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

EE10

MSFC TECHNICAL STANDARD

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.
Revision	C	11/09/2018	The following is the summary of modifications included in Project Management & Systems Engineering Handbook: • Handbook title was modified as follows: Systems Engineering Handbook. • Added section 2. MSFC PROGRAM, PROJECT, ACTIVITY: POLICY, TECHNICAL AUTHORITY, AND SYSTEMS ENGINEERING & QUALITY MANAGEMENT SYSTEM. It includes subjects on: Policy overview; MSFC requirements documentation (MPR 7120.1; MPR 7123.1); User tools - Customization Tool, integrated life-cycle products and reviews; programs/projects/activities (PPA) mission type categorization and risk classification system; customization and tailoring description and examples; Governing authority approval; technical authority overview (MCP 8070.2) which contains subjects on: engineering and institutional technical authority, and dissenting opinion. • Section 3. PROJECT MANAGEMENT was deleted, except for the subsection on, Mishap and Failure Investigation. The new

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Section 3. SYSTEMS ENGINEERING (previously section 4.) contains accepted changes proposed by Subject Matter Experts from MSFC Engineering organizations, and members of the Document Control Board (DCB). In summary the new section 3. SYSTEMS ENGINEERING, includes guidance and best practices for the seventeen systems engineering process as applied to MSFC PPAs, as used to be described under section 4. Systems Engineering REV B of this handbook, plus the following changes:

• SMEs and DCB technical comments accepted by the OPRD for several sub-sections within this section dedicated to Systems Engineering.

• Updated SMEs tables in each one of the seventeen SE processes sections as proposed by the corresponding SME and accepted by the OPRD.

• Added section 3.2.2.1.6 Product Testing. It discusses the overall product testing process scope; Testing types overview; "Test As You Fly" approach; Testing process overview (planning, facilities & equipment, hardware requirements, TRR, etc.); NASA & MSFC testing standards; Industry standards & MSFC requirements for test area facilities & equipment; Systems Engineering processes implemented by the test service provider.

• Sections, 3.3.2.4 Configuration Management (CM) Process & 3.3.2.5 Data Management process were extensively updated: Modified objectives and purpose sections; References to MSFC Guidance Manual (MGM) 7120.3, MGM 8040.1 and other applicable standards; Updated sections on CM Planning and Strategy, Configuration Identification, Configuration Control, Configuration status Accounting and Configuration Verification and Audits including Tables with specific steps for various CM planning and implementation tasks; updated Configuration Control Board (CCB) functions including figures; Configuration audits and configuration verification; Change request preparation and evaluation steps.

• Added section 3.3.3.1 Mishap and Failure Investigations. It discusses the Agency and MSFC requirements; Agency Requirements overview (NPR 8621.1); MSFC guidance and best practices; MCP 8621.1 and MWI 8621.1; MSFC DRDs: STD/SA-SHPoff and/or STD/SA-SHPon; Hazard Analysis and Failure Modes and Effect Analysis (FMEA) and Critical Items List (CIL).

• Added and updated applicable MSFC Data Requirements Descriptions (DRDs) for the SE processes, are listed & briefly defined within the SE processes' sections.

• Imported several figures from NASA/SP-6105 Systems Engineering Handbook as part of examples under specific SE Processes: N^2 Diagram, Timing diagram, Functional Flow Block Diagram, Requirements Allocation Sheet, etc.

• Revised/corrected numbering system for the entire document, including numbering for tables and figures.

• Updated references to other NASA, MSFC and Industry accepted documents: No rev, table, figure or section numbers are included in references.

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			• Revised list of acronyms. • Reorganized and updated Table of Contents. • Editorial modifications: As result of deleting section 3. PROJECT MANAGEMENT, several editorial adjustments were made. Font size for the SMEs Tables modified to, Times 10. Also, additional editorial modifications (i.e., acronyms: PPA; PPA manager; CE, R&R, etc. Spell out: systems engineering; etc.) were made throughout the entire HDBK, plus other format and related editorial changes.

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1.   INTRODUCTION

1.1   Scope

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

Systems engineering principles and practices described in this Handbook apply to MSFC PPAs. Nevertheless, the emphasis of the document is to describe the systems engineering processes necessary for PPA development; therefore, in general, the document refers only to systems engineering.

While all process activities and general guidance are addressed, PPA managers, working with their systems engineers (SEs), and Chief Engineer (CE) may tailor and customize implementation to the specific needs of the PPA consistent with PPA size, complexity, criticality and risk. Tailoring and customizing are mechanisms to encourage innovation and achieve products in an efficient manner while meeting the expectations of the customer. Tailoring results when a requirement is removed or modified from a PPA, whereas, customization results when a best practice or guidance is removed or modified from the PPA (MRP 7120.1). Results of the tailoring will be documented in Program Commitment Agreements (PCAs), Program Plans, Project Plans, and Activity Plans. All PPAs 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 systems engineering principles and processes and to provide general guidance for implementing these systems engineering to PPA at the MSFC. This Handbook also defines the contemporary policies and practices employed at MSFC in the planning and execution of systems engineering processes.

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

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1.3   PPA Leadership Team Roles & Responsibilities

The PPA Leadership Team include, at a minimum, the PPA Manager, CE, Lead System Engineer (LSE), Chief Safety and Mission Assurance Officer (CSO) and Lead Technologist/Principal Investigator (LT/PI, when applicable). The roles and responsibilities (R&R) of the PPA Manager, CE, LSE, CSO and LT/PI should be defined at the outset of each PPA formulation and updated throughout the PPA life-cycle. The following definitions may not be all inclusive dependent on the need of the PPA and how the R&Rs are distributed amongst the Leadership Team.

1.3.1   Definition of PPA Manager

The R&R of the PPA Manager are defined in the PPA Management Toolkit located on the Project & Engineering Collaborative Environment (PECE) website.

1.3.2   Definition of Chief Engineer

As a member of the PPA leadership team, the CE coordinates with the PPA manager and integrates the involved engineering technical disciplines, and Safety & Mission Assurance (SMA), to ensure proper strategic direction and scope-of-work is established for each PPA. The CE is the Engineering Technical Authority (ETA) for the PPA (Section 2.2). The CE roles should be customized depending on the risk posture of the PPA, mission type, flight or technology development investigation, etc. Some general roles of a CE include ensuring engineering adequacy and coordination of in-depth engineering support from the appropriate Engineering Laboratories and Departments, leading and coordinating the technical activities, problem solving, and issue resolution within the Engineering Directorate (ED) and assuring that technical cognizance is maintained over associated contractor activities. It is the CE's responsibility to coordinate with the LSE to identify and implement applicable and technically sound engineering practices and standards, develops technically sound solutions, and that PPA management is aware of all technical risks associated with PPA implementation throughout the life-cycle.

The PPA CE works with the PPA Manager, LSE and element/system//sub-system discipline leads, as applicable, to ensure engineering requirements are fully represented in the PPA and technical planning products. Reviews and concurs on PPA and technical planning documents including: work breakdown structures, deliverable lists, risks and assumptions, facility requirements list, schedules, resource requirements, and cost estimates. The PPA CE is also responsible, in conjunction with the LSE, for ensuring design integration activities identified are necessary and sufficient to obtain verification (across and within subsystem and discipline teams for the PPA systems). The CE executes ETA by establishing the Engineering position (in coordination with the involved disciplines) for PPA technical decisions and resolution of any technical issues. The CE works with the appropriate Engineering management and PPA management to ensure that the correct engineering position is established and represented for all PPA issues and decisions. The PPA CE is responsible for aiding the PPA Manager in resolution of technical issues through the identification, assessment and recommendation of cost-, schedule-, and risk-balanced options.

Often the CE performs the role of mediator when disagreements arise between technical disciplines or between technical disciplines and the PPA Offices. Any disagreements, alternate opinions, or disputes are resolved at the lowest possible level utilizing the dissenting opinion process (refer to MCP 8070.2 for additional details). Any disputes that cannot be resolved between CE and discipline management are elevated to the Engineering Management Council (EMC) for adjudication and decision by the Engineering Director.

1.3.3 Definition of Lead Systems Engineer

As an overall summary of this document, the PPA Lead Systems Engineer is the responsible lead for all PPA systems engineering and integration (SE&I) activities. The LSE is responsible for the formulation and implementation of the assigned PPA SE&I element including: the safety, technical integrity, performance, and mission success of the SE&I element while meeting (cost and schedule) commitments. For PPA and technical planning, the LSE serves as a task leader, providing PPA technical and management support, including defining PPA scope, requirements, solutions and deliverables; consulting with customers, working groups and experts as needed; implementing plans to meet goals and objectives; providing recommendations to coordinate and integrate activities, resolve complex problems impacting PPAs. The PPA LSE is also responsible, in conjunction with the CE, for ensuring design integration activities identified are necessary and sufficient to obtain verification (across and within subsystem and discipline teams) for the PPA systems. A LSE requires a strong ability to frame complex problems, synthesize information, and develop and communicate solutions. This calls upon excellent written, oral communication and presentation skills. Develops technical plans including the SEMP and V&V Plan and other documentation as required.

1.3.4 Definition of Lead Technologist/Principal Investigator

A Lead Technologist (LT) or often called the Principal Investigator (PI) is the senior subject matter expert who conceives the mission, works with stakeholders to define the benefits of completing the demonstration, and advocates for implementation to the customer. Once the PPA is approved for formulation, the LT/PI is responsible for assembling and leading a team of specialized subject matter experts (the technology team) to define, implement and execute selected investigations of the mission. The LT/PI has full responsibility for the scientific integrity of the mission, is the ultimate decision maker on technology content, and must ensure that the overall PPA team maintains focus on the "big picture" vision for the mission. The LT/PI is expected to coordinate with the PPA manager, Deputy PPA manager, CE, and LSE and work with customers to understand requirements and constraints and support leadership and engineering team in defining mission success criteria and lower level PPA requirements. The LT/PI oversees or aids in the development of the technology system architecture, design, and operations and recommend resources and tools to enable efficient and accurate analysis and testing for technology and system development. In addition, the LT/PI defines required measurements to acquire data to validate the technologies' performance and to validate performance models. In conjunction with the CE and LSE, works to solve technology related problems and technology related disputes.

As the warden for the scientific integrity and success of the mission, the LT must be prepared to recommend PPA termination when, in his/her judgment, the successful achievement of established minimum science objectives (the minimum success criteria), is not likely to be achievable within the committed cost and schedule reserves.

1.3.5 Definition of Chief Safety and Mission Assurance Officer

The PPA CSO serves as the PPA level SMA Technical Authority. The PPA CSO ensures that the PPA and technical planning is consistent with Agency and Center SMA design processes, specifications, rules, best practices, etc., necessary to fulfill mission performance requirements for the PPA. The PPA CSO assesses hazards applicable to the PPA and facilitates Risk Management for the PPA to assist the PPA Manager in assuring that Risk Informed Decision Making and Continuous Risk Management practices are followed and defines any occupational safety, health, and environmental requirements the PPA may have. The CSO also develops the Safety and Mission Assurance Plan (SMAP), if appropriate, and provides the SMA component to the PPA Plan as well as reviews of all PPA and technical planning documents. If the PPA establishes a Board structure, the CSO provides leadership for SERB (SMA Engineering Review Board) in cooperation with the CE when SMA issues are the driver for an ERB. The CSO also establishes and maintains a system to report failures and non-conformances through a PPA level problem reporting and corrective action system and chairs the Material Review Board (MRB) as needed.

1.4 Reference Documents (see Appendix G)

2. MSFC PROGRAM, PROJECT, ACTIVITY: POLICY, TECHNICAL AUTHORITY, AND SYSTEMS ENGINEERING & QUALITY MANAGEMENT SYSTEM

2.1 MSFC Policy: Compliance, Assessment, Tailoring, and Governance Approval

2.1.1 Policy Overview

Marshall Space Flight Center (MSFC) has historically achieved successful mission execution, effective PPA management, and efficient systems engineering. In support of these goals, MSFC has established PPA requirements and associated technical practices via policy documents with the goal of clearly defining requirements but also offering options for tailoring those requirements to each PPA's unique needs. With an increased emphasis on minimizing cost and reducing schedule, MSFC is encouraging an integrated and streamlined approach to customize and tailor policy expectations, emphasizing risk-based decision making, and increased efficiency and affordability without compromising safety.

NASA's systems engineering and technical management policies employ a standardized PPA management life-cycle concept with variations corresponding to mission categorization. NASA HQ defines the basic systems engineering processes and the technical review expectations. However, based on each Center's unique portfolio of PPAs and mission categories, the Agency

allows each Center to define its own systems engineering processes, technical reviews, and product requirements.

2.1.2 MSFC Requirements Documentation

Two procedural documents have been developed and refined over the years to specify the PPA management and systems engineering requirements necessary for the successful execution of all identified categories of PPAs. These Marshall Procedural Requirements (MPRs) are: the MPR 7120.1 MSFC Engineering and Program/Project Management Requirements, and the MPR 7123.1 MSFC Systems Engineering Processes and Requirements. Both are available on the Marshall Integrated Document Library (MIDL) website. These documents support the following primary mission types: spaceflight systems for human or robotic exploration and operations in space, space technology development, and scientific research. MPR 7120.1 identifies specific PPA management and systems engineering requirements for each mission categorization.

2.1.3 User Tools

2.1.3.1   Integrated Life-cycle Products and Reviews Display Tools

A global view of the integrated PPA life-cycle is available by accessing the "Integrated Life-Cycle Products and Reviews" file, available on the MIDL. This pdf file can be viewed by the user or plotted in a large format for presentations and reviews. It provides a complete overview of all requirements, products, and reviews, for each PPA category and is consistent with information within the MPRs.

A companion tool, the "Integrated Life-Cycle Milestone Overview" is available on the MIDL which displays only the integrated life-cycle milestones. This more streamlined graphic is a useful chart for wall display during presentations or reviews. It displays three levels of reviews: subsystem reviews, PPA life-cycle gates, and PPA life-cycle gates. Useful characteristic of this chart is its depiction of the order of reviews as well as the sequence and flow of information between reviews. This chart displays all potential reviews and the relationships between reviews as specified within the MPRs.

The user may request the original Visio file from which each of these graphical displays was created by contacting the Systems Engineering Office. If the user has access to Visio software, the source file, the original files can be modified to display only the unique life-cycle products and reviews planned for a particular PPA. The user may find it useful to create a unique wall display based on their tailored products and review criteria. The Systems Engineering Office is available to assist the user in modifying the Visio file for their particular application and in plotting large wall displays.

The "Integrated Life-Cycle for Programs/Projects/Activities/Tasks" chart (see Figure 1.) is available on the MIDL in editable format in both Excel and Word, enabling the user to extract and edit specific tables for display of a particular tailoring scheme. The "MSFC Integrated Program and Project Life-Cycle Reviews and Products - Word, is identical to that in the Appendix of the MPR 7123.1. Also available is the "Integrated Life-Cycle Tables – Excel," organized by tabs with

one set of products on each tab. Both files contain all products and reviews specified within the MPRs, formatted for different applications. Each set of products can be extracted as individual tables for insertion into PPA plans or presentations.
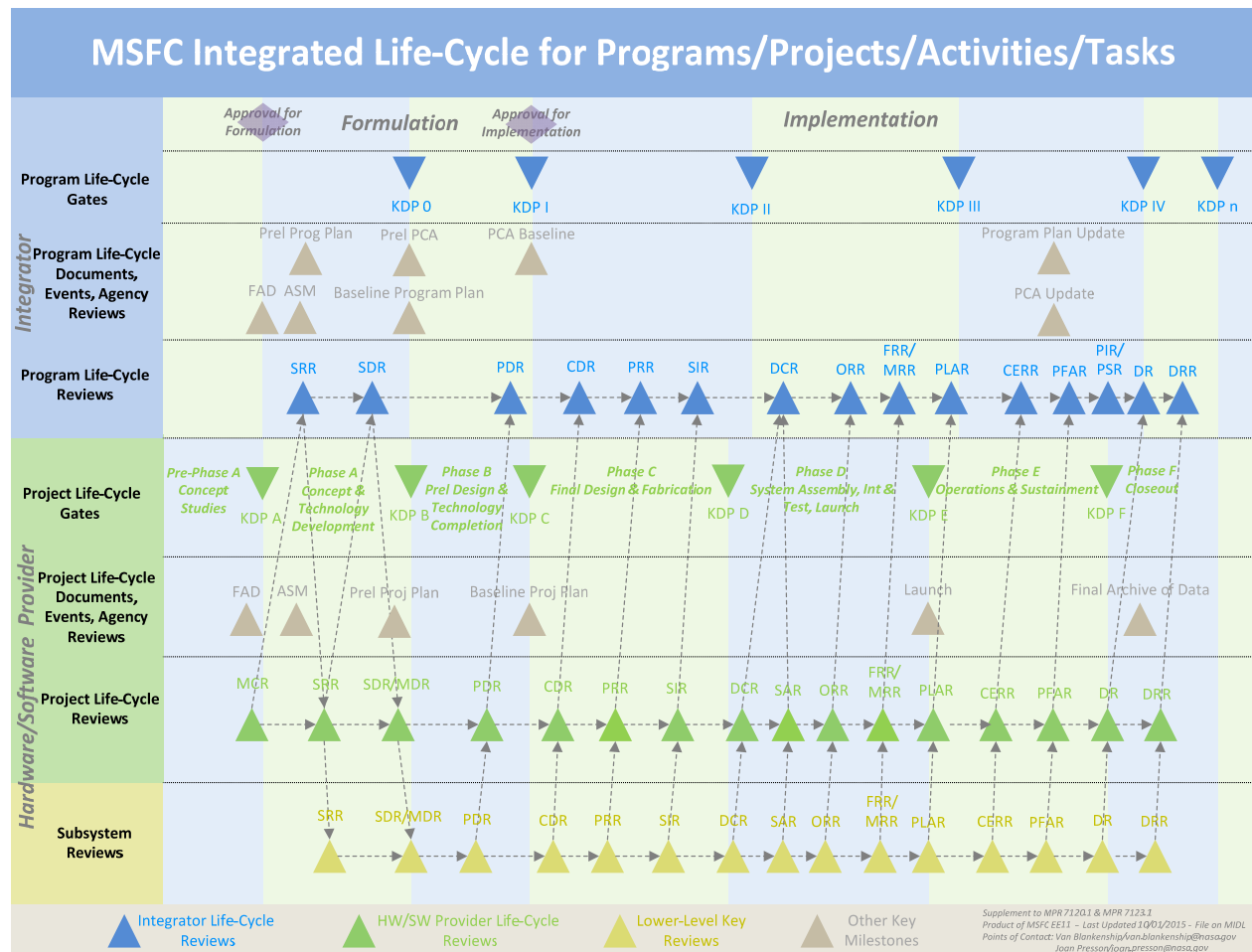
Figure 1. MSFC Integrated Life-Cycle for Programs/Projects/Activities/Tasks
(NOTE: See Appendix A for acronyms)

2.1.3.2 Automated Generation of a Compliance Matrix via the "Customization Tool"

All products and reviews specified within the MPRs are not necessarily applicable to each PPA. Each mission area has unique expectations for the programmatic and technical reviews as well as the products required at each review. Certain requirements are only applicable to particular PPA life-cycle types or for efforts above a specified life-cycle cost threshold or risk tolerance level. To assist the user in migrating through the many requirements described within the MPRs, a "Customization Tool," is available on the MIDL which generates a compliance matrix based on user input.

