the decision maker.

F.2 <u>Reference Documents</u>

Blair, James C., Robert S. Ryan, Luke A. Schutzenhofer, and W. Randall Humphries, Launch Vehicle Design Process: Characterization, Technical Integration, and Lessons Learned, NASA/TP-2001-210992, Marshall Space Flight Center, AL, May 2001

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Kepner, Charles H., and Benjamin B. Tregoe, The New Rational Manager, Princeton Research Press, NJ, 1981

[1] "Decision analysis", wikipedia, http://en.wikipedia.org/wiki/Decision_analysis, accessed 27 February 2012

Thomas, Lawrence Dale, A methodology for commonality analysis, with applications to selected space station systems, Doctoral Dissertation, University of Alabama in Huntsville, 1988

Ryan, Robert, James Blair, John Townsend, and V. Verderaime, NASA Technical Paper 3642, Working on the Boundaries: Philosophies and Practices of the Design Process, July 1996

ANSI/AIAA G-020-1992. Estimating and Budgeting Weight and Power Contingencies for Spacecraft Systems

ISO/IEC 15288-2008, Systems and software engineering-System life-cycle processes, Section 6.3.3.3

Systems Engineering Process Activities, a “How-to” Guide; International Council on Systems Engineering (INCOSE)

Other references as listed in the body of MSFC-HDBK-3173

F.3 Decision Analysis Benefits and Risks

Decision analysis tools, procedures, and methods can provide the decision maker and other stakeholders with insight into a decision problem- definition of the structure of the problem, priorities of the stakeholders, constraints and options, and requisite information. Selection of the scope and fidelity of a Decision Analysis process to support the maturation of a problem solution require an understanding of the nature of the problem and the constraints on the solution space. The decision to engage a formal DAS process balances the need for valid, understandable, and sufficiently detailed logic against the time and resource demanded for developing and communicating the decision analysis product. Aspects of the decision problem include comprehending the problem, hypothesizing potential courses of action, assessing resource and agreement enablers and constraints, and estimating of the uncertainties in both the supporting data and the likelihood of the potential outcomes.

Planning the technical work of engineering a system requires domain knowledge to predict the decisions that require formal in-depth decision analysis, and other decisions that may utilize portions of a decision analysis procedure. Engineering judgement is often used in place of, or in sequence with, formal decision analysis activities.

The risk of shortcutting decision analysis is that the decision made may overlook important factors or conditions that compromise the efficacy of the course of action selected. Shortcutting also increases the likelihood that similar decisions, following the precedent set by the first decision, may lead long run to failure of the system. The risk of over-reliance on or over-prescription of formal decision analysis procedures and documentation is that decision makers may experience “paralysis by analysis”. More information does not necessarily make for better decisions. Also, the analysis package may become more important than the decision that is to be made.

F.4 Decision Making Approaches

Decision Analysis is tightly coupled with other SE processes. The initiation of a formal, documented decision analysis activity is specified for high consequence, architecture-defining decisions in the SEMP during the Technical Planning process. Other decision analysis activities may be defined in the SEMP for critical, resource constrained or technically constrained decision points. Decision making controls the pace and validity of the developing system. All decision making, whether supported by formal decision analysis procedures or tools, or by engineering judgment and design practice contributes to the performance, cost, and schedule of the final product.

Some argue that all decision-making is making trades between alternatives. Much of SE literature describes trades as the linch pin process for organizing and coalescing the myriad of inputs into a system configuration that is realized. The concept of “trades” mirrors the human mind activity of assessing the likelihood of success of various courses of action on meeting some preferred end state. The engineering of a system largely consists of adopting a set of system component structures and relationships) that will likely validly meet the expected behavior. Since the human mind can only hold a finite number of objects and their relationships in mind, the aggregation and prioritization processes of trade studies is reflective of how the human mind works.

Within the Trade Studies concept, there are various methods for organizing and representing data. Some of those methods are discussed here. Other methods that are similar to trade studies, but for specific objectives follow the discussion of trade studies.

In MPR 7123.1, decision analysis (DA) is narrowly defined predominantly as trade studies or cost analysis. The significance of the concept of trade studies is evident in most literature on systems engineering. Conducting well formulated and executed trade studies is an essential activity, but it is not the only method or procedure used in design decision making. Time constraints combined with high consequence impacts may make approaches that superceed rigorous or formal (or documented) decision making processes enticing. Be aware of the risks of short cutting rigor in decision making. Conversely, studies have shown that more information does not always lead to a better decision, or the ability to decide with more certainty. Knowing when enough information and analysis has been obtained is a judgment skill that can be developed.

The objective of planning the decision approach is so that a requisite decision model is developed and documentable. A REQUISITE DECISION MODEL does not require you to agree with the result of the model, just that you understand the process and can select an alternative. A requisite decision model answers the question: At what point do we decide that a decision model is adequate so that further refinements and revisions are not worth carrying out? A model is considered to be REQUISITE when it provides the decision maker with enough guidance and insight to decide upon a course of action.

A requisite decision model uses the sense of unease among the problem owners about the results as a signal that further modeling may be needed or that intuition is wrong. The model can be considered to be requisite when no new intuitions emerge about the problem. The model is not an exact replication of the mind of the decision maker; it is just good enough framework.

An intentional approach to applying decision analysis techniques, tools, procedures by anticipating the types and significance of decisions during Technical Planning aids in the execution of daily decision making activities, and prepares the decision maker for the types of challenges he or she may encounter.

F.4.1 Multicriteria Decision Analysis (MCDA)

The Trade Study decision analysis process shown in a plethora of systems engineering and design engineering sources is essentially the form of Multi-Criteria Decision Analysis (MCDA). Variations on the specific steps are captured in other MCDA models, such as SMART and SMARTER (Edwards), or SIMILAR (Bahill and Dean; Daniels, Werner, and Bahill). Refined techniques such as the Kepner-Tregoe decision analysis process provide some additional confidence in the validity of the resulting comparative attractiveness of the options evaluated.

Trade studies address selection of a specific alternative given a short list of alternatives and defined criteria. Formal trade studies often result from an exploratory effort to formulate alternative solution options, which include long series of investigation, evaluation, and decision making. Formal trade studies assume a static decision environment and solution space. Formal trade studies and cost-benefit analyses are not the only types of decision analysis activities conducted by System Engineers doing

SE processes. Some other types of decision analysis are listed in the body of this document, but the list is not comprehensive.