The "Customization Tool" contains a comprehensive database of requirements, guidance, product maturity specifications, and life-cycle review expectations applicable to all MSFC PPA life-cycle classifications. This database of information is a compilation of the information specified within the MPRs. When using the "Customization Tool," the user initiates the built-in macro, activating a series of user input screens prompting the user to select the information corresponding to the particular PPA. Based on user input, the tool filters information within the database and generates a compliance matrix in Excel format, specific to user's needs.

The compliance matrix specifies the applicable requirements, along with recommendations for customizing and tailoring these requirements. It also provides a standard methodology to facilitate the process of determining, documenting, and obtaining approval for a specific tailoring approach and policy compliance assessment. The automatically generated compliance matrix is a significant time-saver for the user, as it streamlines and integrates policy expectations based on PPA scale factors, consolidating data into a single manageable worksheet.

In addition to generating a compliance matrix, the "Customization Tool" provides matrices that summarize all required products, entrance and success criteria, best practices, recommended products, and the associated maturity levels for each of the technical and programmatic reviews within the PPA's life-cycle. This information is provided to assist the PPA implementation team in customizing the review planning to match the unique needs and characteristics of a particular PPA and its mission objectives.

Once a compliance matrix is generated via the "Customization Tool," MSFC encourages tailoring these requirements to further align with the unique characteristics of the PPA. This is accomplished through the team's careful consideration of each requirement and its applicability. As each requirement is considered, the team notes the applicability as one of the following: not applicable, applicable with modifications, or applicable with the intent to fully comply. If the team does not intend to fully comply with any requirement, a rationale is documented on the spreadsheet. The information in the spreadsheet becomes a working copy for the team. A summary of this information is extracted for presentation to Center management at the Engineering Management Council (EMC) and Program/Project Management Advisory Committee (PPMAC). Center management approval is required when the team plans to tailor requirements, and the approval process is specified within MPR 7120.1.

2.1.4 Program, Project, Activity Mission Type Categorization and Risk Classification System

2.1.4.1 Risk Classification System Defined

Effectively using the tools, particularly the "Customization Tool," requires an understanding of the PPA Mission Type (MT) Categorization system. MSFC's categorization system is derived from the Agency payload risk classification system found in NASA Procedural Requirement, NPR 8705.4 Risk Classification for NASA Payloads. The MT categorization scheme is defined on the "Instructions" tab within the "Customization Tool" as follows:

• Table 1 defines the MTs: Type 1, Type 2.a, Type 2.b, Type 3.a, Type 3.b, Type 3.c, Type 4, and Type 5;
• Table 2 defines the mission categories: Ground-Based, Manned Flight, or Unmanned flight;
• Table 3 provides a logic diagram for PPA category and type.
Each table is consistent with information contained in MPR 7120.1.

MSFC expands NASA HQ's scope of applicability to include all PPA types, as opposed to only payload PPAs. The MSFC scheme combines the risk tolerance classification concept with the Agency PPA categorization scheme found in NPR 7120.1 which is based primarily on life-cycle cost (LCC). The MSFC scheme utilizes a standard set of scaling factors to classify PPAs into eight pre-defined MT levels. The scaling factors include the following:

1) Mission criticality and significance within NASA's overall strategic plan

2) Acceptable tolerance for the risk of not achieving mission success

3) System complexity

4) Expected magnitude of the Agency's investment cost

5) Expected mission lifetime

6) Primary mission areas supported

2.1.4.2 Determining a Program, Project, Activity's Governing Requirements and Mission Type Categorization Level

The PPA manager should first determine which set of PPA management requirements are applicable for the specific application. NASA PPAs are managed under either space flight requirements, i.e. NPR 7120.5 Space Flight Program and Project Management Requirements or research and technology requirements, i.e., NPR 7120.8 NASA Research and Technology Program and Project Management Requirements. Both sets of NASA HQ requirements are flowed down into MSFC requirements as specified within MPR 7120.1. For all PPA types, the intended set of applicable governing requirements should be specified by the parent mission directorate, or PPA office. If uncertain, the PPA manager should refer to their PPA formulation authorization document (FAD) for details. If the governing requirements are not specified within the authorization documents, then the PPA manager should obtain guidance from the parent mission directorate, or PPA team.

A special category of mission types, the MT 4 and MT 5 are MSFC-specific classifications for efforts outside the range of Agency recognized PPAs. These efforts involve work that MSFC performs for other Centers. These efforts are presented to the EMC and then to the PPMAC to request approval for delegation of authority to the lowest level of MSFC management. For these activities, MSFC applies a streamlined set of activity management and reporting requirements to ensure that they meet the requirements that are driven from the parent PPA at NASA HQ.

Confusion may exist when determining PPA MT category. Often a PPA does not fit precisely within the boundaries of a particular category. Perhaps the most difficult to assess is a PPA's MT. The PPA team should use a best judgement approach and document assumptions. These assumptions should be included within the presentation package to Center management when seeking tailoring approval.

2.1.4.3 Importance of a Well-Defined Categorization System

MT categorization not only provides a framework for defining the effort, but also provides the context for assessing policy expectations and determining tailoring needs. When reviewing and approving tailoring requests, the MSFC governing authorities utilize the MT framework as a framework for risk-informed decision-making.

Not only are the mission types used to define the applicability for selected technical and programmatic products and technical reviews throughout the life-cycle, but they are also used as the basis for recommended implementation approaches for specific products and technical reviews defined within the "Customization Tool." (see section 2.1.5.1). The customized implementation approaches were developed from lessons learned and include recommendations and best practices for implementing various products with varying degrees of rigor and complexity.

2.1.5 Customization and Tailoring

2.1.5.1 Tailoring Requires Best Judgment

It is essential that the MSFC systems engineering community has a common definition of tailoring and customization. Tailoring results when a policy requirement is eliminated, or modified, to accommodate the unique nature of a PPA. Customization results when a best practice or guidance is eliminated, or modified, to accommodate the unique nature of a PPA.

Generation of a condensed compliance matrix via the "Customization Tool" is the initial step in the tailoring process. Once the automated compliance matrix is generated, the actual requirements tailoring occurs, as the user evaluates each requirement, employing best technical and programmatic judgment to determine applicability of each requirement specified. The user evaluates the requirements in the matrix item by item, determining what is, or is not, applicable to the particular effort. Even though the "Customization Tool" filters requirements based on PPA common characteristics, many requirements are dependent on particularities known only to the PPA team, characteristics impossible to specify within a standard set of questions.

For certain selected requirements, the tool will indicate a recommended methodology for implementing that requirement, e.g., implementing a control plan product as part of the overall PPA plan. For other products or requirements, the compliance matrix may indicate non-applicability to specific MTs that are below a certain threshold level. For example, some products are not applicable for MT 3, risk class D, and less than $150M LCC. When the "customization recommended" field is blank, this indicates that there is no specific recommended approach for implementing this particular requirement.

Typically, tailoring of PPA requirements is a joint effort by the PPA manager and the responsible CE.

2.1.5.2   Compliance Assessment

As each requirement is considered and the implementation approach is chosen, the user completes the compliance matrix columns, filling in the appropriate fields, indicating the PPA's approach as either:

1) full compliance

2) compliance with the intent of the requirement

3) tailoring with justification

4) "not applicable" with justification

Approval for the proposed tailoring is obtained from the appropriate governing authority as indicated in the compliance matrix which is consistent with information in MPR 7120.1. In practice, tailoring is "seeking relief" from certain requirements based on the PPA's size, complexity, and acceptable risk.

2.1.5.3   Tailoring Rationale and Justification

For all requirements designated "full compliance" or "compliance with the intent of the requirement," the user should indicate the documentation that will be used to satisfy the requirement. The user should include rationale to justify any requirements to be tailored or implemented in a manner that, although not precisely what is prescribed in the requirement, satisfies the basic intent and scope of the requirement. The user should also provide rationale justifying any requirements determined not to be applicable. This does not include requirements that are obviously not applicable based on objective PPA characteristics, e.g., a requirement that is not applicable because the requirement states that it only applies to PPAs with a LCC greater than a certain value, and the PPA in question is less than that value. Any requirement that is determined to be "not applicable" or that is tailored requires concurrence from the PPA manager, the Lead Systems Engineer and the designated CE and CSO. A summary of the tailoring justifications and the "not applicable" justifications become part of the package presented to MSFC management for approval prior to PPA implementation.

Fundamental within the tailoring philosophy is that risks must be continually considered. Tailoring rationale should include the following:
1) specifics as to how the approach differs from the requirement statement.
2) the scope and duration of the deviation.
3) identification of any additional risk incurred due to the alternate approach
4) why it is acceptable to incur the additional risk
5) stating rationale for "no additional risk."

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The rationale justifying the tailoring should be described within the context of the PPA's acceptable risk tolerance level, i.e., risk class A-D, as described in the MPR 7120.1 Mission Type classification scheme, wherever practical.

2.1.5.4 Compliance Matrix Example

Figure 2. is a snapshot of a portion of a compliance matrix generated by the "Customization Tool" and further customized by the user. Notice the three columns on the far right labelled "Program/Project Compliance," in which the user has made comments justifying the tailoring rationale.

Requirement Statement or Product Name Black text = Agency required, Red text = Agency guidance, Green text = MSFC (added) required, Blue text = MSFC (added) guidance	Recommendation per Mission Type		Actual Customization				Approvals Required for Tailoring	Program/Project Compliance			Approvals Signatures for Tailoring
	Type 2.b	Additional guidelines/commments	Implemented as recommended	Modified	N/A	Comments		Program/ Project Documentation	Comply? (Full, Tailored, or NA)	Rationale for Decisions, Comments, Waiver/Deviations	
23. Planetary Protection Plan (Certification at PDR) (see NPD 8020.7 and NPR 8020.12)		Only required for Lunar & Planetary Robotic Missions. Only required for robotic missions that may encounter other solar system bodies, including those to and from the Earth's Moon, and to all robotic solar system exploration missions returning extraterrestrial samples to the Earth or the Moon. May be combined with other plans.			*	Mission does not include any planetary aspect. System will be an ISS payload.	CD, SMD		N/A	Does not include any planetary aspect. System will be an ISS payload.	
24. Nuclear Safety Launch Approval Plan Baseline at SDR/MDR) (see NPR 8715.3)		Only required for missions involving the launch of radioactive materials into space.			*	Mission does not involve any radioactive material.	CD, OSMA		N/A	Mission does not involve any radioactive material.	
25. Range Safety Risk Mgt Process Documentation (Baseline at SIR) (see NPR 8715.5)		Only required for range operations involving space launch vehicles, entry vehicles (including sample return capsules), reusable launch vehicles (RLVs), fly-back boosters, expendable launch vehicles (ELVs), high altitude balloons, sounding rockets, drones, and unmanned aircraft systems (UAS).			*	Project not responsible for range operations. System will be an ISS payload. Will meet launch provider range safety requirements.	CD, OSMA		N/A	Project not responsible for range operations. System will be an ISS payload. Will meet launch provider range safety requirements.	
26. DM Plan (Baseline at SRR)							CD				
27. Quality Plan (Baseline at PDR)							CD				
28. Education Plan (Baseline at PDR)	N/A if < $150M LCC and high risk tolerance	Not applicable for small category 3, class D projects with LCC<$150M, per tailoring guidance on OCE "Other policy documents" webpage.			*	Not applicable for small category 3, class D projects with LCC<$150M, per tailoring guidance on OCE "Other policy documents" webpage.	CD, OE		N/A	Not applicable for small category 3, class D projects with LCC<$150M, per tailoring guidance on OCE "Other policy documents" webpage.	

Figure 2. Example of a Compliance Matrix Generated by User via the "Customization Tool"

During the customization & tailoring process and initial compliance assessment, Lead Systems Engineer (LSE), the CE and/or PPA Manager with awareness of the CSO should consult and collaborate with the Systems Engineering Office during the initial compliance assessment. The Systems Engineering Office will assist with explaining the applicability and intent of MSFC requirements and their relationship to Agency level requirements. The Systems Engineering

Office will also provide examples of tailored compliance matrices from other small PPAs, and assist with developing appropriate rationale for the proposed tailoring approach. If any tailoring requires Agency-level approval, the Systems Engineering Office will begin preliminary communications with the appropriate contacts to determine the specific information or documentation needed.

2.1.5.5 Customization Tool in Practice

An example of utilization of the "Customization Tool" is the compliance matrix generated for the "3D Printing in Zero-G," a small technology demonstration project which demonstrated additive manufacturing technology in a microgravity environment. This project flew onboard the International Space Station (ISS) inside the Microgravity Science Glovebox. This project was managed as an activity in support of research and technology. It was an MT 4 activity category with relatively low cost, but high visibility for MSFC and the Agency via the technology demonstrated. Additionally, it had high acceptable risk tolerance. Figure 3 below is an excerpt from this project's customization approach.

Figure 3. "3D Printing in Zero-G" Example of the Compliance Matrix Generated by User via the "Customization Tool"

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Another example of the "Customization Tool" in practice is the compliance matrix for the Marshall Grazing Incidence X-ray Spectrometer (MaGIXS) effort. This is a small research investigation to study the solar coronal heating through solar spectrum measurements, awarded to MSFC via the NASA Research Announcement (NRA) for Research Opportunities in Space and Earth Sciences. This instrument will fly a suborbital mission onboard a Sounding Rocket. This effort was managed as an activity in support of research and technology development. As an MT 5 activity, it represents one extreme of the mission type scale, i.e., very low cost, low criticality, and high acceptable risk tolerance. Figure 4 below is an excerpt from this activity's customization approach.

NPR # and Section	MPR 7120.1 Section	MPR 7120.1 Requirement Statement	Approvals Required for Tailoring	Program/Project Compliance			Approval Signatures for Tailoring
				Program/ Project Documentation	Comply? (Full, Tailored, or NA)	Rationale for Decisions, Comments, Waiver/Deviations	
MSFC Derived	28.3	Type 4 and 5 activities shall report the results of the Activity Agreement and Activity Plan to the Director of the MSFC office responsible for managing the activity and to the Engineering Director. The Directors may choose to impose additional project management requirements as determined appropriate based on the particular characteristics of that activity.	CD	MaGIXS Activity Plan, MPR 7120.1 Compliance Matrix Appendix	Full		
MSFC Derived	28.4	Type 4 activities shall also report the results of the Activity Agreement and Activity Plan to the Associate Director, Technical and the Center Director, who may choose to impose additional project management requirements as determined appropriate based on the particular characteristics of that activity.	CD	MaGIXS Activity Plan	N/A	MAGIXS is categorized as a Mission Type 5 Activity per guidance provided in MPR 7120.1, Table 3-1.	
MSFC Derived	28.5	Type 4 and 5 activities shall determine applicability of the following recommended technical reviews, as described in MPR 7123.1. The recommended technical reviews are SRR, PDR, CDR, Design Certification Review (DCR)/ System Acceptance Review (SAR) or Pre-Ship Review, and FRR. Category 4 and 5 activities may customize the entrance/exit/success criteria and degree of formality of the reviews, or combine reviews; provided that they include the minimum data content necessary to accomplish the objectives of each review and satisfy the success criteria that is applicable for that particular activity, as indicated in MPR 7123.1.	CD	MaGIXS Activity Plan	Full		
MSFC Derived	28.6	Type 4 and 5 activities shall assess the seventeen systems engineering processes, as described in MPR 7123.1, to determine applicability of each process for their particular activity, and complete the MPR 7123.1 compliance matrix for those that are determined applicable.	CD	MaGIXS Activity Plan, MPR 7123.1 Compliance Matrix Appendix	Full		
MSFC Derived	28.7	Type 4 and 5 activities shall report the results of the Technical Review and Systems Engineering Applicability Assessments to the Director, Engineering Directorate, for approval and follow the requirements in MPR 7123.1 for those processes determined applicable by the Engineering Director. The Engineering Director may choose to impose additional systems engineering requirements as determined appropriate based on the particular characteristics of that activity.	CD	MaGIXS Activity Plan, MPR 7123.1 Compliance Matrix Appendix	Full	Presentation to the Director, Engineering Directorate (EMC) on the System Engineering Applicability Assessment MPR 7123.1 compliance assessment. Request delegation to the STO Manager and STO Chief Engineer.	
MSFC Derived	28.8	Type 4 activities shall also report the results of the Technical Review and Systems Engineering Applicability Assessments to the Associate Director, Technical and the Center Director, who may choose to impose additional systems engineering requirements as determined appropriate based on the particular characteristics of that activity.	CD	MaGIXS Activity Plan	N/A	MAGIXS is categorized as a Mission Type 5 Activity per guidance provided in MPR 7120.1, Table 3-1.	

Figure 4. Example of Compliance Matrix for the Marshall Grazing Incidence X-ray Spectrometer (MaGIXS) Effort

2.1.6. Governing Authority Approval

2.1.6.1 MSFC Center Level Approval

The PPA manager presents an overview of the compliance assessment and proposed tailoring approach to the appropriate MSFC governance authorities per the process detailed in MPR 7120.1 and MPR 7123.1 The PPA should work with the appropriate CSO to assess the SMA requirements ensuring that the applicable SMA requirements are either implemented or that relief is properly requested and approved by the appropriate level of governance authority. The PPA manager obtains concurrence at each level of the governance authority, unless the governing official has already delegated approval authority to a lower level. Each authority may choose to delegate approval for a specific PPA, on a case-by-case basis. In addition, individual requirements may necessitate different levels of approval. For any requirement that needs Agency-level approval, the PPA has to obtain the concurrence of the Associate Director, Technical before obtaining Agency approval.