F.4.1.1 *General Form of Decision Analysis Process and Trade Studies*

From Table 3.1 in NPR 7123.1, the Process Traceability Matrix includes the following expected process activities. The Process Traceabliity Matrix is essentially the format for prescribed methods for trade studies with the addition of precursory work in establishing guidelines on determining which technical issues require formal trade studies. Establishing guidelines and defining which technical issues require formal decision analysis is a function of the Technical Planning process. Virtually all other SE processes may invoke the initiation of a Decision Analysis process, with the architecting processes of System Design and the Technical Planning and Technical Assessment processes most frequently requesting a formal DA process activity.

All formal DA process iterationsinclude the following steps to prepare, execute, report, and document the decision analysis.

a. Establish guidelines to determine which technical issues are subject to a formal analysis/evaluation process to include:

(1) **when to use a formal decision-making procedure,**
for example, as a result of
an effectiveness assessment
a technical tradeoff
a problem needing to be solved
response to a risk exceeding the acceptable threshold
verification failure
validation failure
make-buy choice
evaluating a solution alternative
resolving a requirements conflict

(2) **what needs to be documented**;

(3) **who will be the decision makers**, including their responsibilities and decision authorities

(4) **how decisions will be handled that do not require a formal evaluation procedure**.

b. Define the criteria for evaluating alternative solutions to include:

(1) some of the types of criteria to consider include the following:
technology limitations
environmental impact
safety
risks
total ownership and
life-cycle costs impact
life-cycle schedule impact
capabilties (“ilities”, for example, affordability, reliability, robustness)
others as identified and relevant

(2) the acceptable range and scale of the criteria

(3) Priority: the rank of each criterion by its importance (may be approximated)

c. Identify alternative solutions to address decision issues to include alternatives for consideration in addition to those that may be provided with the issue

d. Select evaluation Methods, Procedures, Tools, and Techniques and documentation processes
based on the purpose for analyzing a decision
and on the availability of the information used to support the
method
procedure
technique
tool
documentation process

e. Evaluate alternative solutions with the established criteria using the selected methods, etc. to include:

(1) evaluation of <u>assumptions</u> related to evaluation criteria

(2) evaluation of *the <u>validity</u>, <u>sufficiency,</u> and <u>completeness</u> of* the evidence that supports the assumptions, logical representations, analytical methods, and conclusions

(3) evaluation of whether <u>uncertainty</u> in the values for alternative solutions affects the evaluation

(4) evaluation of potential combinations of all or parts of evaluated alternatives or multiple path courses of actions to mitigate risks,

(5) evaluation of the probablity of meeting the goals and objectives given each course of action/solution/alternative

f. Select recommended solutions from the alternatives based on the evaluation criteria to include
documenting the information that justifies the recommendations
documenting the predicted impacts of taking the recommended course of action

g. Report the analysis and evaluation results or findings, including the recommendations, impacts, and corrective actions

h. Capture work products from decision analysis activities to include:
(1) decision analysis guidelines generated

(2) *explanation of the flow of logical principles and conditions that justify the analysis or evaluation approach and the expected and resulting conclusions (logic flow diagram)*

(3) strategy and procedures used

(4) analysis or evaluation approach, including:
criteria methods, *procedures,* tools and *techniques* used

(5) analysis or evaluation results *prioritized or significant findings that inform engineering judgment translated or formatted for contextualized engineering and management decision making (data compiled and associated with the level and nature of engineering and management decision authority)*

(6) assumptions made in arriving at recommendations, uncertainties, sensitivities of the recommended actions (sensitivity analysis), and corrective actions

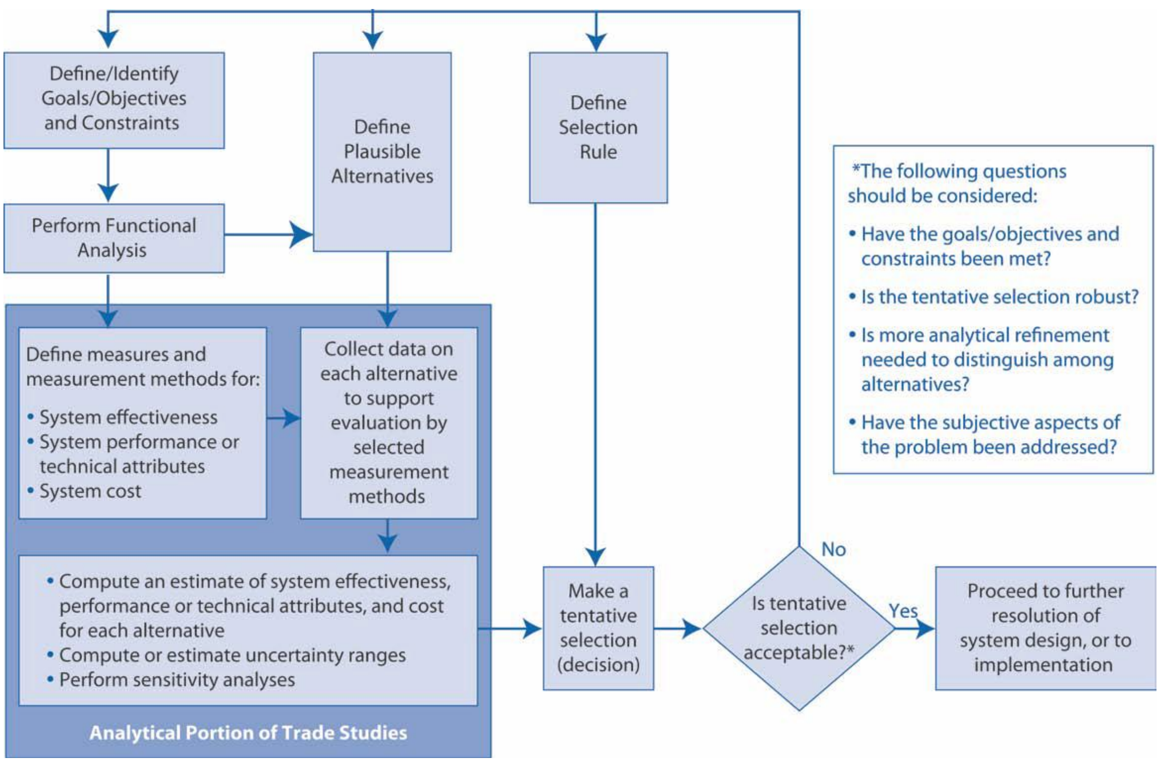
(7) lessons learned - recommendations for improving future decision analyses

<u>Trade Studies</u>

The purpose of a trade study is to provide an objective foundation for the selection of one or more approaches for the solution of an engineering problem. There are multiple ways to accomplish a trade study, but all trade studies have common characteristics:

1. Minimum requirements that have to be achieved by definition
2. Visible alternatives that satisfy requirements
3. Selection criteria such as cost, schedule, technical
4. Metrics for evaluating alternatives
5. Weighting factors for each criteria
6. Ranking/scoring process

A general trade study process is shown in the figure below.



Thomas (2001) provides some guidelines for conducting trade studies.[2] When defining the trade objectives, go/no go criteria is identified. The objectives address the "must haves" instead of the "wants". When determining alternatives, there are two or more distinct options that have comparable maturity and definition. Generally there will be 4 to 7 alternatives. Defining the evaluation criteria and weights will depend on characteristics that are key to the customer. They usually fall under the categories of cost, schedule and technical, although some practitioners lump cost into schedule or schedule into cost since delays in schedules usually increase costs.

NASA recently prescribed a stochastic combination of cost and schedule into a Joint Confidence L, a measurement of the joint probability of achieving the stated cost on the stated schedule. This information can be used to estimate the likelihood of success on cost and schedule factors. Other factors, such as long term viability of vendors or material sources, or life-cycle sustainabilty or affordability may also be identifed as criteria. If identifying stakeholders needs has been sufficiently done, identifying criteria and weights will be easier.

Identifying weights can be a difficult task. Some alternative methods are shown in the following sections. Sensitivity analysis is performed to illustrate how the decision recommendation might change if the actual preferred weighting or grading varies from those assumed in the analysis.

Metrics are collected to grade the alternatives. Metrics can be quantitative measures or engineering judgment. Some metrics may also be qualitative, and it is important to state how qualitative measures will be normalized. There may be some indirect measurements such as parts counts, number of interfaces, or processing hours that reflect criteria that may not be directly quantifiable.

A trade tree is a useful tool for depicting the trade space, including "trades within trades". A Trade Tree example for the International Space Station PM Study is shown below.

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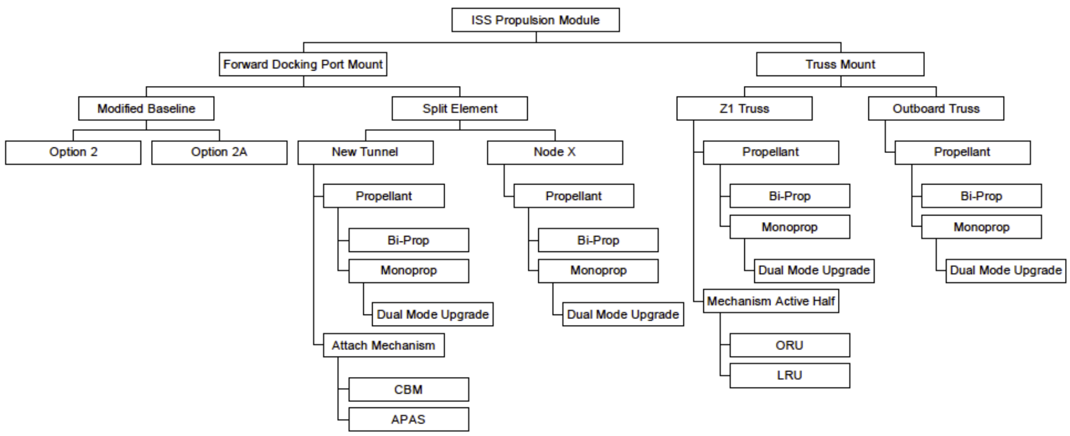
[2] Thomas, L. Dale, "Systems Analysis and Trade Studies", presented in ISE 734 Value and Decision Theory, University of Alabama in Huntsville, 30 May 2001

ISS PM Study Trade Tree

Systems Management Office



Ranking and scoring alternatives can be arithmetic or statistical. Typically, spreadsheet scoring and computation is sufficient. The “ordinal” approach to grading or scoring is just doing a straight ranking of the alternatives. Alternately, cardinal scoring will assign relative values of how well something meets the requirement or objective, such as on a scale from 1 to 10. The alternatives are then ranked according from best to worst score.

Relative Ranks of Options

Systems Management Office

	Category	Criteria	Mod B/L 2	Mod B/L 2A	SE	NX	Z1
Programmatic	Schedule	Development Schedule	1	5	3	3	3
	Cost	Development	4	5	3	2	1
		Life Cycle	5	4	2	3	1
	Risk	Cost	4	5	3	2	1
		Schedule	3	5	4	1.5	1.5
			17	24	15	11.5	7.5
Technical	Safety	Shuttle	4.5	4.5	2	2	2
		ISS	4	5	3	1	2
	Design Complexity	mechanisms	3	5	1	4	2
		on-orbit interfaces	1	5	3	3	3
		component count	2	4	3	5	1
	Design Pedigree	design heritage	3	5	3	1	3
	Resources	electrical power	1	2	4	5	3
		data	4	5	2	3	1
		thermal	3	3	3	3	3
		EVR maintenance	3	3	3	3	3
		EVA maintenance	2.5	2.5	2.5	2.5	5
		IVA maintenance	4.5	4.5	2.5	2.5	1
	Performance Effectiveness	prop budget	1.5	1.5	4	4	4
		maintainability	1	5	2.5	2.5	4
			38	55	38.5	41.5	37

Note: 1 is best, 5 is worst

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Relative Ranks of Options (con't.)

Systems Management Office

	Category	Criteria	Mod B/L 2	Mod B/L 2A	SE	NX	Z1
Integration	ISS Impacts	Assembly sequence	3	3	3	3	3
		plume effects	1.5	1.5	3.5	3.5	5
		science payloads	3	3	3	3	3
		reboost attitude	2.5	2.5	2.5	2.5	5
		PM/ISS interfaces	3.5	3.5	3.5	3.5	1
	Shuttle Impacts	PM function when shuttle	4.5	4.5	2	2	2
		PM/Shuttle interfaces	3.5	3.5	3.5	3.5	1
	Verification	Thermal vacuum test	3	3	3	3	3
		acoustic test	3	3	3	3	3
	Activation Complexity	EVA manhours	3.5	3.5	1.5	1.5	5
		EVR hours	3.5	3.5	1.5	1.5	5
	Returnability	EVA manhours	4.5	4.5	2	2	2
		EVR hours	5	4	1.5	1.5	3
	Ground Ops	turn-around time	4.5	4.5	2	2	2
	Logistics	shuttle flights over life cycle	5	4	2	2	2
			53.5	51.5	37.5	37.5	45