The requirement is to obtain approval of the MSFC or NASA HQ management authority, as appropriate. This may be accomplished within standard meeting forums, e.g., PPMAC, EMC, Safety and Mission Assurance Council (SMAC), PPA Office Monthly Reviews. Alternatively, it may be accomplished "out-of-board" at the discretion of the management authority. The standard EMC meeting minutes will serve as record, if approved, within the board meeting, but the "out-of-board" option requires generation of a Memorandum of Record (MOR) to capture evidence of approval by the appropriate authority. Approval by the board is preferred, as this method provides greater visibility for the PPA and facilitates discussion with various PPMAC organizational representatives. Figure 5 captures the MSFC tailoring approval process.

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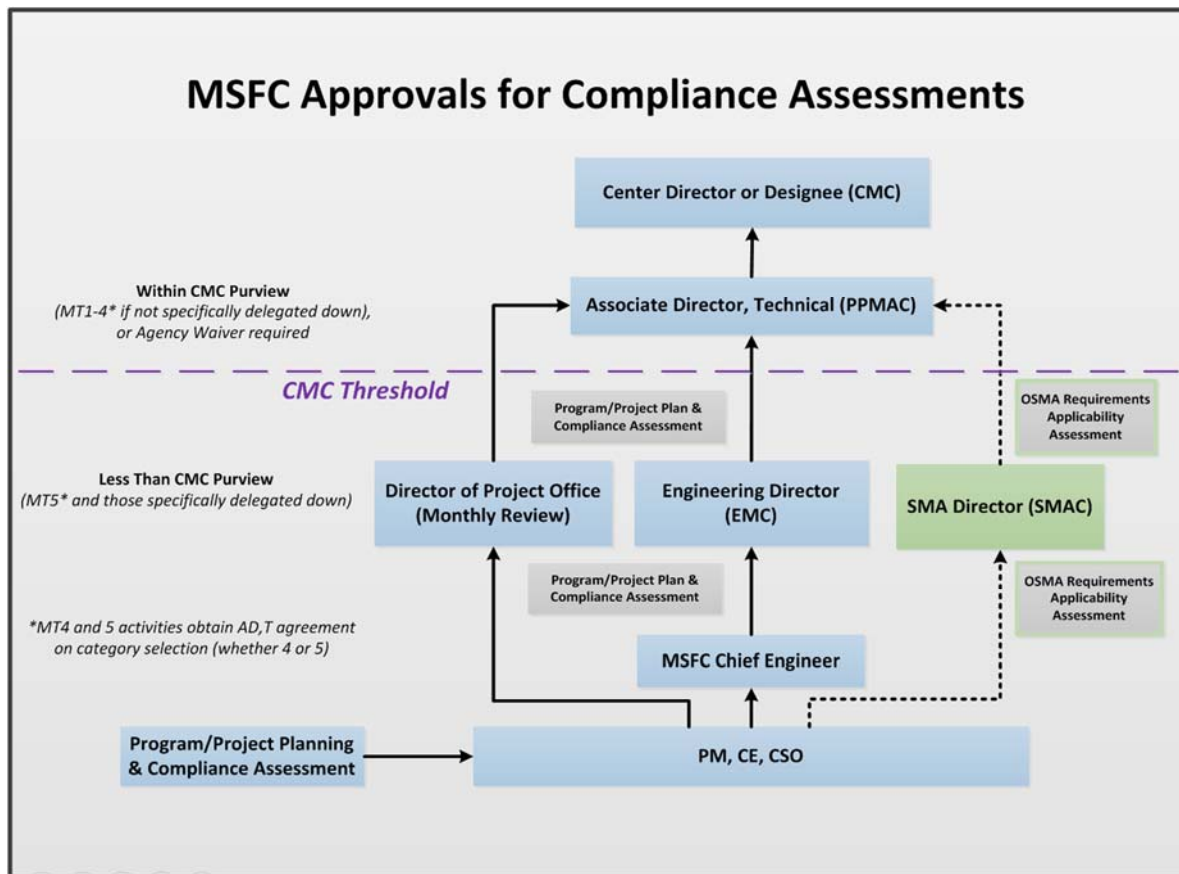
Figure 5. MSFC Tailoring Approval Process

2.1.6.2   Agency Level Approval

When Agency level approval is required, the SE Office is available to work with the PPA manager in obtaining that approval, following concurrence from the MSFC Associate Director, Technical. In most cases, the PPA manager may proceed with implementation once the Center level approval is obtained. The Systems Engineering Office will work with the PPA manager and the CE to document and communicate the draft "Request for Relief" to the NASA Headquarters (HQ) Point-of-Contact (POC). The Systems Engineering Office maintains a list of HQ POCs and will prepare the relief request memo, per a standard template. The Systems Engineering Office will obtain the concurrence of the PPA manager, CE, and CSO (if applicable), and route the request through the MSFC Directives Manager for concurrence of the Document Control Board (DCB) Chairperson prior to submitting to the Associate Director, Technical.

The MSFC Associate Director, Technical will submit the "Request for Relief" memo to the appropriate HQ Authority and will communicate the results, i.e., the response memo, from HQ to the PPA manager and Systems Engineering Office. Formal relief request and response memos will be retained as records on the PPMAC website, and a copy will be provided to the PPA and the CE. The PPA should document the results in the compliance matrix along with the

corresponding memos, or, alternatively, include a reference to the PPMAC record location. Figure 6 captures the Agency "relief request" approval process.
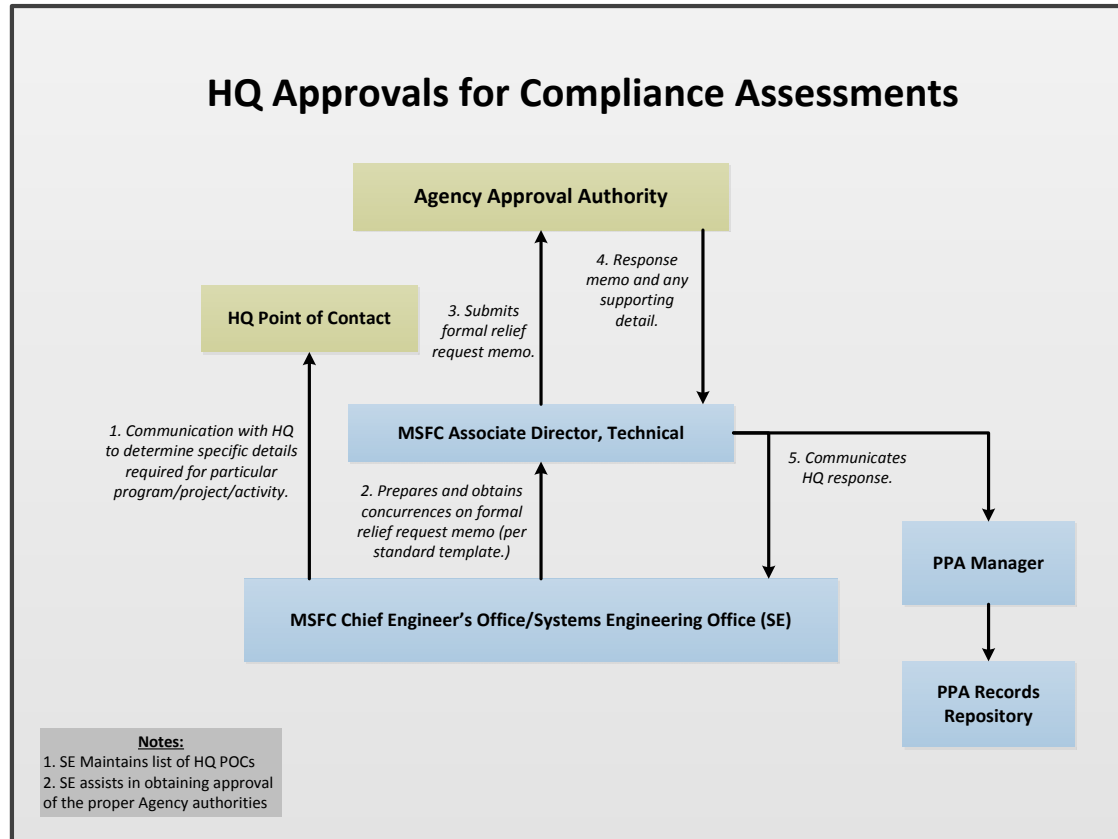
Figure 6. Agency "Relief Request" Approval Process

There are limited situations in which NASA Headquarters approval is required, and these instances are specified within the Compliance Matrix generated via the Customization Tool. Within the Compliance Matrix, there is a column titled "Approvals Required for Tailoring" which specifies any approvals required by displaying the name of the approving organization for each requirement. In most cases, this field indicates "CD" for Center Director. In some cases it specifies "OCE," indicating that approval by the Headquarters Office of the CE is required for tailoring that requirement. In a few cases, "OSMA," indicating that the Office of Safety and Mission Assurance must approve tailoring of the requirement. There may occasionally be a Headquarters Directorate specified, indicating that a particular Directorate's approval is required for tailoring a specific requirement, but those are rare. Typically, this column indicates one of the following: CD, OCE, or OSMA.

For assistance with understanding and obtaining the necessary approvals, please contact the Systems Engineering Office.

2.1.7 Conclusion

MSFC's evolving systems engineering and PPA management culture is intended to promote an integrated and streamlined approach which should preserve valuable resources and increase efficiency. Although a new philosophy and culture of streamlining and tailoring has emerged, MSFC management remains sensitive to risk-based decision-making. As each PPA team develops its unique tailoring approach and presents the proposal to MSFC management for approval, it is essential that the MSFC governance authorities receive adequate information in order to gain the necessary insight and oversight for decision-making that ensure mission success.

2.2   Technical Authority Overview

Within NASA, Technical Authority (TA) is a fundamental aspect of NASA's governance structure, which utilizes a system of checks and balances between Programmatic Authorities and Institutional Authorities to ensure mission success by balancing the need for cost and schedule efficiency with appropriate emphasis on availability of workforce/infrastructure, technical rigor, and compliance with applicable requirements from Agency/Center policy and technical standards. TA is a primary component of Institutional Authority. TA provides for independently funded oversight of PPAs in support of safety and mission success. TA flows down from the Administrator, through the NASA CE and the NASA Chief Safety & Mission Assurance Officer, to the Center Directors. At MSFC, SMA TA flows to the SMA Director, and Engineering Technical Authority (ETA) flows to the Engineering Director (refer to MCP 8070.2, (MSFC) Technical Authority Implementation Plan for additional details). Below the level of the Engineering Director, ETA splits into two parallel paths; 1) system level ETA flows through the MSFC CE to the applicable CE for the PPA to which they are assigned, and 2) discipline level ETA flows down through the Engineering line managers for the disciplines in their respective organizations.

The CE coordinates with the PPA manager and integrates the involved technical disciplines and SMA to ensure proper strategic direction and scope-of-work is established for each PPA. It is the CE's responsibility to ensure that MSFC utilizes technically sound engineering practices, develops technically sound solutions, and that PPA management is aware of all technical risks associated with PPA implementation throughout the life-cycle. The CE executes ETA by establishing the Engineering position (in coordination with the involved disciplines) for PPA technical decisions and resolution of any technical issues. The CE works with Engineering Department/Laboratory/Division/Branch management and PPA management to ensure that the appropriate engineering position is established and represented for all PPA issues and decisions. Often the CE performs the role of mediator when disagreements arise between technical disciplines or between technical disciplines and the PPA Offices. Any disagreements, alternate opinions, or disputes are resolved at the lowest possible level utilizing the dissenting opinion process (refer to MCP 8070.2 for additional details). Any disputes that cannot be resolved between CE and discipline management are elevated to the EMC for adjudication and decision by the Engineering Director. Likewise, any disputes that cannot be resolved between Engineering

and PPA management are elevated to the Center Management Council (CMC) for adjudication and decision by the Center Director.

The CE also works closely with the LSE for day-to-day coordination, communication, and integration of technical direction with the various disciplines. The LSE is sometimes supported by other systems engineers who handle lower level integration, reviewing technical information, and making appropriate recommendations to the LSE and CE.

The CE works technical details with the LSE and supporting engineers as the situation necessitates. The CE integrates the output from the LSE, Systems Engineering, engineering disciplines, SMA, PPA office, and support contractors. The CE, the LSE, and the systems engineer work in close coordination to ensure that for each decision the perspective of all stakeholders are considered and all relevant technical issues are addressed; keeping the PPA management informed of any risks or technical issues as appropriate. However, since the LSE and the systems engineers do not have formal ETA, the CE makes the final decision when reviewing technical recommendations from the LSE/systems engineers and reporting to the PPA Manager.

The CE works with the PPA Manager to define the roles and responsibilities for technical support within the PPA. In some small PPAs with limited workforce allocation, there may not be a dedicated CE for each PPA, but there is always one individual designated to perform the CE function, although they may also support other small PPAs. In addition, the CE may perform the duties of the LSE and/or systems engineer, if an LSE or systems engineer is not assigned for that particular PPA. The MSFC model for ETA and technical support is very flexible with many options for customizing how the designated roles are filled and how day-to-day operations are performed, as long as the final technical decisions are made by those within the formal ETA delegation chain.

2.3   Systems Engineering Matrix to Quality Management System

Table 1, below, illustrates the relationship between an AS9100D Quality Management System (QMS), and the systems engineering processes. The QMS supports implementation of the systems engineering processes throughout the life-cycle, and serves to ensure quality of the products and effectiveness of the processes. AS9100 compliance is required both in-house at MSFC and by the prime contractors for flight projects. ISO quality standards which are tailored for suppliers are flowed down as applicable.

Table 1. AS9100D and Systems Engineering

SE PROCESS	AS9100D REQUIREMENT
Stakeholder Expectations	Needs and Expectations of Interested Parties; Customer Focus; Customer Communication
Technical Requirements Definition	Requirements for Products and Services
Logical Decomposition	Design and Development Planning/Inputs
Design Solution Definition	Design and Development Outputs; Resources; Organizational Knowledge
Product Implementation	Design and Development Controls; Control of Production and Service Provision
Product Integration	Control of Externally Provided Processes, Products and Services
Product Verification	Design and Development Controls: Verification Activities
Product Validation	Design and Development Controls: Validation Activities
Product Transition	Release of Products and Services; Post Delivery Activities
Technical Planning	Operational and Planning Control
Requirements Management	Design and Development Planning/Inputs; Control of Externally Provided Processes, Products and Services
Interface Management	Control of Externally Provided Processes, Products and Services
Technical Risk Management	Actions to Address Risks and Opportunities
Configuration Management	Design and Development Changes; Changes to Requirements; Identification and Traceability; Control of Changes; Control of Nonconforming Outputs
Technical Data Management	Documented Information; Control of Documented Information; Control of Changes
Technical Assessment	Performance Evaluation; Monitoring, Measurement, analysis and Evaluation; Internal Audits
Decision Analysis	Measurement Review

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3.   SYSTEMS ENGINEERING

Systems engineering is an engineering approach that systematically considers all aspects of a PPA in making system design choices. Systems engineering as a methodology is applicable to all levels of a PPA, and to all levels of a design (i.e., system, subsystem, and component). The success of complex space vehicles and space vehicle PPAs 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.   Assist the PPA manager in assessing risks and identifying mitigations. Proper PPA planning will then strive to mitigate the identified risks.

A systems engineering function is needed on every development and operational PPA. The planned systems engineering and integration activities for a PPA are normally described in a Systems Engineering Management Plan (SEMP) that is used in managing the systems engineering functions. (A SEMP is normally not required for small, research type PPAs.) Systems engineering is responsible for ensuring the top PPA 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 PPA 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 PPA ensures that all assembly and integration activities and support are identified, planned, scheduled, and executed to support the overall PPA 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 PPA ensures testing facilities are developed and verified and ready to support the PPA schedule. Identifying any special test equipment early ensures its availability. The PPA 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 Systems Engineering Engine (see Figure 7) 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 Systems Engineering 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 7, The NASA Systems Engineering Engine.

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

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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 (TRM) Process, the Configuration Management (CM) Process, the Technical Data Management (TDM) Process, the Technical Assessment Process, and the Decision Analysis Process.

The Technical Management Processes connects PPA 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 PPA's objectives. The PPA management team also uses the eight technical management processes to execute PPA 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.

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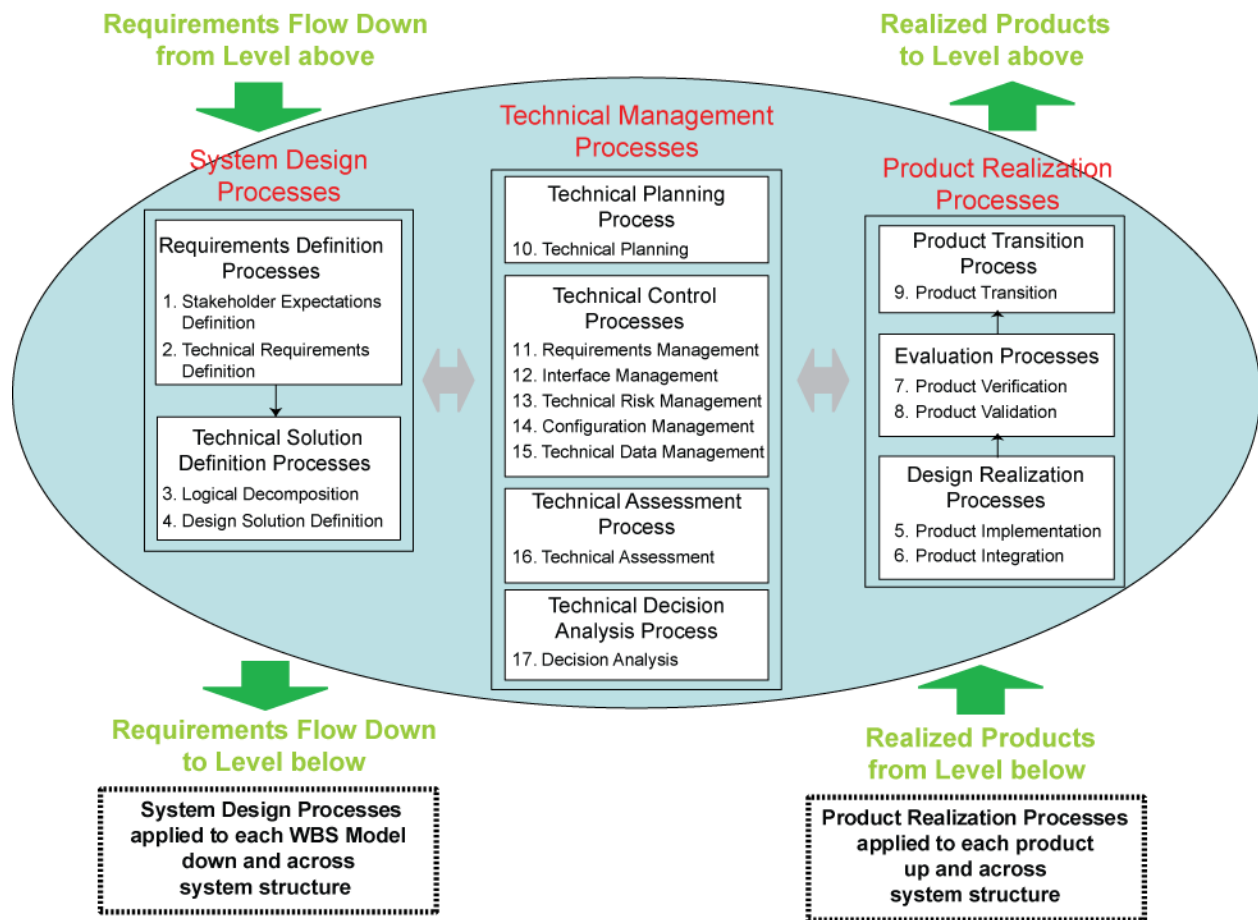
Figure 7. The NASA Systems Engineering Engine

The *System Design Processes* employ a "top down" design of each product in the system structure. The *System Design Processes* include SED, TRD, LD, 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, TRM, CM, TDM, technical assessment, and decision analysis processes.