Note: 1 is best, 5 is worst

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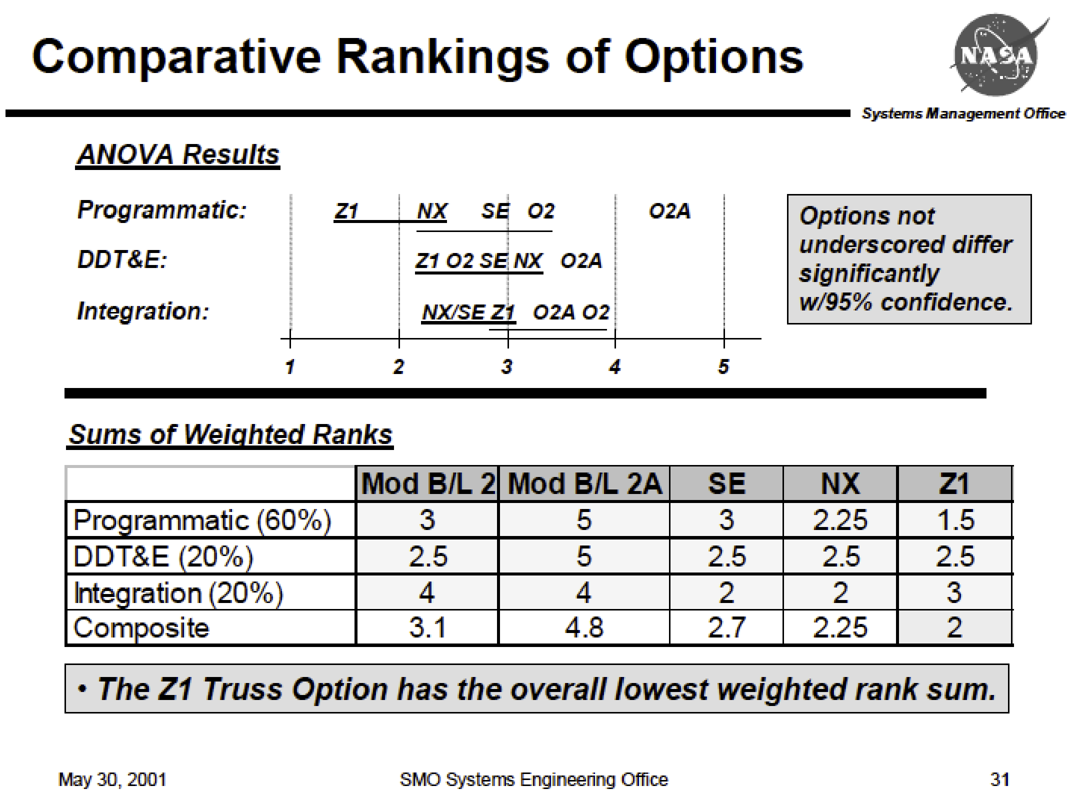
Thomas (1988) demonstrated an analytical method for trade studies that evaluates the statistical significance of the differences in the weighted grade between different alternatives. Using appropriate ANOVA analysis, it can be determined if an alternative is truly better than a close ranking one, or if they are statistically not significantly different. The method is an Analysis of Variance (ANOVA) by Ranks within each category, and uses key discriminant analysis.



	Mod B/L 2	Mod B/L 2A	SE	NX	Z1
Programmatic (60%)	3	5	3	2.25	1.5
DDT&E (20%)	2.5	5	2.5	2.5	2.5
Integration (20%)	4	4	2	2	3
Composite	3.1	4.8	2.7	2.25	2

A clear recommendation is formulated from the analyses and is validated with engineering judgment. Clear rationale accompanies each recommendation. The strengths and weaknesses of each option are to be understood as well as an estimation of the uncertainty of the analysis.

F.4.1.2 *SMART Method*

The Simple Multi Attribute Rating Technique (Edwards, 1971) (SMART) method is shown here as a comparison to the generic Trade Study procedure as described for engineering trades. The general form of SMART and other similar methods follow the basic MCDA approach, with some differences in how weighting, grading, and aggregation is handled. The basic form of all of these methods follows the most basic model of how humans make decisions, that is by recognition, judgment, decision, and acting.[3]

SMART:

1. Identify the decision makers

2. Identify and define the decision problem

3. Identify and agree on the Technical Performance Measures of the decision problem that the successful selected alternative will meet

4. Identify Alternative Courses of Action

5. Idenfity the Attributes relevant to the decision Problem (TPMs)
   a. #1 is usually cost
   b. The other attributes may be objective or subjective

6. Grade Attributes: Obtain data and numerically grade (assign values to) each Attribute for each Alternative (Alternative's Performance Grade)

7. Weight Attributes: Determine a weight value for each Attribute (Attribute weight value)

8. Score: Multiply each Grade (except COST) by the corresponding attribute weight
   a. Sum the weighted grades over each Alternative to obtain an Alternative Score

9. Plot Cost versus Score of all attributes
   a. Develop an Efficient Frontier

10. Delta's: Make a Provisional Decision, judgment (not the objective necessarily) based on the delta dollar values to the decision makers

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[3] Jung, Karl Gustav, 1905

11. Sensitivity Analysis : Perform a sensitivity analysis to gage the robustness of the model to the grade and wieght value changes

Axioms of SMART (Assumptions):

"Axioms" means a set of postulates that may be regarded as reasonable. If a decision maker (dm) is rational (behaves consistently in relationship to the principle) and if a decision maker accepts the axioms, the decision maker accepts the preference rankings indicated by the method. The axioms of the SMART method are:

1. DECIDEABILITY: a dm can decide and make a judgment

2. TRANSIVITY: A>B, B>C, then A>C

3. SUMMATION: A>B, B>C, then A>>C

4. SOLVABILITY: necessary for the bisection method to develop value function;
   a. assumes theoretical options exist to consider
   b. there may actually be gaps, physical constraints, limit the math

5. FINITE BOUNDS: (Upper and Lower)for the Value
   a. The best is not equal to positive infinity
   b. The worst is not equal to negative infinity
   c. Quantifiable
   d. Close enough to be relevant (apples to apples and not log log)

Assumptions Made when Aggregating Values Using SMART

1. SMART assumes that risk and uncertainty are not issues

2. This is a LINEAR ADDITIVE MODEL
   a. This model is not appropriate to use when there is an interaction between scores
   b. Requires MUTUAL PREFERENCE INDEPENDENCE
      i. One preference cannot depend on another
      ii. If Mutual Preference Independence does not exist
         1. Return to the Value Tree and redefine attributes to eliminate dependence
         2. Use Multiplicative Model (Bayes Rule) (Not widely used)

SMARTER is an enhanced method of SMART. It is SMART Exploiting Ranks and simplifies SMART. It is explained in The strategy of Heroic Approximation (Edwards and Barron, 1994). SMARTER uses a very simple decision making model that may only approximate the real decision problem, but is less likely to involve errors because judgments are simpler. SMART and SMARTER agree 75 to 87% of the time The two differences with SMARTER are:

1. The Value Functions are assumed linear
   a. As a check: ask the dm if value(delta at bottom) = value (delta at top)
   b. If value (delta at bottom)/ value(delta at top) < 2, linear is OK but the swing weights calculation is changed

2. Rank swings in order of importance
   a. Use aRank Order Centroid (ROC) weights to convert weights.

Rank Order Centroid (ROC) Weights
If you have

	Number of Attributes					
Rank	2	3	4	5	6	7
1	75.0	61.1	52.1	45.7	40.8	37.0
2	25.0	27.8	27.1	25.7	24.2	22.8
3		11.1	14.6	15.7	15.8	15.6
4			6.3	9.0	10.3	10.9
5				4.0	6.1	7.3
6					2.8	4.4
7						2.0

F.5 <u>Decision Analysis Methods and Reference Sources</u>

In addition to the decision analysis methods listed in the body of this document (MSFC-HDBK-3173), some other decision analysis methods include:

SIMILAR - a basic decision process model that both describes and prescribes how logical decisions can be made. SIMILAR is an acronym that stands for State the problem, Investigate alternatives, Model the system, Integrate, Launch the system, Assess performance, Re-evaluate.[4]

Kepner-Tregoe[5]- copyrighted method for eliciting and aggregating attributes, grades, weights, and scores

The reference document, Systems Engineering "Toolbox" for Design-Oriented Engineers, NASA Publication 1358 provides guidelines for conducting the following decision analysis procedures in the stated categories:

- Concept Development Tools
  - Trade Studies
  - Cost-Benefit Studies
- System Safety and Reliability Tools
  - Risk Assessment Matrix
  - Preliminary Hazard Analysis (PHA)
  - Energy Flow/Barrier Analysis
  - Failure Modes and Effects (and Criticality) Analysis
  - Reliability Block Diagram
  - Fault Tree Analysis
  - Success Tree Analysis
  - Event Tree Analysis
  - Fault Tee, Reliability Block Diagram, and Event Tree Transformations
  - Cause-Consequence Analysis
  - Direct Graphic (Digraph) Matrix Analysis
  - Combinatorial Failure Probability Analysis Using Subjective Information
  - Failure Mode Information Propagation Modeling
  - Probabilistic Design Analysis
  - Probabilistic Risk Assessment

[4] Daniels, Jesse, Paul W. Werner, and A. Terry Bahill, *Quantitative Methods for Tradeoff Analysis*, Systems Engineering, Vol. 4, No. 3, 2001

[5] Kepner, Charles H., and Benjamin B. Tregoe, The New Rational Manager, Princeton Research Press, NJ, 1981

- Design-Related Analytical Tools
  - Sensitivity (Parametric) Analysis
  - Standard Dimensioning and Tolerancing
  - Tolerance Stackup Analysis
- Graphical Data Interpretation Tools
  - Scatter Diagram
  - Control Chart
  - Basic and Applied Research (Bar) Chart
  - Time-Line Chart
  - Stratification Chart
  - Pareto Chart
  - Histograms
- Statistical Tools and Methodologies
  - “Student-t” Analysis
  - Analysis of Variance
  - Correlation Analysis
  - Factorial Analysis
  - Confidence/Reliability Determination and Analysis
  - Regression Surface Methodology
  - Response Surface Methodology
- Total Quality Management (TQM) Tools
  - Benchmarking
  - Cause and Effect Diagrams (also known as Fishbone Diagrams, or Ishakawa Diagrams)
  - Cost of Quality
  - Design of Experiments
  - Evolutionary Operation
  - Brainstorming
  - Checklists
  - Delphi Technique
  - Nominal Group Technique
  - Force Field Analysis
  - Quality Functional Deployment (including House of Quality)
  - Quality Loss Function
  - Statistical Process Control
  - Flowchart Analysis
  - Work Flow Analysis
- Trend Analysis Tools
  - Performance Trend Analysis
  - Problem Trend Analysis
  - Programmatic Trend Analysis

Supportability Trend Analysis
Reliabilty Analysis

Integrated product and process design disciplines involved in designing “quality” into the product produced a range of procedures and methods or representations to assist developers and decision makers in mutually understanding and communicating information, assessment, and interactions between factors. The “House of Quality” model and Value Stream Mapping are examples of quality- and value-focused DA.

F.6 Examples of Decision Analysis Methods

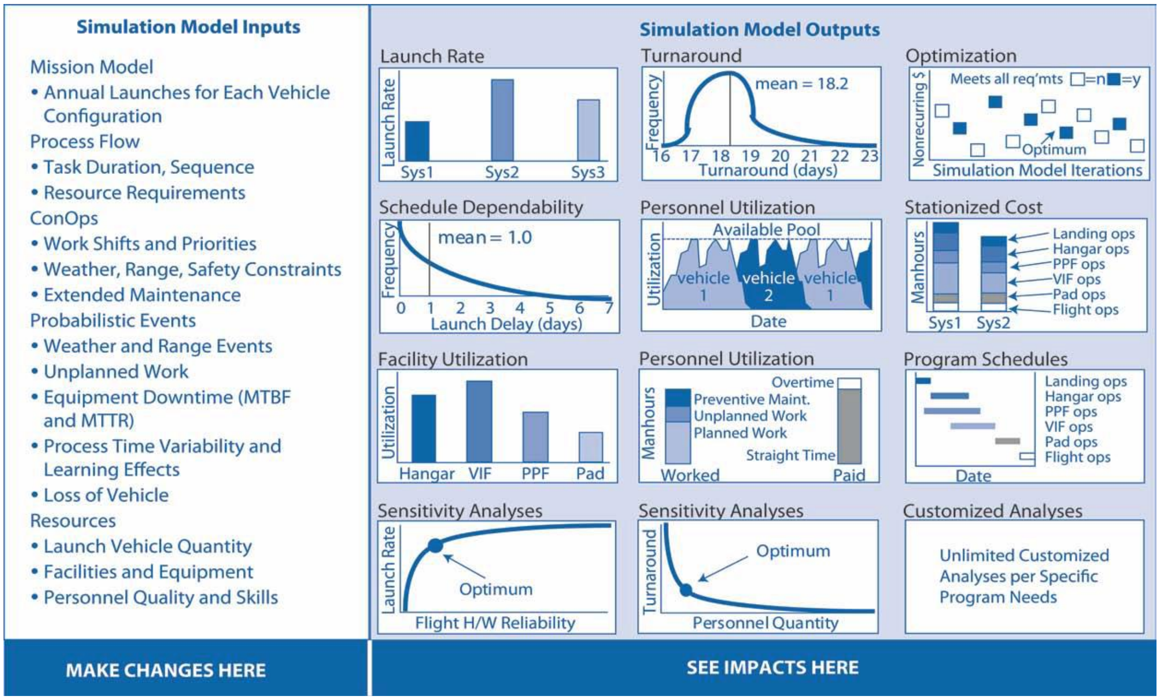
Examples of DAS procedures for those mentioned both in the body of this document and those listed in this Appendix are shown below.