The NASA Systems Engineering Handbook, NASA/SP-6105 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 M-del 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 8, the System 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.
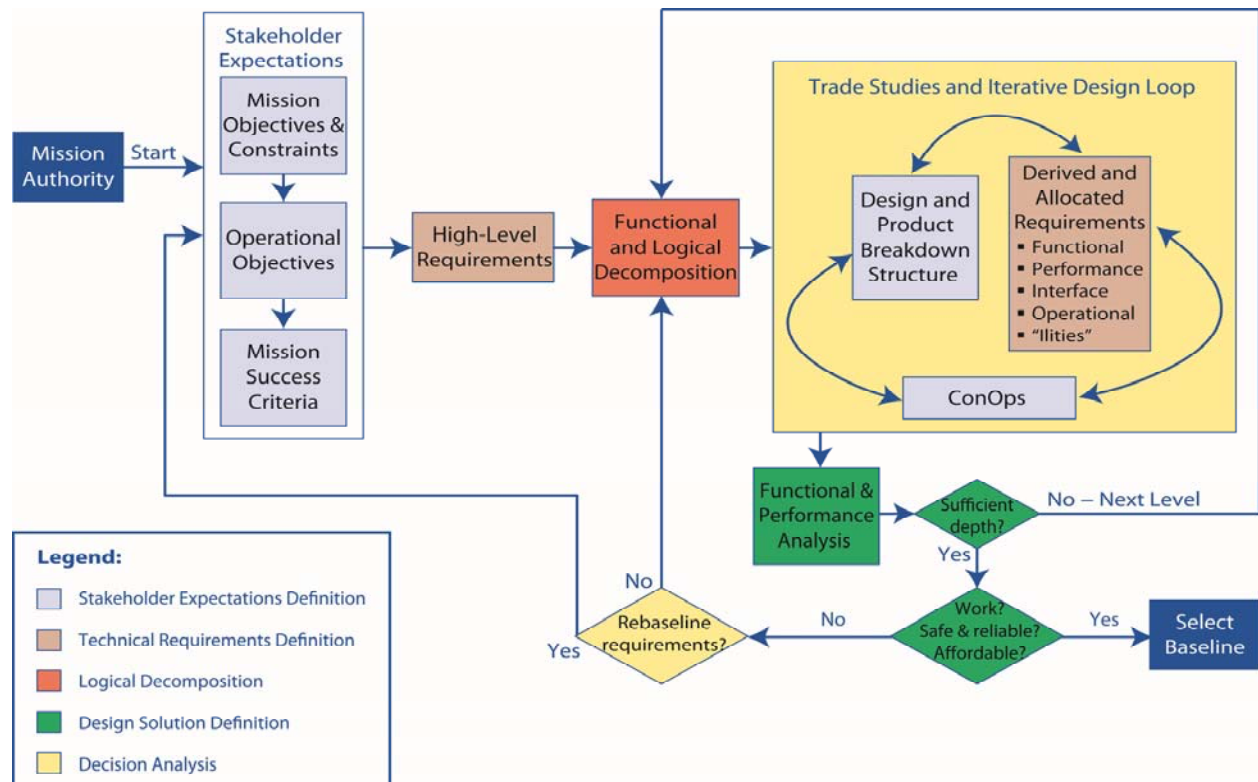
Figure 8. Interrelationships Among the System Design Processes

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 8) have much more of a serial relationship with one another. In the Technical Management Processes the relationship is much more parallel in nature.

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3.1   Systems Design Processes

3.1.1   Requirements Definition Processes

3.1.1.1   Stakeholder Expectation Definition

The Stakeholder Expectations Definition (SED) Process is the initial process within the systems engineering engine that establishes the foundation from which the system is designed and the product is realized. The stakeholder expectations are typically captured in a PPA 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 PPA Plan and/or SEMP will point to this higher-level Agency documentation for the capturing the stakeholder expectations. The stakeholder SED process is used to elicit and define use cases, scenarios, concept of operations (ConOps), 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-cycle enabling 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.   TA, standards, regulations, and laws.

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

   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 systems engineering 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 TRD, LD and Design Solution Processes. This linkage is important since some requirements will become fully defined only

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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 SED Process.

Key Inputs and Sources:

     a.   Customer expectations (from users and PPA).

     b.   Other stakeholder expectations (from PPA and/or other interested parties of the WBS model products recursive loop).

     c.   Customer flow-down requirements from previous level WBS model products (from DSD 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 TDM Process).

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

     c.   Baseline ConOps (to TRD Process and CM Processes).

     d.   Measures of Effectiveness (MOEs) (to TRD Process and TDM Process).

3.1.1.1.1   Stakeholder List

Advocacy for new PPAs 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 PPA 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 PPA.

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

Tasks	Steps
Task 1 Identify Stakeholders Number so it can be referenced.	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, PPA 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 PPA 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 PPA 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	Provides methodology to identify stakeholder.

MSFC Technical Standard EE10		
Title: Systems Engineering Handbook	Document No.: MSFC-HDBK-3173	Revision: C
	Effective Date: November 9, 2018	Page 36 of 277

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 PPA 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

3.1.1.1.2   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 NGOs Document. Stakeholder expectations can also be elicited informally through an interview process or working group/ 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

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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 ConOps. 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.

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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. PPA 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 facilitate 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 PPA set of stakeholders that the Stakeholder Expectations Document has achieved sufficient maturity to be baselined.

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Tasks	Steps
	b. Obtain signature approval to baseline the Stakeholder Expectations Document from the appropriate Designated 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 CM procedures.

Examples	
Expectations Prioritization Matrix	Prioritization will facilitate the decision making process when conflicts and inconsistencies when collecting and analyzing stakeholder expectations.

3.1.1.1.3 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.

Figure 9 below, shows the relationships of MOEs, MOPs, and Technical Performance Metrics (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 TRD process activities.

MOEs — Derived from stakeholder expectation statements; deemed critical to mission or operational success of the system

MOPs — Broad physical and performance parameters; means of ensuring meeting the associated MOEs

TPMs — Critical mission success or performance attributes; measurable; progress profile established, controlled, and monitored

Figure 9. 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
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 PPA set of stakeholders that the MOEs have achieved sufficient maturity to be baselined. b. Baseline the MOEs in accordance with established CM procedures.
Manage and maintain MOEs	The baselined MOEs are placed under formal configuration control in accordance with established CM procedures.

Resources / Examples for MOE Development

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

Defense Acquisition University Systems Engineering Fundamentals	Metrics.
DAU Test and Evaluation Management Guide, Fifth Edition	Evaluation.

3.1.1.1.4   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 PBS. The system level ConOps is provided during the concept studies phase and provided for the Mission Concept Review (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 PPA 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 PPA. The proposed capabilities are listed order of priority (importance) in terms of meeting the stated NGOs 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

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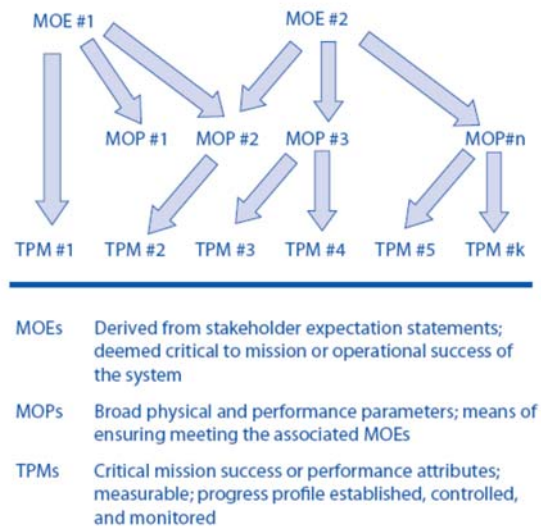your expectations are identified. The current maturity level of these technologies is the basis for quantifying the level of risk to the PPA.

The following MSFC Data Requirements Descriptions (DRDs) are applicable to the development of this systems engineering process providing expectations as described:

STD/SE CONOPS Concept of Operations, provides additional content expectations for developing a ConOps, to satisfy the requirements of MPR 7123.1. The ConOps specifies the uses, capabilities, and functions of the system, from which requirements are developed. The ConOps provides guidance to the system's developers on how the system will be used, operated, and maintained during all life-cycle phases so that their designs, development, integration, and tests will accommodate the needs, goals, objectives, missions, and operational philosophy of the stakeholders.

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.	(1) Identify strategies for development and integration, production, test, operations and logistics. (2) Identify, analyze and clarify constraints resulting from these strategies.
Baseline the ConOps.	(1) Obtain approval from the PPA set of stakeholders that the ConOps has achieved sufficient maturity to be baselined. (2) Baseline the ConOps in accordance with established CM procedures.
Manage and maintain ConOps.	The baselined ConOps is placed under formal configuration control in accordance with established CM procedures.

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Resources / Examples for Con Ops Development

NASA Systems Engineering Handbook, NASA/SP-6105	See Figure 10 End-to-end operational architecture.
NASA Systems Engineering Handbook, NASA/SP-6105	Lunar sortie timeline.
NASA Systems Engineering Handbook, NASA/SP-6105	See Figure 11 Lunar sortie DRM.
NASA Systems Engineering Handbook, NASA/SP-6105	See Figure 12 Detailed, integrated timeline for a science 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™	A guide prescribing the format and contents of the ConOps document.
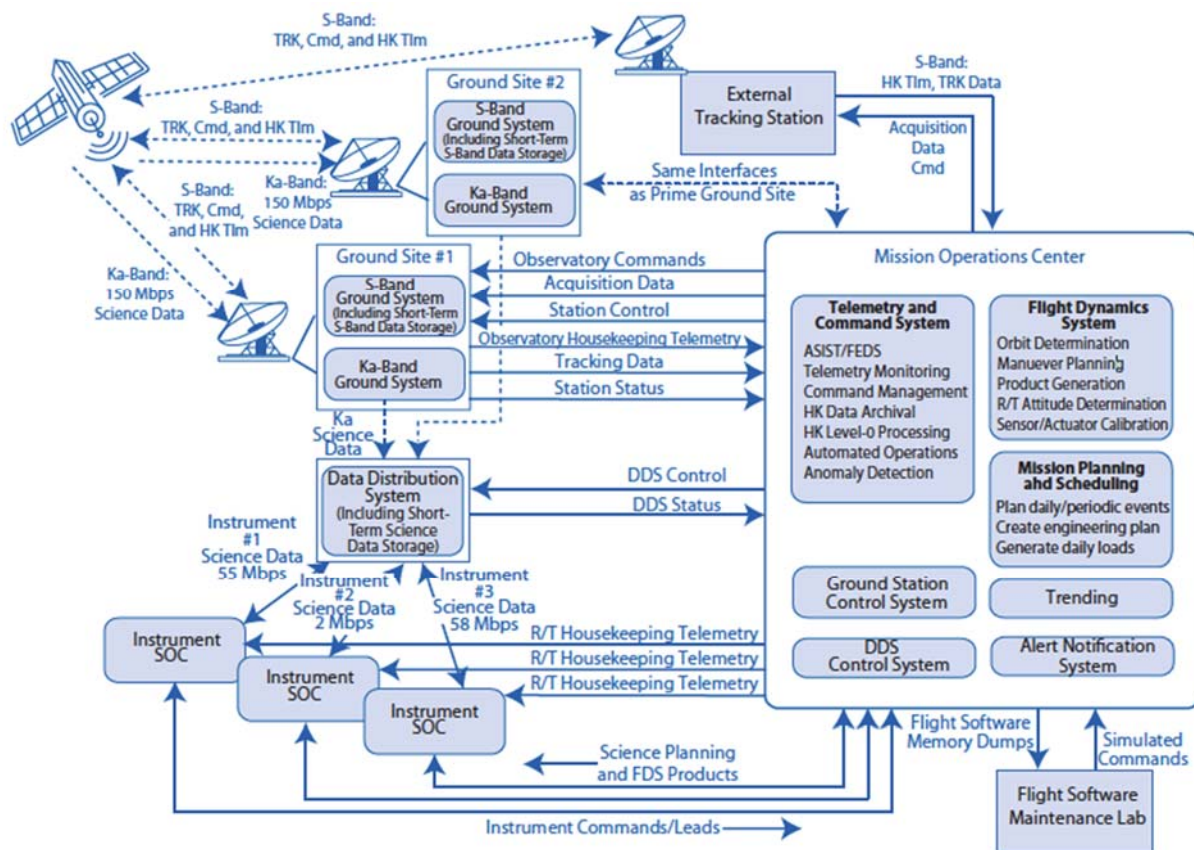
Figure 10. Example of an Associated End-to-End Operational Architecture
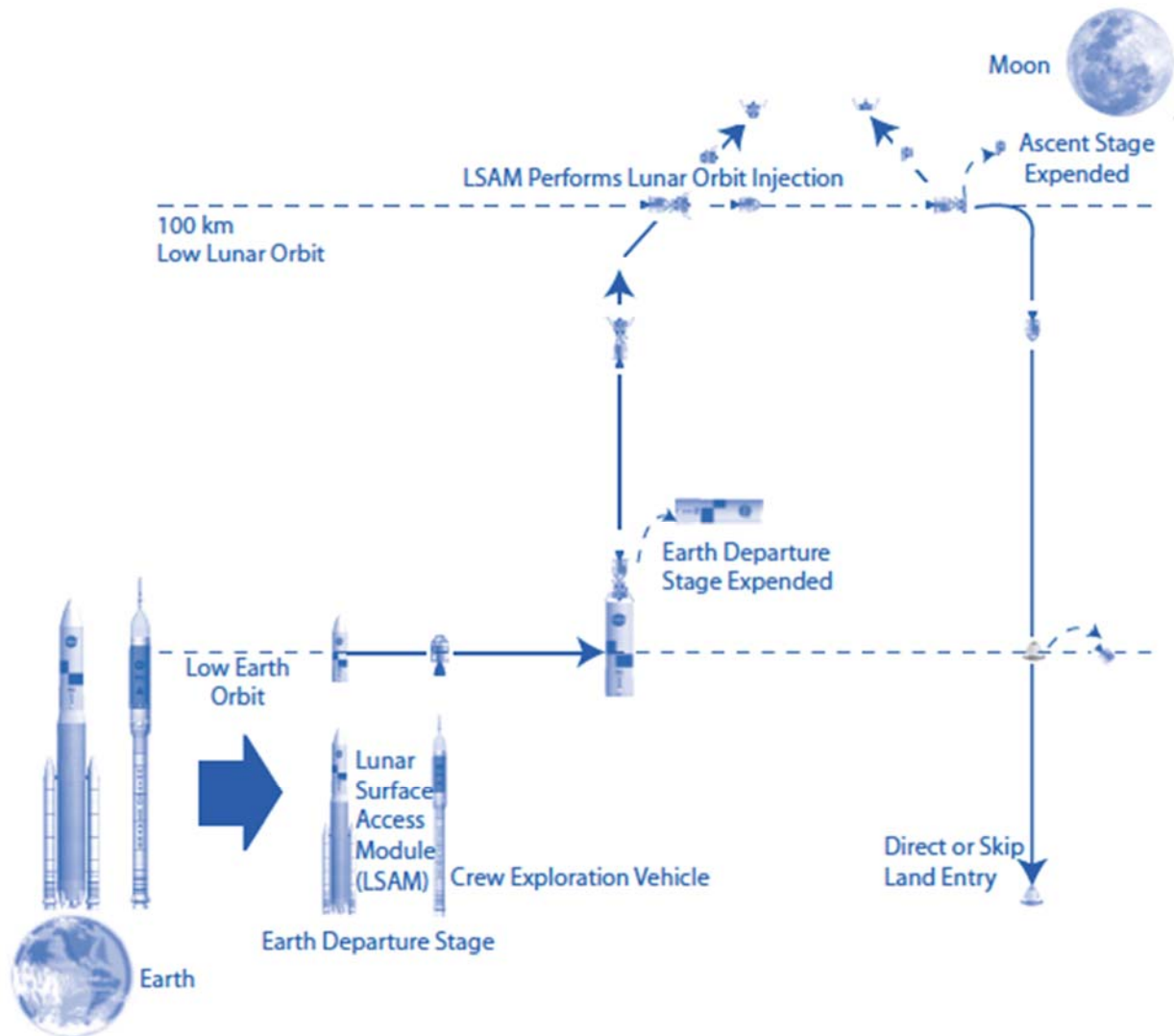
Figure 11. Example of a Lunar Sortie DRM Early in the Life-Cycle

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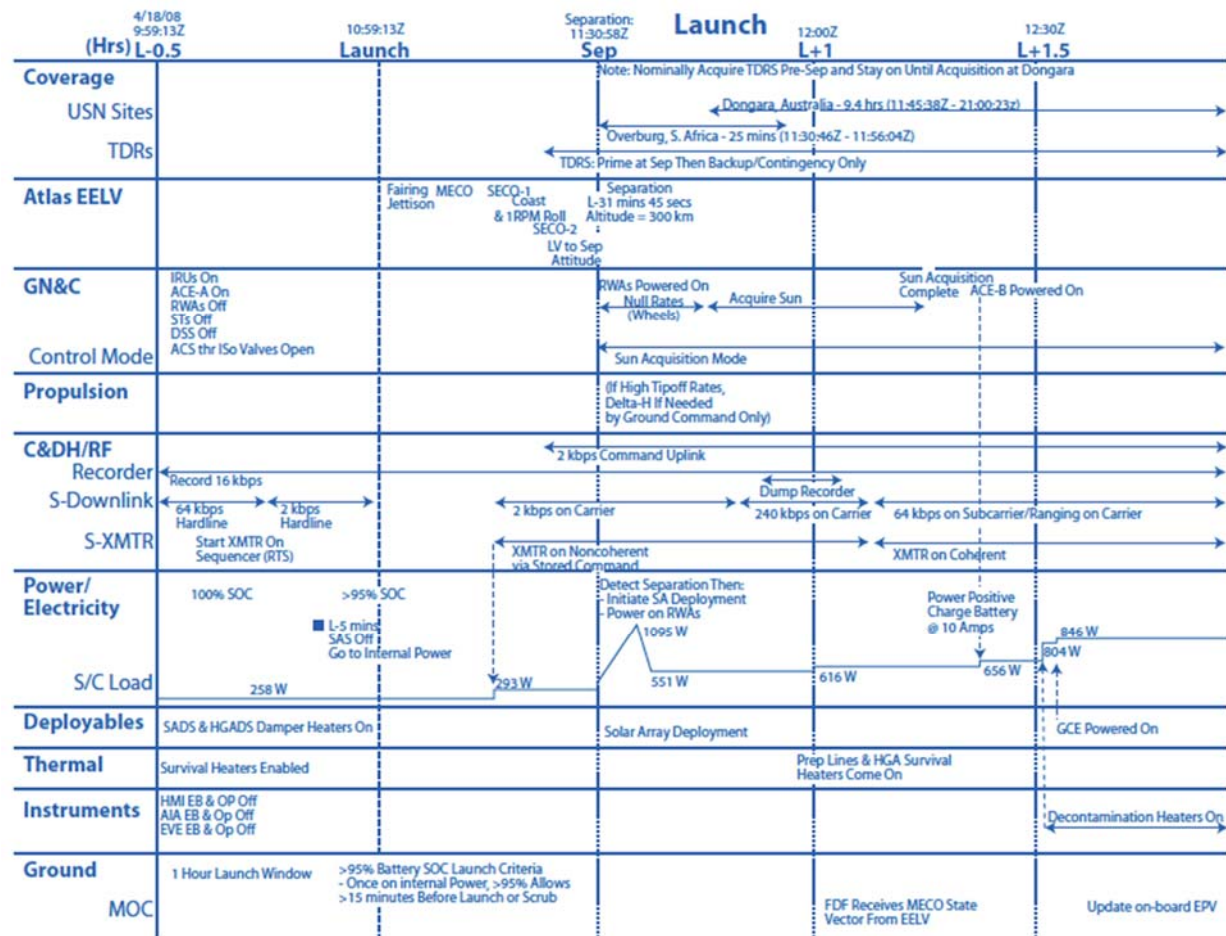
Figure 12. Example of a More Detailed, Integrated Timeline Later in the Life-Cycle for a Science Mission

3.1.1.2 Technical Requirements Definition

The 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.

Key Inputs and Sources:

      a.   Baselined set of stakeholder expectations (from SED and CM Processes).

    b.   Baselined ConOps (from SED and CM Processes).

    c.   Baselined Enabling Product Support Strategies (from SED and CM Processes).

    d.   Measures of Effectiveness (from SED and TDM 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 Systems Engineering 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.

Key Outputs and Destinations:

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

    b.   Sets of MOPs that satisfy the MOEs to which a set is related to (LD and TDM Processes).

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

3.1.1.2.1 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 PPA stakeholders.

The LD process continues to further decompose and be allocated to lower levels of the system for every level of the 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.

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As part of the requirements vetting process, it is important to focus not only on the requirements but also on the verification method and associated activities for those requirements, to be discussed at the same time. Such activities that involve analyses, and/or testing that are necessary for verification need to be identified early in the requirements development process so they can be assessed against allocated resources, budget and schedule. Linking requirements development with verification methods will avoid potential cost-bearing and schedule problems later in the PPA life-cycle.

The following MSFC DRDs are applicable to the development of this systems engineering process providing expectations as described:

STD/SE-REQSPEC, Requirement Document/Specification, provides content expectations for developing requirements documents and/or specifications, to satisfy the requirements of MPR 7123.1. Requirements documents specify "what" must be achieved by a system of interest. Specifications specify "how" design requirements are going to be achieved, or "how" an end item is going to be fabricated, and has more definition to the trade space. It includes functional and performance requirements, operational environments, and interface requirements. Specifications are usually implemented at lower levels of system definition where the end-item is ready for Make/Buy/Code.

STD/SE-IRD Interface Requirements Document, provides content expectations for developing an Interface Requirements Document (IRD), to satisfy the requirements of MPR 7123.1. The IRD identifies basic functional and physical performance requirements which are the basis for generating the design solutions found in the Interface Control Document (ICD). Interface requirements may be captured as part of the PPA set of requirement documents or specifications (See STD/SE-REQSPEC), but can also be contained in a separate IRD due to a complicated interface or due to signature approvals between two or more parties.

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. 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.
	
	b. Generate a requirements rationale statement that explains how the specific requirement was derived by referencing source material versus trying to justify the requirement.
	c. Generate a bi-directional traceability matrix between the functions and operations performed by the system of interest and the technical requirements.
	d. Ensure derived technical requirements trace back to a single parent requirement.
	e. 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

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	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.

Consolidate and prepare Technical Requirements Document.	Refer to DRD (STD/SE-REQSPEC) "Requirement Document/Specification" (REQSPEC)," for a description on preparing the requirement document or specification for a specific Configuration Item (CI).
Submit the completed set of technical requirements for approval.	a. Obtain approval from the PPA 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 CM procedures.

Examples

NASA Systems Engineering Handbook, NASA/SP-	See Figure 13 Example of a Functional Flow Block Diagram (FFBD) Flow Down
NASA Systems Engineering Handbook, NASA/SP-6105	See Figure 14 Example of an N^2 Diagram
NASA Systems Engineering Handbook, NASA/SP-6105	See Figure 15 Example of a Timing Diagram
NASA Systems Engineering Handbook, NASA/SP-6105	Figure 16 Example of The Flow Down of Requirements
NASA Systems Engineering Handbook, NASA/SP-6105	Trade Studies
NASA Systems Engineering Handbook, NASA/SP-6105	See Figure 17 Example of a Requirements Allocation Sheet
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
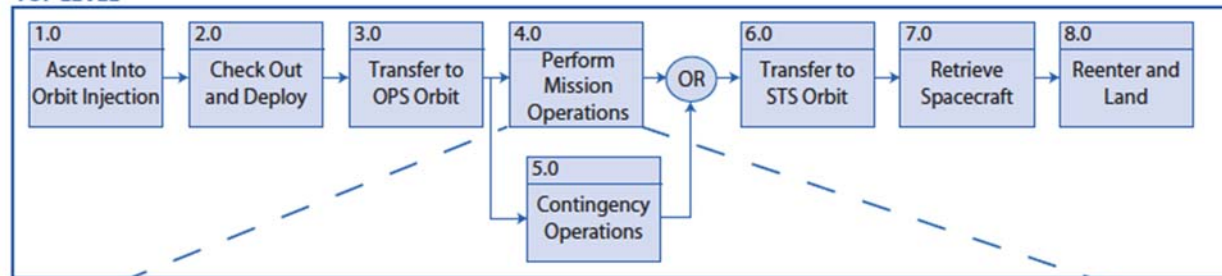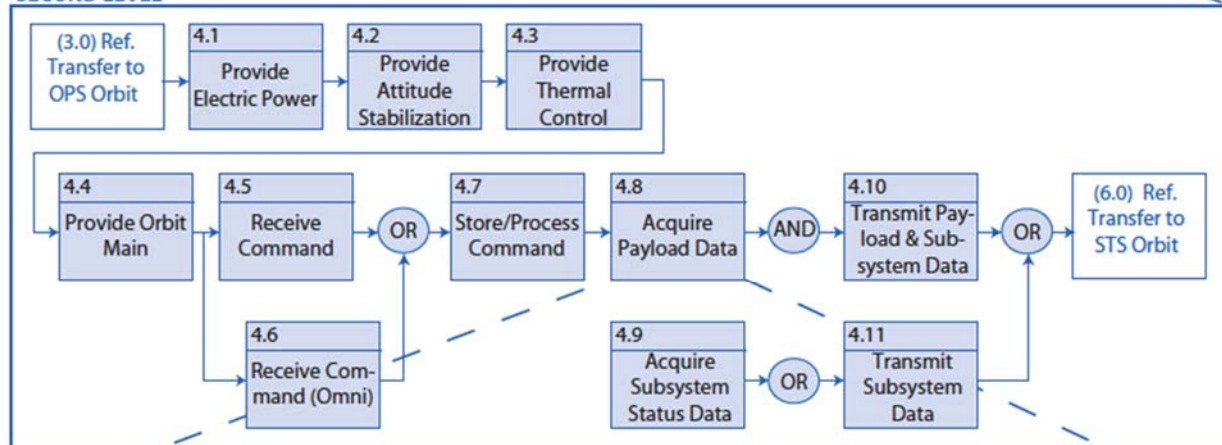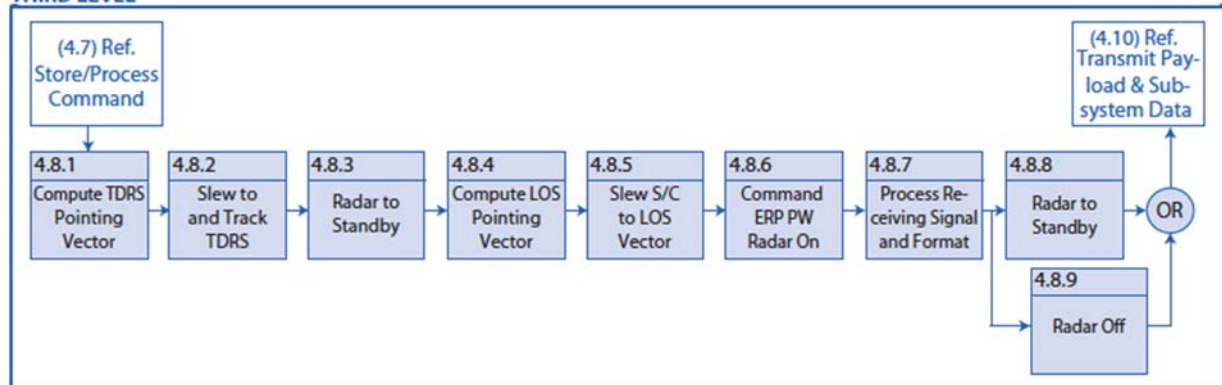
Figure 13. Example of a Functional Flow Block Diagram (FFBD) Flow down

Figure 14. N² Diagram for Orbital Equipment

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Figure 15. Example of a Timing Diagram

Figure 16. Example of Flow Down of Requirements

Figure 17. Example of a Requirements Allocation Sheet

3.1.1.2.2 Measures of Performance

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 PPA risk.

Examples of MOPs are contained in the NASA Systems Engineering Handbook, NASA/SP-6105.

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 CM procedures.

Examples

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

3.1.1.2.3   Technical Performance Measures

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.

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 CM procedures.
Status and Report TPMs.	Prepare and submit TPM status reports in accordance with PPA communication requirements.

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

3.1.2   Technical Solution Definition Processes

3.1.2.1   Logical Decomposition

LD is the process for creating the detailed functional requirements that enable NASA PPAs to meet stakeholders' expectations. The LD process identifies "what" will be achieved by the system at each level to enable a successful PPA. 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 PPA.

The LD process is used to:

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

b. Decompose the parent requirements into a set of LD models and their associated sets of derived technical requirements for input to the DSD Process.

Inputs and Sources:

a. The baselined set of validated technical requirements, including interface requirements (from TRD and CM Processes).

b. The defined MOPs (from TRD and TDM Processes).

Outputs and Sources:

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

b. The set of LD models (to DSD and CM Processes).

c. LD work products (to TDM 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 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, Interface 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 PPA 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 PPA SEMP.

The LD process employs similar tools and techniques that were used to perform the TRD process. 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 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 LD 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.

3.1.2.1.1 System Architecture

The system architecture lays out the elements of the system or product hierarchy so that the components, sub-systems, systems functional and physical relationships, dependencies, and interfaces can be clearly defined and understood as shown in Figure 18 below. This may also be used to assess influences that may be made to a dependent component, sub-system, or system when a design or function modification is made.
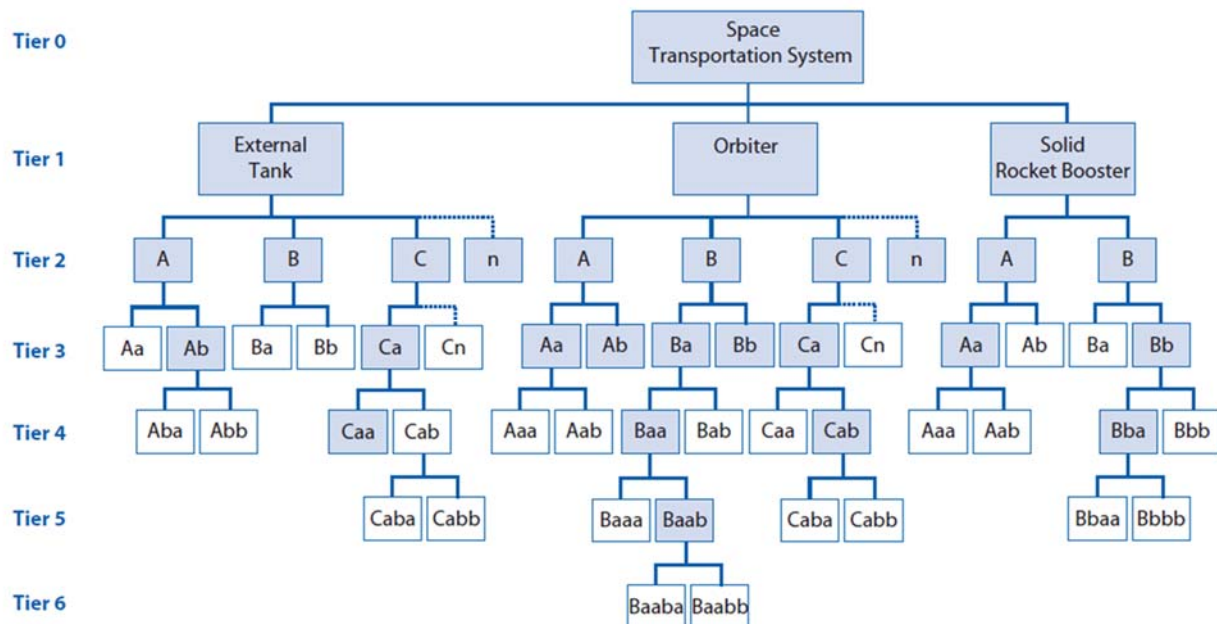
Figure 18. Product Hierarchy: Complete Pass Through System Design Processes Side of the Systems Engineering Engine

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 MSFC DRD is applicable to the development of this systems engineering process providing expectations as described:

STD/SE SARCH System Architecture, provides content expectations for developing a System Architecture, to satisfy the requirements of MPR 7123.1. The System Architecture describes the organization of a system (i.e. "system of interest") composed of hardware and/or software items