Modeling and Simulation

Modeling and simulation of rocket engineering disciplines have already been developed for components and engine or motor performance. Architecting of propulsion vehicles often require development of unique parametric performance and cost models to rapidly generate potentially viable configurations that are then assessed using other formal DA methods. COMPRE and COSYSMO are two parametric cost models developed at NASA for propulsion vehicle modeling and architecting. A disadvantage of parametric cost models is that they can tell you what you did, but not necessarily predict the future really well.

Blair, Ryan, Schutzenhofer, and Humphries technical report titled Launch Vehicle Design Process: Characterization, Technical Integration, and Lessons Learned (NASA/TP-2001-210992) is an excellent source of information on the technical integration of various types of modeling and simulation, as well as other types of analyses used in evaluating the performance and developing architecture and design solutions for rocket propulsion. It is highly recommended that these external sources of information be used to gain a deeper understanding of the intricacies of engineering a system.

An example of a modeling and simulation analysis is shown in the figure below.



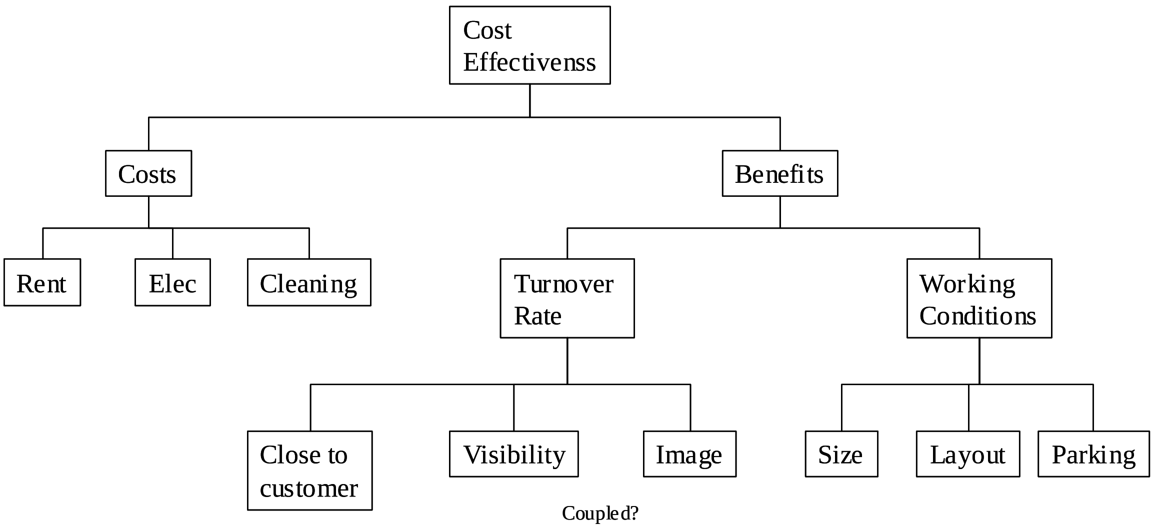
Cost Study

Cost-benefit analyses are special case trade studies

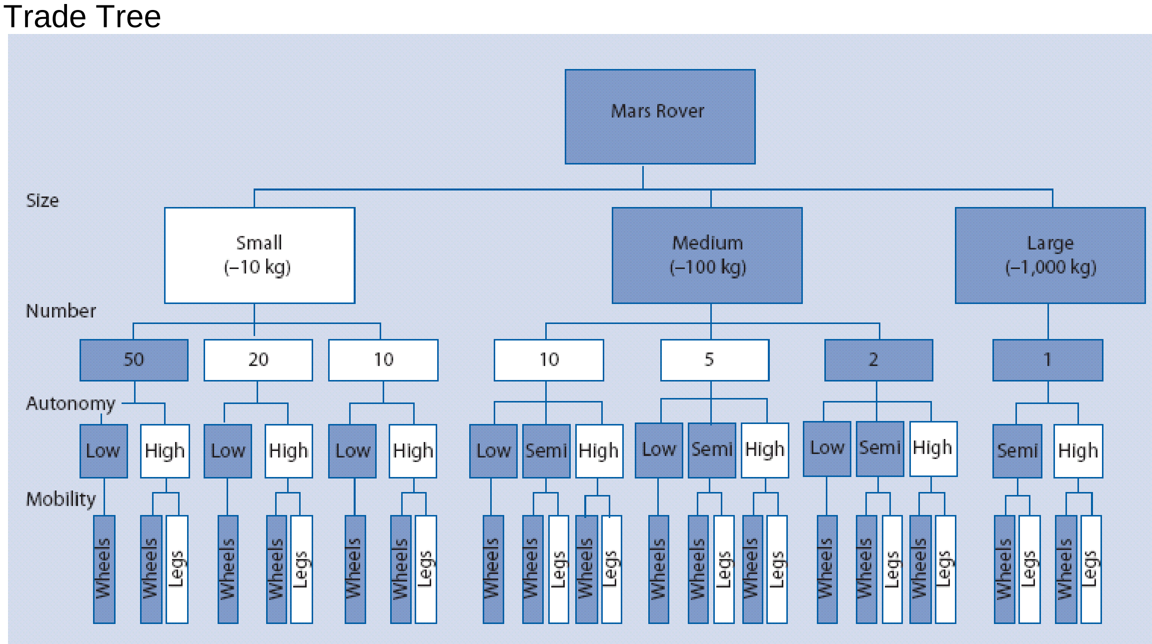
- Compares system or component performance to its cost
- Helps to determine affordability and relative values to alternate solutions

Supports identification of affordable, cost optimized mission and performance requirements
Supports the allocation of performance to an optimum functional architecture
Provides criteria for the selection of alternative solutions
Provides analytic confirmation that designs satisfy customer requirements within cost constraints
Supports product verification