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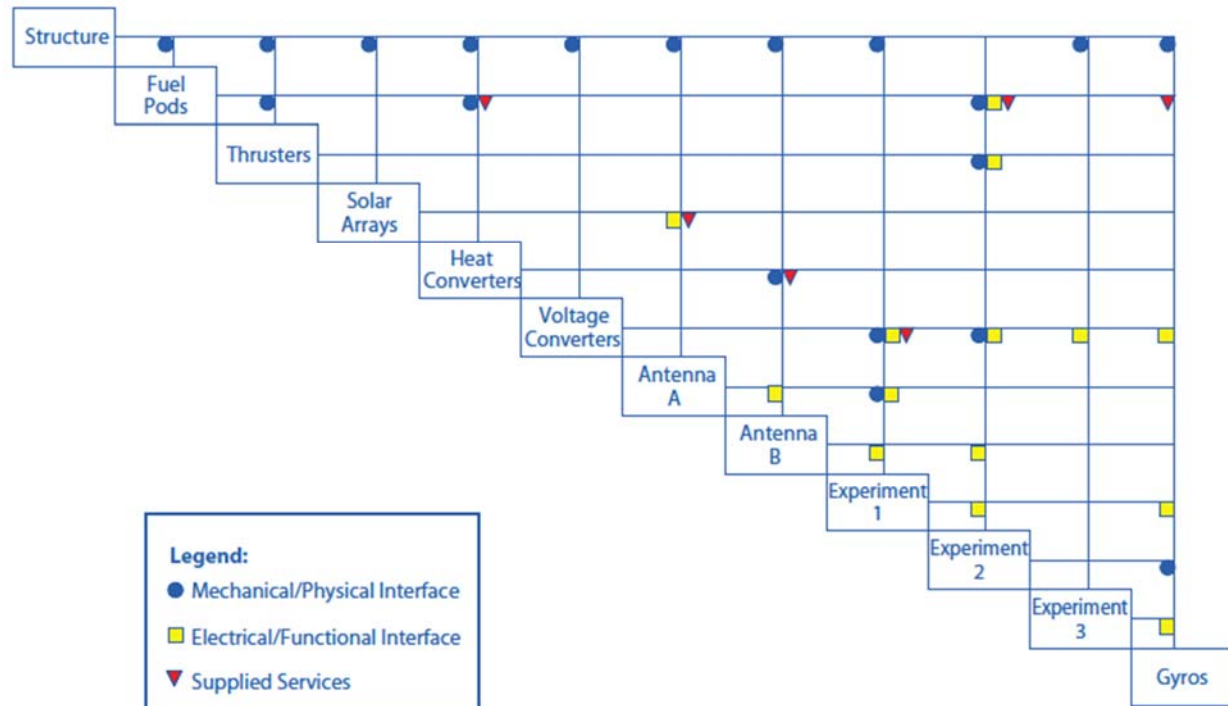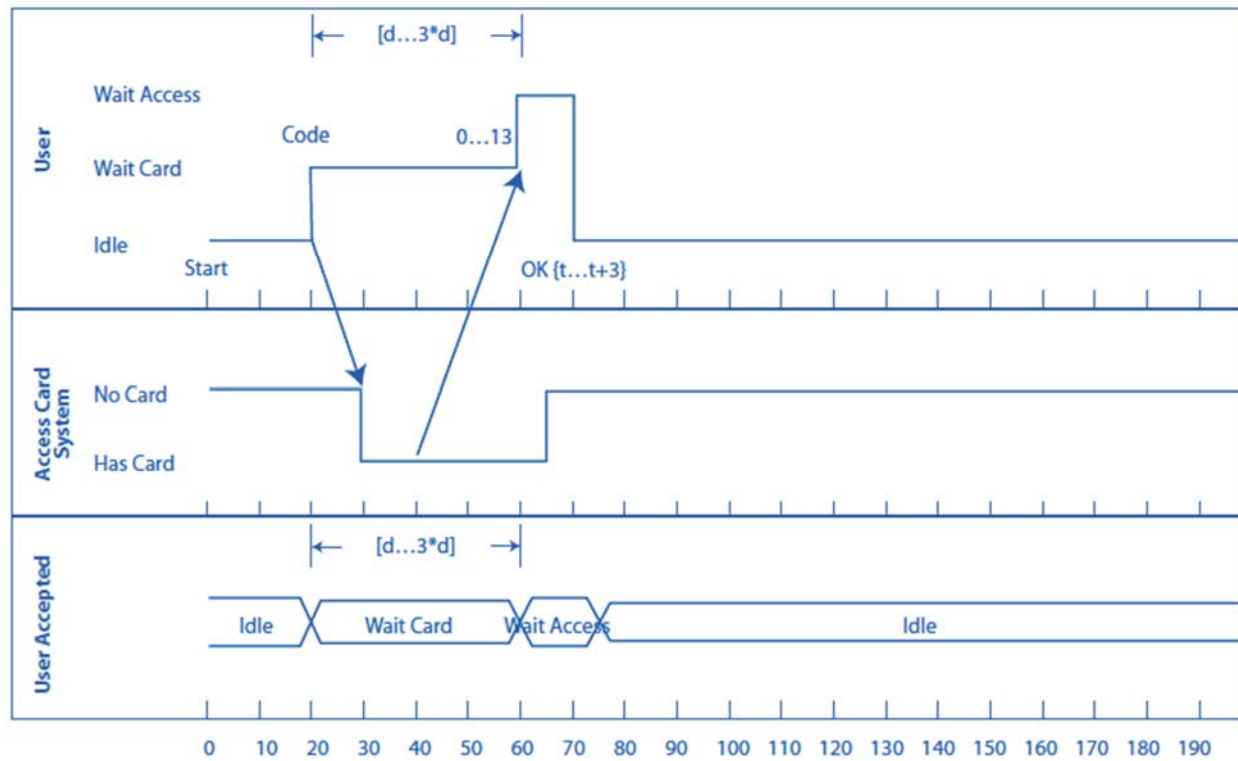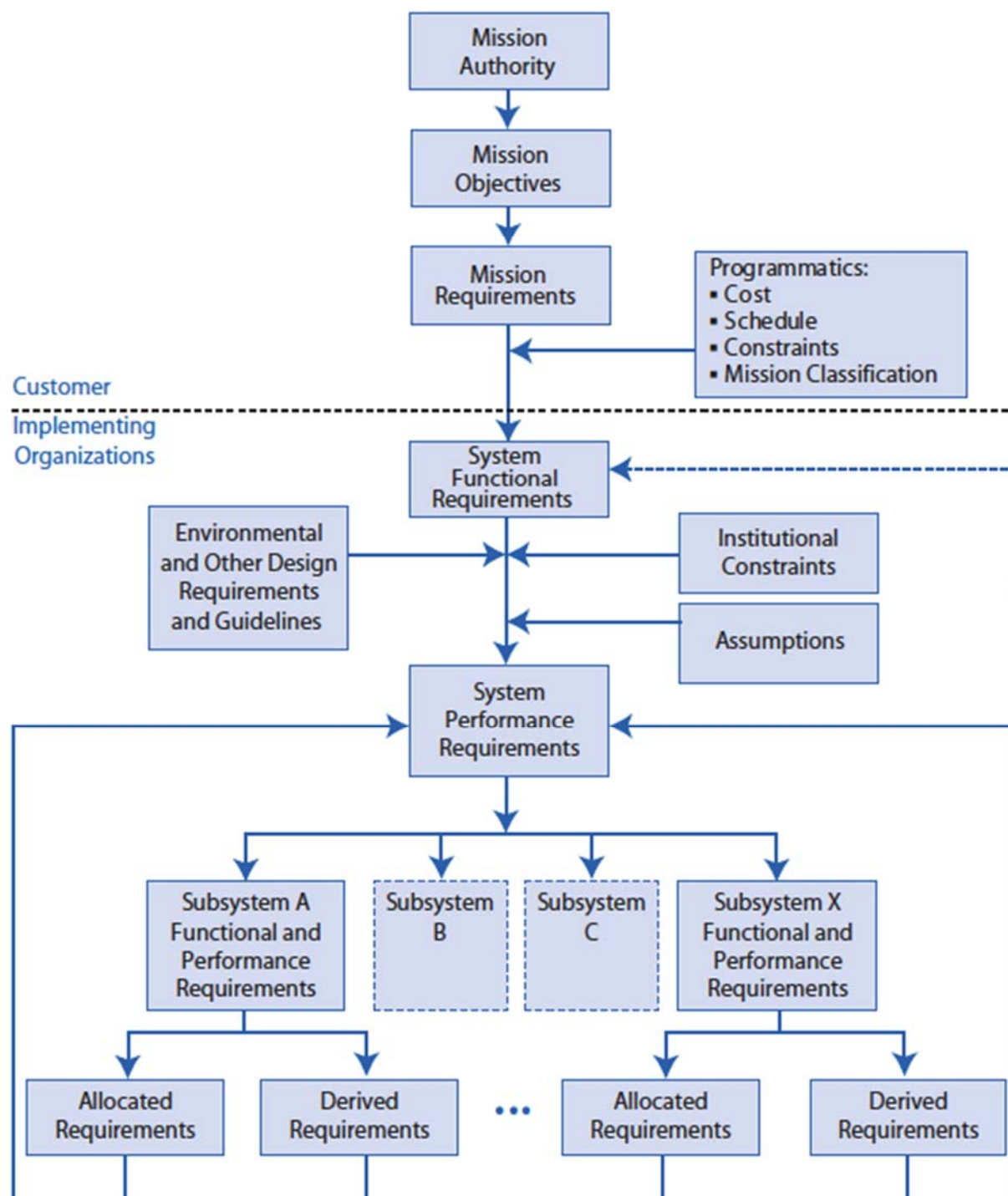along with each items' function(s), use(s), intra-dependencies within the system, and inter-dependencies with external items.

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

Tasks	Steps
Define system architecture model.	a. Define the structure and relationships of hardware, software, communications, operations, etc. b. 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 CM procedures.

Examples

NASA Systems Engineering Handbook, NASA/SP-6105	See Figure 19 Example of a PBS.

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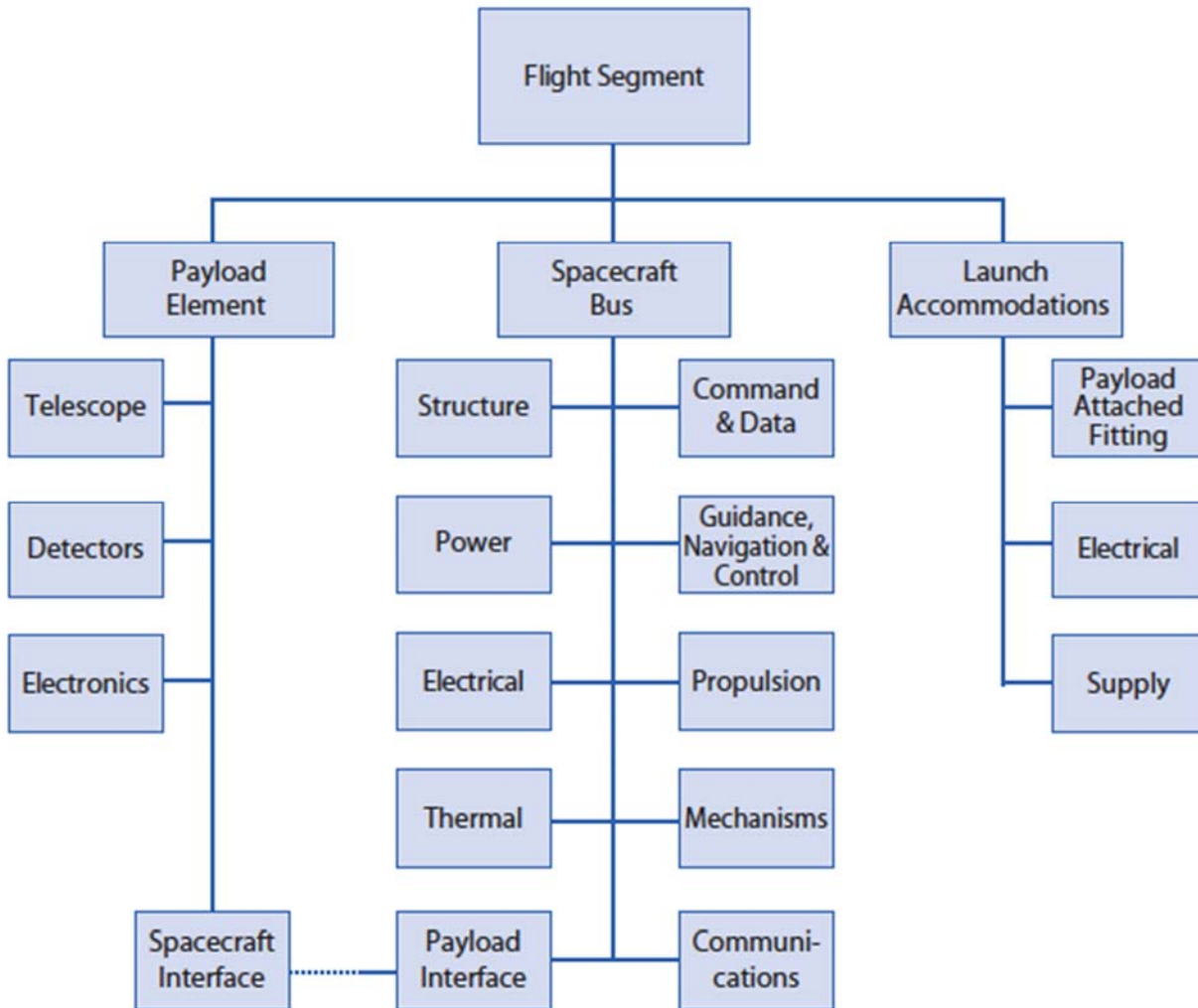
Figure 19. Example of a Product Breakdown Structure

3.1.2.1.2 Decomposed and Allocated Set of Derived Technical Requirements

As the system architecture is defined, the top-level system requirements (defined in the TRD Process) can be decomposed through LD 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:
	   a. Functions
	   b. Time
	   c. Behavior
	   d. Data Flow
	   e. Objects
	   f. States and Modes
	   g. 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	a. Methods to perform functional analysis include:
	   (1) FFBDs.
	   (2) Enhanced FFBDs.
	   (3) 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 a set of derived technical requirements that satisfy each of the identified functions.	a. Follow the guidance on writing good technical requirements contained in NASA Systems Engineering Handbook, NASA/SP-6105, and Appendix C of this Handbook.
	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 parent requirement(s).
	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 the set of derived 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 Appendix C: How to Write a Good Requirement.
Submit the completed set of derived technical requirements for approval.	a. Obtain approval from the PPA 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 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 CM procedures.

Examples

NASA Systems Engineering Handbook, NASA/SP-6105	See Figure 13 Example of a Functional Flow Block Diagram (FFBD)
NASA Systems Engineering Handbook, NASA/SP-6105	See Figure 14 Example of an N^2 Diagram
NASA Systems Engineering Handbook, NASA/SP-6105	See Figure 15 Example of a Timing Diagram
NASA Systems Engineering Handbook, NASA/SP-6105	See Figure 16 Example of The flow down of requirements
NASA Systems Engineering Handbook, NASA/SP-6105	Trade Studies
NASA Systems Engineering Handbook, NASA/SP-6105	See Figure 17 Example of a Requirements Allocation Sheet
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 DID DI-IPSC-81413A, System/Subsystem Specification
System Requirements Document template	STD/SE-REQSPEC

3.1.2.2   Design Solution Definition

The DSD process translates high-level requirements derived from stakeholder expectations and the outputs of the LD process into a design solution. The process involves transforming the defined LD 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

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used to generate the end product specifications that will be used to produce the product and to conduct product verification and validation (V&V). 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.

Inputs and Sources:

      a.   A baselined set of LD models (from LD and CM Processes).

      b.   A baseline set of derived technical requirements including interface requirements (from LD and CM Processes).

Outputs and Sources:

      a.   A WBS model DSD 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 SED, 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 SED 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 V&V plan that will be used to define the activities to show the product complies with physical and functional performance requirements to meet PPA objectives.

      f.   Baseline operate-to and logistics procedures (to TDM 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, TRD, LD, and DSD processes to select a preferred design solution at the PDR and a final design solution that satisfies the technical requirements at the Critical Design Review (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 2 lists and correlates the maturation of the technical baseline with the corresponding technical design review.

Table 2. 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 (TDP) will continue to evolve as additional artifacts are generated to support the production and manufacturing of the end product. The complete TDP, as defined by MIL-STD-31000, is usually provided in conjunction with the acceptance and delivery of the end product to the customer.

Figure 20 and Figure 21 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 standalone PPAs in and of themselves and the Systems Engineering 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 LD 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 PPAs. Meanwhile, the Integrated Logistics Support Plan (ILSP) would provide a conceptual description of the different transportation methods envisioned for transporting the system.
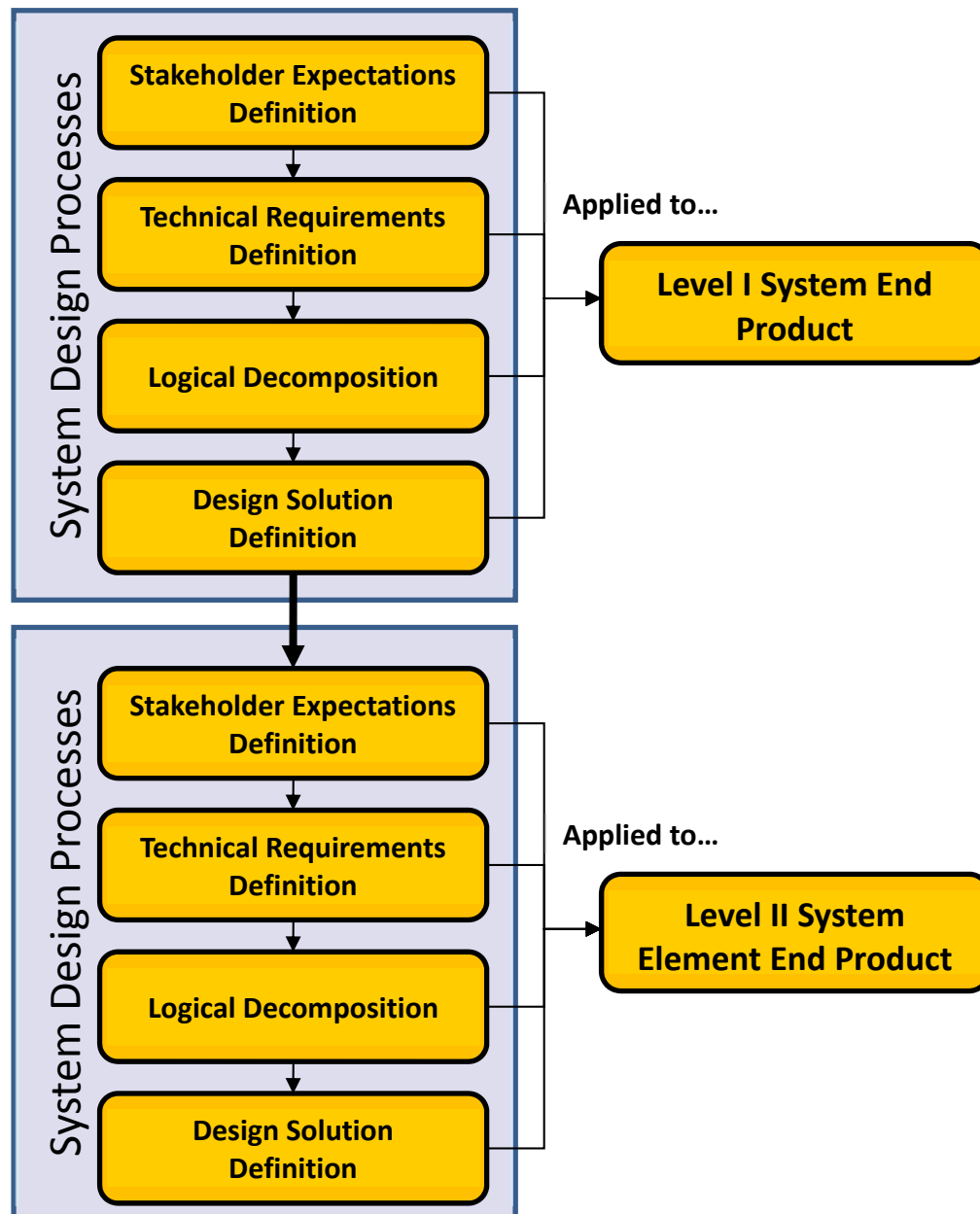
Figure 20. Recursively Applying System Design Processes
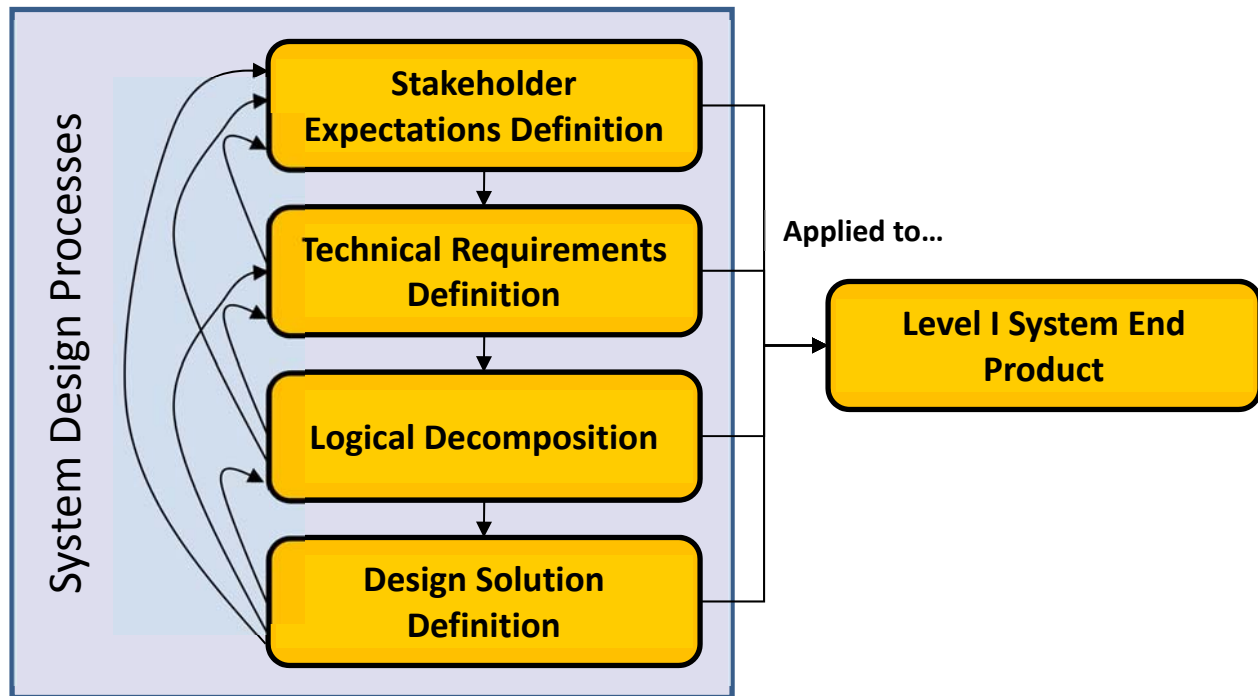
Figure 21. Iteratively Applying the System Design Processes

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.