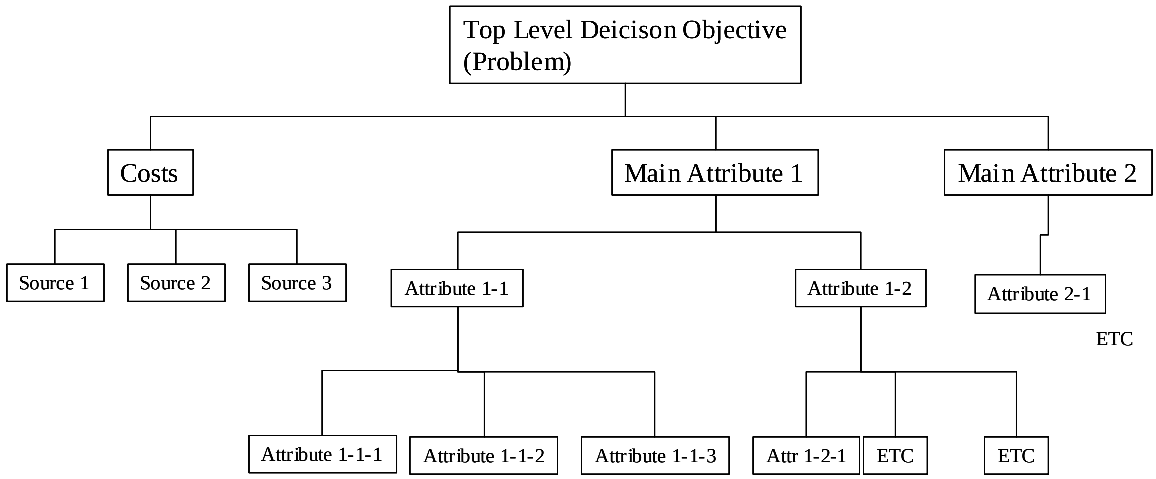
A notional cost- benefit analysis tree is shown in the example below.



Trade Tree



Value Tree



Developing a Value Tree:

A. Determine the decision objective, costs, and attributes to be evaluated.

B. Determine alternative solutions to the problem issue.

C. Assign Values to Measure Performance (GRADE) of each Alternative on each Attribute

For Cost, all cost data has the same unit of measure ($$$). Also, use standard equations to get the Present Value (PV) of the various sub-attributes to obtain a single COST VALUE for each Alternative. For attributes other than Cost, obtain sufficient level of detail such that each attribute grade is based on EQUIVALENT MEASURES (apples to apples). Normalize data whenever possible. If one attribute depends on another, this implies that the two attributes are not independet, so you can't use an additive model. You need to look at the delta or difference between the option grades to guage the relative strength or weakness of one option over another. It is the interval or improvement between points that we compare. Ordinal ranking for weighting will skew the scoring

There are two Methods for Assigning Grades (Values of Performance)

i. Direct Rating
ii. Value Functions

Option 1: Direct Rating: Ranking from highest to lowest each alternative based on subjective preferences of the dm

1. Identify Extremes: Highest and Lowest
   a. Assign Highest a score of 100

   b. Assign Lowest a score of 0

   c. Or can use any two numbers for highest and lowest

   d. If you use 1-100 on one set of attributes, use 1-100 on all sets

   e. Likewise if you use 1-10 on one set of attributes, use 1-10 on all sets of attributes

2. With Pairwise comparisons decide on how much MORE preferable (deltas or interval) one option is to the next starting with comparing one of the leftover options to the lowest.
   a. You will end up with a VALUE SCALE of the options
      i. Interval is significant, not the ratio of one number to the next

   b. You can iterate until you are comfortable with the rankings

   c. You may need more information to judge
   d. You may need more decomposition to judge

   e. Doesn't need to be precise

Option 2: Value Functions
1. Obtain quantifiable data on an attribute (ie: Floor space, sq ft, etc)

2. Obtain dm's personal value regarding quantified data
   a. Bigger is better
   b. Or smaller is better

3. Assign the highest quantified data a value of 100
   a. Value(Highest value)=100

4. Assign lowest quantified data a value of 0
   a. Value(lowest value)=0

5. Develop a VALUE FUNCTION
   a. Ask dm to rank directly

b. Bisection Method
   i. Ask dm what data value would have a grad value halfway between the high value and low value
      1. an increase from lowest to 50%=an increase from 50% to highest
         a. ie: Value(50%) = 50
   ii. Ask for quarter points
      1. value(75% of data) = 75
      2. value (25% of data) = 25
   iii. Plot the values on a y-axis as a function of the data range
   iv. Can assign Grades based on this scale just by cross referencing to quantified data point on x-axis

D. Determine WEIGHTS for each ATTRIBUTE

As a note, direct ranking is not appropriate for weighting; it can lead to errors. Direct ranking does not reflect range, the relationship from most to least preferred. The Final Score for each alternative is their grade multiplied by their weight. If the actual range is very small ie: the weights are very nearly equal, ordinal Rank Weight would overexaggerate differences (the deltas). If the actual Range Very Large ie: a nonlinear dispersion of weights, then ordinal Rank Weight would minimize and underestmate impact of the deltas.

METHODS TO USE for DETERMINING WEIGHTS for each ATTRIBUTE

1. Swing Weights

2. Rank Sum *recommended

3. Sum of Ranks *recommended

4. Rank Reciprocal

SWING WEIGHTS

Swing Weights: compares relative change (swing) in importance to dm from most to least

1. Define the relative Attribute Ranking
   a. The Candide Waterfall:
      i. Ask, “imagine the best of all possible worlds”

b. Ask, “If you could change just one attribute, which attribute would change the worst of all possible worlds (woapw) to the best of all possible worlds (boapw)?”
    i. That Attribute is #1

c. Continue to ask question b of “which is next attribute to change woapw to boapw?”
    i. Obtains an Ordinally ranked list of attributes

2. Assign Relative Weights
    a. Assign 100 to the top #1

    b. Assign 10 to the bottom attribute

    c. Pairwise compare the attributes going from the bottom to the top to develop the relative distribution from Attribute Weights = Swing Weights

1. Normalized Attribute Weighting
    a. Obtain ranks (by pairwise comparison)

    b. Assign initial weights with 100 = top choice, most preferred to 0 or 10=least preferred

    c. Normalize the weights to add up to 100
        i. Sum initial weights
        ii. Divide each initial weight by the summed weights and multiply by 100 for each i=1,N

2. Uniform Weighting- all attributes have the same weight

3. Rank Sum
    a. Obtain rank order by pairwise comparison

    b. Ordinally rank attributes in reverse order, ie: Most preferred = N, next=N-1, last or least = 1

    c. Sum the values of the ordinals (if N=5, sum=15)

    d. Divide the ordinal rank by the summation of the ordinals and multiply by 100

e. So if N=5, sum=15, weight i=1 is (5/15)*100=33.33
    i. Then rank = 4, sum =15, weight of i=2 is (4/15)*100=26.67

4. Rank Reciprocal
    a. Obtain rank order by pairwise comparison

    b. Weight intial = 1/rank = {1, ½, 1/3, ¼, …1/N}

    c. Sum initial weights = 1+1/2+1/3+1/4+…+1/N

    d. Weight of each attribute = ((1/$rank_i$)/(sum of (1/$rank_i$))*100

Notes on Weighting of Attributes
1. Rank Attributes before Weighting them
   Rank to determine relative priority of each attribute
    A. Methods To Rank
        1. Pairwise Comparison
        2. Candide Waterfall (Swing Weights)

Pairwise Comparison Ranking Method
1. List Attributes, count= N

2. Calculate number of comparisons = N*(N-1)/2

3. Develop a pairwise matrix

4. Pairwise compare attributes and WRITE DOWN THE PREFERRED ATTRIBUTE

5. For each attribute, count # of pairwise comparisons
    a. Shows preference

6. Rank attributes based on totals

Pairwise Comparison Matrix Example:
Attribute

	A	B	C	D	E	Total
A	-	B	A	A	A	A=3
B	-	-	B	B	B	B=4
C	-	-	-	C	?	C=1.5
D	-	-	-	-	E	D=0

E - - - - - E=1.5

Ranking then becomes B>A>C=E>D

Alternative Ranking after another iteration B>A>C>E>D

E. SCORES: Aggregating the Benefits Using the Additive Model

A. GRADE = measure of how well each alternative performs on each attribute
   a. WEIGHT = relative importantance of each attribute to dm
   b. Multiply each GRADE by each WEIGHT to get a Weighted Grade

B. Add the weighted grades up across each attribute to obtain a Benefits score = AGGREGATE VALUE (final score)

F. Graphing: Plot Cost Versus Score

Cost Axis is from HIGHEST TO LOWEST (Backward)

DEVELOP AN EFFICIENT FRONTIER

Options on the Efficient Frontier dominate all other options

G. Make a Provisional Decision (Edwards and Newman 1986)

a. From the Efficient Frontier, start at the lowest scored, lowest cost option (extreme right option) on the frontier

b. Go to the next point up on the Efficient Frontier
   i. The Efficiency Frontier cannot have a negative slope
c. Calculate a delta cost from lowest scored lowest cost option to next option up

d. Calculate the delta cost/delta benefit = x

e. Then do the same calculation for the next two points on the Efficient Frontier = y

f. If x<y, decide is x $/pt benefit worth it to the dm?
   i. If not, choose lower cost option
   ii. If yes, choose higher cost option and ask “is y worth it?”
      1. If no, choose lower cost option
      2. If yes, choose higher cost option

H. Sensitivity Analysis

To gage how ROBUST the choice of an alternative is to changes in the figures (weights or grades) used in the analysis, usually weights

Answers questions like

Did I pick the right numbers?

Did I weight the attributes correctly?

V&V: Verification and Validation

Verify: Steps done correctly

Validate: Done the correct steps

Adjust weights to help resolve conflicts in Team

Plot graphically and List Tabularly

Sensitivity Analysis: To gage how ROBUST the choice of an alternative is to changes in the weights or grades used in the analysis, primarily WEIGHTS

1. Determine which Attribute weight to examine or change

2. Plot each alternative score for values of attribute weighted at 0 and 100
   a. Usually large changes in these figures are required before one option becomes more attractive than another

   b. May build a new Efficient Frontier

   c. Shows dominated options
      i. Shows that regardless of how you weight an attribute, others will dominate

   d. FOCUS ON THE IMPORTANT FEW RATHER THAN THE TRIVIAL MANY
3. “Flat Maxima” (Winterfeldt and Edwards, 1986)

Notes: Value Tree Assessment Criteria (Keeney and Raifa, 1976)

1. COMPLETENESS: All the attributes of interest have been included
   a. Sample size is sufficient to approach normality

2. OPERATIONALITY: The lowest level attributes are specific enough to evaluate and compare them for the different options
   a. To levels yo can compare

b. Apples to apples

c. Quantifiable and Verifiable

d. What is the “image”” – to definition for equal measurement

3. DECOMPOSABILITY: The performance of an alternative (option) can be judged independently of it’s performance on other options (INDEPENDENCE)
   a. Combine coupled attributes into one attribute

   b. OR decompose until they are not coupled

4. ABSENSE OF REDUNDANCY: NO DUPLICATES!
   a. Double counting = Double weight

   b. Check effect of deleting each option in turn

   c. If attributes use the same criteria, they are redundant

5. MINIMUM SIZE: KISS, SIMPLIFY
   a. Decompose only as low as needed for evaluation

   b. Eliminates dominated attribtues, those whohse contributions does not change the final decision result, ie; if atttribute scores are all the same, eliminate the attribute from calculations

   c. Regression

   d. Not more than 4 or 5 signficant variables max

SMARTER DISADVANTAGES

1. May obtain a different Efficient Frontier
   a. BE careful before excluding dominated options
      i. The assessment of the worth of a value point is based on NORMALIZED weights which can lead to large discrepancies

2. By simplifying the dm’s judgemental task, we may be encouraging only superficial consideration of the problem
   a. May preclude insights we hope to obtain

b. Sometimes need deeper, tougher thinking

F.8 Definitions

Decision Support System (Tool): "Decision Support System- generally a computer based information system that supports business, organizational, [or technical] decision-making activities. DSSs serve the management, operations, and planning levels of an organization and help to make decisions, which may be rapidly changing and not easily specified in advance. DSSs include knowledge-based systems. A properly designed DSS is an interactive software-based system intended to help decision makers compile useful information from a combination of raw data, documents, personal knowledge, or business models to identify and solve problems and make decisions.[6]"

Compensatory decision model- the procedures and computations aggregate values of criterion such that low values on one criteria can be compensated for by high values on another criterion.

Non-compensatory decision model- during the selection phase, values are not aggregated so that the representation of the comparison of alternatives does not compensate a low value on one criterion with a high value of on another criterion

Requisite decision model- a decision model that contains all the information and structure that supports justifying a recommendation for making a decision. The decision maker does not have to select the recommendation resulting from a requisite decision model, but the model provides sufficient information such that the decision maker has confidence in selecting a course of action.

[6] "Decision support system", wikipedia, http://en.wikipedia.org/wiki/Decision_support_system, accessed 27 February 2012