3.1.2.2.1   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 PPA's position with the product life-cycle.

A sample of DSD metrics include the following:

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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.

n. Prioritization, Impacts to Cost and Schedule and associated risks.

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.	a. Review technical requirements and functional architecture.
	b. Establish design objectives.
	  (1) Performance.
	  (2) Reliability.

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	(3) Compatibility. (4) Design flexibility to adapt to changing environment. (5) Extensibility to be used in new or multiple applications. (6) Cost. (7) Schedule. c. Prioritize objectives and prepare an objectives hierarchy.

Identify and define alternative design solutions.	a. 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.
	   b. Identify technology requirements and assess the availability and risk.
	   c. Identify potential off-the-shelf solutions.
	   d. Integrate with Specialty Engineering.
	   (1) Safety and Reliability.
	   (2) Quality Assurance (QA).
	   (3) Software Assurance.
	   (4) Integrated Logistics Support (ILS).
	   (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.	Scope and content of the full design description depends on what is appropriate for the product life-cycle, life-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 this Handbook. 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.

References: MSFC-HDBK-3701 MSFC Integrated Engineering Principles Handbook

3.1.2.2.2   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.

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 PPA 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 MSFC DRD is applicable to the development of this systems engineering process providing expectations as described:

STD/LS-ILSP Integrated Logistics Support Plan, provides content expectations for developing an ILSP, to satisfy the requirements of MPR 7120.1. The ILSP is used by space flight PPAs to describe life-cycle support concepts, requirements, plans for supportability, logistics support

analyses, and management of logistics support resources, to provide sustainable and affordable PPAs.

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 DGA.
Maintain the logistics and operate-to procedures.	Update the logistics and operate-to procedures, as required. a. Major program milestone review. b. Major technical review.

3.2   Product Realization Processes

3.2.1   Design Realization Processes

3.2.1.1   Product Implementation

The formulation of the product implementation approach is done in conjunction with the development of the PPA's SEMP. Development and subsequent revisions to the PPA's compiled SEMP are undertaken and performed as part of the Technical Planning process. The overall scope of the PPA will ultimately determine the resources and schedule needed to complete the PPA 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 PPA 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
        (11) Applicability.
        (12) Manufacturability.
        (13) Affordability.
        (14) Maintainability.
        (15) Evolvability.
        (16) Accessibility.

    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	a. Assemble and review the list of work products required to support the product implementation approach.

Product Implementation Approach.	b. Review Stakeholder NGOs
	   (1) FAD.
	   (2) PCA.
	   (3) PPA 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 PPA's product implementation strategy and approach. b. Provide an overview on how the planning team is organized and description of R&R. 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 PPA stakeholders.
Submit for concurrence and/or approval	Submit the final product implementation planning information for concurrence and/or approval to the proper DGA.
Maintain the Product Implementation Approach	Update the product implementation strategy and approach, as required, based on: a. Major program milestone review. b. Major technical reviews.

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3.2.1.1.1 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. b. Present the evaluation and assessment results along with a recommendation to the designated decision authority.
Proceed 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.
Capture work products associated with the approved product implementation decision.	Capture, manage, and maintain process implementation work product in accordance with the approved TDM process; to include: a. Design drawings. b. Design documentation. c. Code listings. d. Model descriptions. e. Implementation procedures. f. Operator manuals. g. Maintenance manuals. h. etc.

3.2.1.1.2 Data Requirements Description

The following MSFC DRDs are applicable to the product Implementation Process:

+ STD/SE-IP Integration Plan

+ STD/DE-DRMAD Design Reference Mission Analysis Document

+ STD/DE-ISPA Integrated System Performance Analysis

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+ <u>STD/CM-EIDAL Electrical Integration Drawings and Associated Lists</u>

+ <u>STD/DE-CSAS Radio Frequency Communications System Analysis and Studies</u>

+ <u>STD/DE-DHSA Data Handling & Software Systems Analysis</u>

+ <u>STD/DE-EISA Electrical Integration System Analyses</u>

+ <u>STD/DE-MFM Mission and Fault Management (M&FM) Design, Analysis, and Test</u>

+ <u>STD/DE-MPCP Mass Properties Control Plan</u>

+ <u>STD/DE-MPR Mass Properties Report</u>

+ <u>STD/DE-SED Space Environment Definition</u>

+ <u>STD/DE-SFS End-to-End System Functional Schematics</u>

+ <u>STD/MA-IMS Integrated Master Schedule</u>

+ <u>STD/MP-MP Manufacturing and Assembly Plan</u>

+ <u>STD/QE-COQ Certificate of Qualification (COQ)</u>

3.2.1.2   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 PPA SEMP. For smaller PPAs, the PPA SEMP may be used to fully describe how the system will be assembled, integrated, and verified.

The following MSFC DRDs are applicable to the development of this systems engineering process providing expectations as described:

The integration plan defines the integration and verification strategies for a PPA interface with the system design and decomposition into the lower level elements. MSFC DRD STD/SE-IP Integration Plan, defines the integration strategies for product/system integration.

The Manufacturing and Assembly Plan (MAP), DRD STD/Materials and Processes (MP)-Manufacturing and Assembly Plan (MAP), 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 MAP 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.

STD/SE-IP INTEGRATION PLAN, provides content expectations for developing an Integration Plan, to satisfy the requirements of MPR 7123.1. An Integration Plan defines the integration strategies for product/system integration.

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) PPA 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 Integration 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 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 PPA's product integration strategy and approach. b. Provide an overview on how the planning team is organized and description of R&R. c. Provide an overview on the schedule needed to develop the product integration planning information to include specific deliverables, major milestones and due dates.

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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 PPA stakeholders.
Submit for concurrence and/or approval.	Submit the final product integration planning information for concurrence and/or approval to the proper DGA.
Maintain the Product Integration Approach.	Update the product integration strategy and approach, as required, based on: a. Major program milestone review. b. Major technical reviews.

3.2.1.2.1 Assemble and Integrate End Product

The focus of this effort is to successfully assemble, integrate, and verify the PPA interface. Appendix F, Decision Analysis Methods, 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 PPA, 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 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.

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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 V&V activities are pursued as a means to potentially compress schedule and reduce costs.

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 TDM process requirements.

3.2.1.2.2   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.

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3.2.2   Evaluation Processes

3.2.2.1   Product Verification and Product Validation

The Product Verification process is used to provide objective evidence 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 V&V 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-, element-, discipline-, or interfacing PPA-furnished verification data or manufacturing or processing records to ensure the requirements(s) have been incorporated or met. Validation of records can be used as the method to satisfy incorporation of requirements for such items as commercial off-the-shelf products, products purchased to standards, or closure of allocated requirements.

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 V&V 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:

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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 TDM Process).

c. Product verification approach (from DSD 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.

    (8) Results of corrective actions (to TDM Process).

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

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b. Baselined stakeholder expectations (from CM Process).

c. Product validation approach (from DSD 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.

(7) Results of corrective actions (to TDM Process).

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

Successful V&V will lead into qualification of the final hardware/software (HW/SW) design.

3.2.2.1.1   Product Verification/Product Validation Requirements

Product Verification/Product Validation requirements provide the basis for V&V planning covered in Section 4.2.2.1.2. These product V&V requirements are compiled with the set of PPA requirements per DRD STD/SE-VVREQ, Verification/Validation Requirements. V&V

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 PPAs 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.

Reference: MSFC-HDKB-2221, Volume I and Volume II

3.2.2.1.2 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. 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 (DM)s.

Test Like You Fly (TLYF) is a pre-launch V&V 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 TLYF 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 TLYF 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 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 PDR.

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 detailed description of each verification/validation activity based on the verification/validation requirements,
	
	 b. Define and document the organizational R&R 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 (GSE).
	    (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, Failure Mode and Effect Analysis(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 PPA 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 CM procedures.

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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 PPA SEMP. b. The Product Verification/Product Validation planning information is placed under formal configuration control in accordance with established CM procedures.

3.2.2.1.3   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: a. Performance criteria. b. Environment test limits. c. Tolerances. d. Margins. e. Specifications. f. Constraints. g. Inspection points. h. Effectivity and location.
Submit the completed Product Verification/Product Validation Success Criteria for approval.	a. Obtain approval from the PPA 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 CM 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 PPA SEMP and/or PPA Verification/Validation planning information. b. The baselined Product Verification/Product Validation Success Criteria is placed under formal configuration control in accordance with established CM procedures.

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3.2.2.1.4   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:
	
	a. Identify item/article being subjected to test, demonstration, inspection, or analysis.
	
	b. Identify the objectives established for the verification/validation activity.
	
	c. 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 PPA safety and reliability verification requirements (e.g., hazard reports, FMEA/ CIL, reliability prediction including PRA (as applicable).
	
	d. Describe the sequence of steps and operations to be performed.
	
	e. Identify measuring and recording equipment to be used.
	    (1) Type.
	    (2) Range.
	    (3) Accuracy.
	    (4) Operating instructions.
	f. Confirm that required support equipment has been calibrated and its certification is valid.
	
	g. Confirm that support equipment has been verified prior to use.
	
	h. Document layouts, schematics, or diagrams that show identification, location, and interconnection of item/article, support equipment, and measuring equipment.
	
	i. Document test article configuration and identify software loads, GSE vs. flight.
	
	j. Identify hazardous situations and operations
	
	k. Document safety precautions and instructions.
	
	l. Document environmental and other conditions to be maintained with tolerances.
	
	m. Document data storage and translation requirements
	
	n. Document constraints

Tasks	Steps
	o. Document instructions for handling non-conformances and anomalous occurrences. p. Document the R&R for executing the verification/validation procedures q. 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 PPA 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 CM 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 PPA SEMP and/or PPA Verification/Validation planning information. b. The baselined Product Verification/Product Validation Procedures are placed under formal configuration control in accordance with established CM procedures.

3.2.2.1.5   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 PPA and submitted as needed until full compliance is achieved.

The following MSFC DRDs are applicable to the development of this systems engineering process providing expectations as described:

STD/SE-VVC Verification/Validation Compliance, provides content expectations for developing a Verification/Validation Compliance Assessment, to satisfy the requirements of MPR 7123.1. The Verification/Validation Compliance Assessment is used to identify, assess, and correlate the submitted verification/validation reports against the requirements.

STD/SE-VVREP Verification/Validation Reports, provides content expectations for developing Verification/Validation Reports, in order to satisfy the requirements of MPR 7123.1. Verification/Validation Reports are used to report the results of the individual verification/validation activities.

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: a. Conclusions. Recommendations. b. Deviations/waivers. c. Plots. d. Pictures. e. As recorded results. f. Procedures that were used. g. Traceability to the verification/validation success criteria. h. Additional independent assessment (IA) (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 PPA 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 PPA 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 PPA SEMP and/or PPA. b. Verification/Validation planning information. c. The baselined Product Verification/Product Validation Reports and Compliance are placed under formal configuration control in accordance with established CM procedures.

3.2.2.1.6 Product Testing

Testing can occur in the development laboratories (i.e. those contained in the developing engineering departments and laboratories) or involve larger capabilities contained by the MSFC

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Test Laboratory. Tests conducted in the MSFC Test Areas and MSFC Test Area laboratories are coordinated with test conductors and planning is essential to ensure schedule and budget properly incorporate test planning. Based on schedules and capabilities, testing may be performed at other Centers or at the suppliers. Tests include both development testing and qualification testing leading to product V&V discussed in section 4.2.2.1. Development testing are tests conducted to support design understanding and decisions in developing the system. Qualification testing involves testing the system beyond the defined operational limits to ensure that it will work reliably in the specific mission environment. These qualification tests are used in the determination of the Certificate of Qualification (COQ) and Certificate of Flight Readiness (CoFR). Often the results in development and qualification testing are used as evidence in system verification.

Special integration facilities are often developed to support integrated HW/SW testing and human/system interaction testing. This is discussed more in the section D. Hardware, Software, and Human System Integration, below.

Test planning is done early in the life-cycle and major testing should be known by the first requirements review. Testing in development laboratories should be defined early as well to ensure the proper test equipment is known and available to support the testing.

TLYF is a testing philosophy that examines all applicable mission, operational, and flight characteristics within the intended operational environment and determines the fullest extent to which those characteristics can be applied in testing.
Testing can occur at any point in the PPA life-cycle, or may be performed for research purposes independent of a PPA. During Phase A, for example, concept development testing may occur in order to develop data and rationale for design reviews. Early testing may occur to mitigate risk, down select designs, screen materials, advance the Technology Readiness Level (TRL), develop new processes, certify personnel and equipment, or qualify suppliers. For a long-term PPA such as the Space Shuttle, testing can occur throughout the operational phase to support sustaining engineering, and for the reasons listed here. Testing is done at any level from piece part, component, subassembly or subsystem, system and integrated systems, including HW/SW integration, in order to develop, verify and validate, qualify or accept the manufactured product.

Testing takes place to support troubleshooting and failure investigations, in order to duplicate the failure under controlled conditions, and subsequently to qualify a new design or process, or develop a repair. It is important for all levels of testing that the configuration of the test article is traceable to the test data.

Some development tests can be expensive and involve some level of technical and/or program risk. Testing of new design turbo pumps on the Space Shuttle Main Engine (SSME) is a good example. During development testing, the SSME Project Office specified flight requirements compliance in all development operations, including QA. This was an expensive test with some risk to the project, and the SSME was considered to be flight hardware. Any engine component had to be available for launch on a flight engine if needed. Another examples is sub-scale solid

rocket motor testing which was performed for the Redesigned Solid Rocket Motor (RSRM). These tests were also expensive, and material selection decisions were made, based on the data, for an eventual full scale qualification test. In similar cases, there is a role for QA insight/oversight as a risk mitigation. Inspections can also be considered test data, since measurements of erosion or excessive wear, for example, can be a significant part of the design process.

NASA and MSFC have developed a number of test standards and handbooks as listed in Table 3, NASA and MSFC Testing Standards, for a few specific types of testing. The handbooks provide guidance, best practices, and lessons learned for test planning, and promote consistency across the agency for launch vehicles, spacecraft and payloads. The standards provide agency requirements in support of design, V&V, qualification and acceptance. The handbooks and standards also support the TLYF approach. Systems Engineering Processes implemented by the Test Service Provider

Table 3. NASA and MSFC Testing Standards

Document Number	Title
NASA-HDBK-7004	Force Limited Vibration Testing
NASA-HDBK-7005	Dynamic Environmental Criteria
NASA-HDBK-7008	Spacecraft Dynamic Environments Testing
NASA-HDBK-7009	NASA Handbook for Models and Simulations: an Implementation Guide for NASA STD 7009
NASA-HDBK-7010	Direct Field Acoustic Testing (DFAT)
NASA-STD-7001	Payload Vibroacoustic Test Criteria
NASA-STD-7002	Payload Test Requirements
NASA-STD-7003	Pyroshock Test Criteria
NASA-STD-7009	Standard for Models and Simulations
MSFC HDBK 670	General Environmental Test Guidelines (GETG) for Protoflight Instruments and Experiments
MSFC STD 3676	Development of Vibroacoustic and Shock Design and Test Criteria

Reference: Shepherd, C., "A Systems Engineering Approach to Quality Assurance for Aerospace Testing", ASQ World Conference, 2015.

The test organizations, such as MSFC Test Laboratory, will assist PPAs and system engineers in the establishment and development of test plans and requirements. The complexity of the processes will depend upon the PPA life-cycle phase (e.g., research vs. qualification), the level of

the test article and/or software (e.g., component vs. system), the type of test (e.g., materials test vs. integrated stage test or launch), and other factors such as the use of heritage hardware, or repeated testing at the same test location.

The PPA system engineer, based on the established stakeholder expectations and technical requirements works with the test organization to establish the test requirements and parameters. Once the decision is made that testing is required the test organization should be contacted as soon as feasible to determine the optimum location for the test, and to begin the planning process. However, information at this point is often preliminary, and the test organization may need to participate in this process very early in the life-cycle, especially if new or modified facilities and/or hardware are needed. In the interest of maintaining a schedule, this entire process can be iterative, often with final test requirements and as-built drawings being completed in time for the Test Readiness Review. Therefore, the test PPA needs some level of work tracking and constraint checks to confirm readiness in coordination with the test organization. See ED-OWI-004, Test Program Control.

The test team performs a LD process with the customer's Test Requirements Document (TRD/Test Plan) in order to thoroughly understand the required parameters and derived requirements. A template example for the TRD can be found in ET01-PRO-OWI-001, Test Program Documentation and CM Plan (CMP). The test team must begin the process of identifying test equipment, test facilities, support equipment, fixtures, software needs, and instrumentation. This is closely followed by design of equipment, fixtures, new facilities or modifications, data channels, and coding of software.

The test team and the customer must coordinate activities, agreements and schedules throughout test planning process. Depending on the magnitude of the effort, this could be an iterative process that could take many months. For example, testing in a wind tunnel, or vacuum chamber, will involve understanding the customer's requirements, acquiring the necessary support equipment, programming of the test environment profile, installing instrumentation, pre-test checkouts, preparing or modifying a test procedure, and performing the test, all of which may take place in a matter of weeks. Testing a rocket engine, or a stage may necessitate extensive modifications to an existing facility or construction of a new test stand, which could take 2-3 years, depending on: the acquisition process; designs; construction; assembly and checkout of structure and special test equipment (STE); installation, checkout and certification of pressure systems; installation and programming of data and control systems; and modification or installation of control rooms. Transportation of the test article may be a significant effort involving the Super Guppy, barges, railcars, specially designed transporters, cranes, and GSE.

Technical requirements, trade studies, cost, schedule, safety, QA, environmental regulations, logistics, calibration, procurements, workforce staffing and training, permits and certifications, codes and standards must be identified, managed implemented and tracked. Requirements changes from the customer must be factored in and schedule adjustment may be necessary, depending upon the timing and magnitude. Interfaces are an important part of the test planning processing, since test article-to-equipment interfaces must be identified and tracked, as well as

each interface at the facility, equipment, and fixture level. Depending on the complexity of the test and test article, some type of ICD may be required.

TRM can also be a significant aspect of preparations, again, depending upon the magnitude of the effort. Much of this activity proceeds at some level of risk, due to the fact that many customer requirements are still preliminary. Consequently, facility and equipment fabrication may have to proceed with preliminary drawings, in some cases. It is often accepted that the schedule risk of changes to test article and/or test requirements, resulting in redesign of the facility or equipment, has a high probability, but lower consequences, than the cost and schedule risk of waiting until later in the life-cycle to begin the process. Risk is also inherent in the testing process, since there may be unknown properties or failure modes associated with the test article. The test organization must take this into account when locating test facilities, developing access control procedures, crew training, and planning for emergency shutdown and safing.

Configuration of facilities, fixtures, software, and equipment and of the work authorizing documentation (e.g., test request, PPA authorization memos) must be carefully managed and all associated documents, drawings, reports, calculations, analyses, and test data must be managed and maintained in an accessible records system. This is vital to the Technical Readiness Review (TRR) and hazard analysis (see MWI 8715.15 Ground Operations Safety Assessment Program; MWI 8715.17 Hazardous Operations Readiness Review Program) for use of the data by the customer.

At some point during the early and later planning stages, purchases are made and products delivered, such as off-the-shelf valves, tubing, equipment, instrumentation, computers, and possibly liquid propellants or pressurizing gases. Test organizations often have the ability to fabricate facility modifications, support equipment, and test equipment. It should be noted that the industry codes and standards, which provide the safety and reliability of the test facilities and equipment, are based on very exacting industry design and QA methods and controls (see Table 3, Industry Standards and MSFC Requirements for Test Area Facilities and Equipment).

Table 4. Industry Standards and MSFC Requirements for Test Area Facilities and Equipment

American National Standards Institute (ANSI)/ American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code
ANSI /NB23 National Board Inspection Code (NBIC)
American Welding Society (AWS) D1.1, Structural Steel Welding Code
AWS D1.2 Structural Aluminum
American Institute for Steel Construction (AISC), Steel Construction Manual
ANSI/ASME B31.1 Power Piping
ANSI/ASME B31.3 Chemical Plant and Refinery Piping
API 570 Piping Inspection Code

ASTM-MNL-36 Safe Use of Oxygen and Oxygen Systems: Handbook for Design, Operation and Maintenance
ANSI/AIAA G-095-2004 (currently in revision) Guide to Safety of Hydrogen and Hydrogen Systems
SAE AS4059[WMD(12] Aerospace Fluid Power-Cleanliness Classification for Hydraulic Fluids
MPR 8710.1 MSFC Requirements for Ground Based Pressure Vessels and Pressurized Systems
MSFC-Spec-164 Cleanliness of Components for use in Oxygen, Fuel and Pneumatic Systems, Specification for
MPR 8730.5 Metrology and Calibration
MPR 8730.6 Inspection of Hazardous Test Facility Configuration Changes
MPR 8500.2 MSFC Environmental Management System

There may also be support operations, such as precision cleaning and calibration, which must meet exacting standards. Test software must be coded and configuration controlled. Test facility hardware and software must be installed and integrated. This process will eventually include integration of the test article with the test facility or equipment. This includes hardware, control software, and instrumentation.

V&V are also required for the test facility, equipment and software. For safe and reliable operations, all new or modified systems, along with existing systems, must be "baselined" through some type of inspection and analysis process, and tested to determine whether the systems are performing as expected and required, including both planned commands and emergency shutdown. Additional V&V activities may be required after the test article is integrated into the facility system. This could include various types of checkouts, such as proof testing, cold flows, ignition testing, pathfinders, engineering units and calibration samples and sequence runs. There may be some type of Operational Readiness Review separate from the TRR and in parallel with this design, integration and V&V process that is required by NASA Safety or the test organization prior to conducting the test.

All of this leads up to the TRR at which time a board is convened to assess readiness of facility, test article, and crew (MPR 8730.6); safety plans for personnel, facilities, and operations; hazards and technical risk, adequate level of QA, environmental compliance (MPR 8500.2), emergency shutdown capabilities, and other pertinent topics. Once permission to proceed with testing is granted, the V&V *of the test article* can begin, based on the customer's requirements. Depending on the test, many months of planning, fabricating, purchasing, integrating and facility V&V must take place before this point. It is important to note that a PPA TRR generally focuses on the ability of the test article to produce the desired data (see MPR 7123.1), while a testing lab TRR process will focus on facility readiness and safety. The two TRRs may be combined, or they may be performed separately (see MWI 8715.17 Hazardous Operations Readiness Review Program).

The test article is transitioned back to the test customer once the test or test series is complete The test team may participate in PPA data reviews to support any decisions the PPA must perform.

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The test data is provided in a pre-determined electronic or hard copy format, along with any required documentation. The testing organization is responsible for the integrity of the test data, while validation of the test article's performance is the responsibility of the PPA systems engineer.

NOTE: In addition to the systems engineering processes, the test organization:
    a. Manages cost and schedule estimates and tracking.
    b. Acquires qualified civil service and contractor personnel.
    c. Maintains required certifications and permits.
    d. Manages required procurements.
    e. Maintains basic infrastructure.
    f. Works with the Center to provide access control and security.
    g. Complies with agency and MSFC policy.
    h. Coordinates with NASA Safety and Mission Assurance, Facilities Management, Logistics, Protective Services, Environmental Management and Redstone Arsenal, as required.

The following MSFC DRDs are applicable to the Product Testing process:

+ STD/SE-IP Integration Plan

+ STD/DE-DRMAD Design Reference Mission Analysis Document

+ STD/DE-ISPA Integrated System Performance Analysis

+ STD/CM-EIDAL Electrical Integration Drawings and Associated Lists

+ STD/DE-CSAS Radio Frequency Communications System Analysis and Studies

+ STD/DE-DHSA Data Handling & Software Systems Analysis

+ STD/DE-EISA Electrical Integration System Analyses

+ STD/DE-MFM Mission and Fault Management (M&FM) Design, Analysis, and Test

+ STD/DE-MPCP Mass Properties Control Plan

+ STD/DE-MPR Mass Properties Report

+ STD/DE-SED Space Environment Definition

+ STD/DE-SFS End-to-End System Functional Schematics

+ STD/MA-IMS Integrated Master Schedule

+ STD/MP-MP Manufacturing and Assembly Plan

+ STD/QE-COQ Certificate of Qualification (COQ)

3.2.3   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 PPA 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 TDM 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 TDM 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).

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3.2.3.1   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 PPA SEMP. For smaller PPAs, the PPA 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 ILS 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 MSFC DRD is applicable to the development of this systems engineering process providing expectations as described:

STD/LS-SHSR Special Handling and Storage Requirements Document, specifies the required content for the Special Handling and Storage Requirements Document and the Packaging, Handling, Storage and Transportation (PHS&T) Plan, in order to satisfy the requirements of MPR 6410.2. These documents are used by space flight programs and PPAs to identify the requirements for special packaging, handling, storage and transportation for program critical hardware (PCH).

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) PPA 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 PPA's product transition strategy and approach. b. Provide an overview on how the planning team is organized and description of R&R. 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 PPA stakeholders.
Submit for concurrence and/or approval.	Submit the final product transition planning information for concurrence and/or approval to the proper DGA.
Maintain the Product Transition Approach.	Update the product transition strategy and approach, as required, based on: a. Major program milestone review. b. Major technical reviews.

3.2.3.2 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) PPAs. The preparation and execution of the SAR is conducted using the recommended activities contained in the Process Assessment (PA) Manual.

The purpose of an AR 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.

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

MPR 6410.2 contains requirements 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 4000.2.

3.3 Technical Management Processes

3.3.1 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 PPA objectives and life-cycle phase success criteria within the cost, schedule, and risk constraints of the PPA.

The SEMP is generated during the Technical Planning process. The SEMP is a subordinate document to the PPA plan. The SEMP defines how the technical effort will be managed within the constraints established by the PPA and how the PPA 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 PPA life-cycle.

Technical Planning is tightly integrated with the TRM process and the Technical Assessment process to ensure corrective action for future activities will be incorporated based on current issues identified within the PPA. 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.

TDM is a critical component of the technical planning effort. As more work products are developed, maintained, and delivered electronically, the TDM 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

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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 R&R, 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 PPA risk. This testing activity may be required to support PDR. The following are key inputs and outputs to the Technical Planning process.

Inputs and Sources:

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

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

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

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

      e. Re-planning needs (from Technical Assessment and TRM Processes).

Outputs and Destinations:

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

      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 TDM).

3.3.1.1   Systems Engineering Management Plan

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

The technical team develops and updates the SEMP as necessary. The technical team coordinates with the PPA manager to determine how proposed technical activities would impact the programmatic, cost, and schedule aspects of the PPA. 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 PPA will be organized to accomplish the activities, and the cost and schedule associated with accomplishing the activities.

The systems engineer and PPA manager identify additional required technical plans based on the PPA 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 (PRA), 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 PPA, 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 PPA 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 PPA plan. The technical approach to the PPA and the technical aspect of the PPA life-cycle is developed. This determines the PPA's length and cost. The development of the programmatic and technical management approaches requires that the key PPA 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 PPA to PPA. 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 PPA dependent. Even though a PPA 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 PPA. The SEMP is a living

document that is updated as new information becomes available and as the PPA 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 MSFC DRD is applicable to the development of this systems engineering process providing expectations as described:

STD/SE-SEMP Systems Engineering Management Plan, provides content expectations for developing the Systems Engineering Management Plan (SEMP) to satisfy the requirements of MPR 7123.1. The SEMP may be used to develop the overall systems engineering approach for the PPA.

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) PPA 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 DGA.
Maintain the SEMP	Update the SEMP, as required. a. Major program milestone review. b. Major technical reviews. c. Major program milestone review. d. Major technical reviews.

Examples

NASA Systems Engineering Handbook, NASA/SP-6105	SEMP Content Outline
MPR 7123.1 MSFC Systems Engineering Processes and Requirements	SEMP Outline

3.3.1.2   Integrated Master Schedule Input

The technical team will work in cooperation with the PPA team and provide input to the Integrated Master Schedule (IMS). The PPA manager tasks the PPA team with the responsibility for developing and baselining the PPA schedule. The technical team will organize the technical tasks according to PPAWBS in a logical sequence of events while considering the major PPA 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, NASA/SP-6105. In order for EVM to be effective, a properly resourced and executable PPA 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.

The following MSFC DRD is applicable to the development of this systems engineering process providing expectations as described:
STD/MA-IMS Integrated Master Schedule, provides content expectations for developing an IMS for PPA contractors, in order to satisfy the requirements of MPR 7120.1. The IMS provides the contractor's time-phased plan, current status, key milestones, task interdependencies, and major development phases necessary to accomplish the total scope of work. This schedule will be used to provide management insight into contractor status, potential problem areas, and critical path identification, which will serve as the basis for evaluating contractor performance.

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MPR 7120.5	**NASA WBS Handbook**	**NASA Scheduling Handbook**
3.1 Organization		
3.1.1 Product 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		
3.3.4 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 PPA. 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 PPA WBS might affect other elements. A network schedule may be used to calculate how long it will take to complete a PPA.

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 PPA baseline budget and the capability to analyze changes to that baseline resulting from technical and/or schedule changes. The PPA's WBS, baseline schedule, and budget are mutually dependent, reflecting the technical content, time, and cost of meeting the PPA'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 PPA'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 PPA 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.

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Tasks	Steps
	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 PPA 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 PPA constraints.
Define Resource Needs.	Define resource needs for: a. Workforce level. b. Funding profile. c. Facilities. d. 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 PPA team to support IMS development.	a. Collaborate with the PPA team to support the baselining of the IMS. b. Capture any technical planning work products via the TDM process.

Examples

NPR 7120.5, NASA Space Flight Program and Project Management Requirements	WBS Template
NPR 7120.8, NASA Research and Technology Program and Project Management Requirements	WBS Template.
NASA Systems Engineering Handbook, NASA/SP-6105	See Figure 22 Example of a Gantt chart.
NASA Systems Engineering Handbook, NASA/SP-6105	See Figure 23 Relationship Between a System, a PBS and a WBS.

Figure 22. Example of a Gantt Chart

Figure 23. Relationship Between a System, a PBS, and a WBS

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3.3.1.3 Issue Technical Work Directives

The technical team supports the PPA team to ensure work is properly authorized in order to meet the EVM requirements contained in MPR 7120.5. Once the PPA IMS 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 PPA and technical management teams with the necessary insight to make management decisions to ensure the PPA 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 define the work to be performed.	Negotiate with the CAM to reach an agreement on the scope and terms associated with the work to be performed.
Properly receive authorization to begin performing the negotiated work.	a. When properly authorized, begin performing the work. b. Provide regular updates and status on work being performed.

3.3.2 Technical Control Processes

3.3.2.1 Requirements Management

The RM is the process of establishing the PPA requirements and then providing the management control over those requirements to ensure that as PPA 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.

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

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

Once PPAs have been through the formal Project Requirements Review (PRR) and/or SRR and the PPA requirements are formally established by Configuration Control Board (CCB) approval (baselined), management of the requirements through the CM function becomes the primary control mechanism to ensure that PPA implementation adheres to the established requirements. As PPA 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 PPA 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 (CRs) (from the PPA and Technical Assessment Process).

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

d. Product verification and product validation results (from Product V&V Processes).

Key Outputs:

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

b. Requirements Traceability (to CM Process).

c. Approved changes to requirement baselines (to CM Process).

3.3.2.1.1   Requirements Management Plan

A requirements management process is developed 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 CM/DM 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 CM procedures.

Examples

CxP 70016	Constellation Program Requirements Engineering Management Plan (REMP)

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.

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3.3.2.1.2 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 LD 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.

STD/SE-RST Requirements/Specifications Trees, provides content expectations for developing a Requirements/Specifications Tree, in order to satisfy the requirements of MPR 7123.1. Requirements/Specifications Tree is a generation breakdown of the requirements sets with interrelationships to the CIs in the system architecture.

STD/SE-RT Requirements Traceability, provides content expectations for developing a Requirements Traceability matrix, in order to satisfy the requirements of MPR 7123.1. The Requirements Traceability matrix provides the traceability and visibility that requirements have been properly and completely flowed down to the next lower level in the system architecture.

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-6105	See Figure 24 Example of a Requirements Allocation Sheet.

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ID	DESCRIPTION	REQUIREMENT	TRACED FROM	PERFORMANCE	MARGIN	COMMENTS	REF
M1	Mission Orbit	575 +/-15 km Sun-synchronous dawn-dusk orbit	S3, S11, P3	Complies	NA	Pegasus XL with HAPS provides required launch injection dispersion accuracy	F.2.c
M2	Launch Vehicle	Pegasus XL with HAPS	P2, P4	Complies	NA		F.2.c
M3	Observatory Mass	The observatory total mass shall not exceed 241 kg	M1, M2	192.5 kg	25.20%		F.5.b
M4	Data Acquisition Quality	The mission shall deliver 95% data with better than 1 in 100,000 BER	P1	Complies	NA	Standard margins and systems baselined; formal system analysis to be completed by PDR	F.7
M5	Communication Band	The mission shall use S-band SQPSK at 5 Mbps for spacecraft downlink and 2 kbps uplink	S12, P4	Complies	NA	See SC27, SC28, and G1, G2	F.3.f, F.7
M7	Tracking	MOC shall use NORAD two-line elements for observatory tracking	P4	Complies	NA		F.7
M8	Data Latency	Data latency shall be less than 72 hours	P12	Complies	NA		F.7
M9	Daily Data Volume	Accommodate average daily raw science data volume of 10.8 Gbits	P1, S12	Complies	12%	Margin based on funded ground contacts	F.3.e, F.7
M10	Ground Station	The mission shall be compatible with the Rutherford Appleton Laboratory Ground Station and the Poker Flat Ground Station	P1	Complies	NA		F.7
M11	Orbital Debris (Casualty Area)	Design observatory for demise upon reentry with <1/10,000 probability of injury	P3	1/51,000	400%	See Orbital Debris Analysis in Appendix M-6	F.2.e, App.6
M12	Orbital Debris (Lifetime)	Design observatory for reentry <25 years after end of mission	P3	<10 years	15 years	See Orbital Debris Analysis in Appendix M-6	F.2.e, App.6

Figure 24. Example of a Requirements Allocation Sheet

3.3.2.1.3   Requirements Changes

Changes to baselined technical requirements occur throughout the system life-cycle. In conjunction with the CM 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. V&V 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, PPA 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 CRs.	a. Document requested requirement(s) change with rationale.
	b. Communicate the requested change to all relevant stakeholders.

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	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).

3.3.2.2   Interface Management

Interface management is a process to assist in controlling interface product development. The management and control of interfaces is crucial to successful PPAs. 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 PPA.

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 PPA 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.

During PPA 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. 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 ICDs. ICDs are necessary at contractual, element, and potentially NASA Center boundaries. They are not necessary at internal interfaces within a PPA 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 TRD). The interface requirements are typically captured in IRDs, but also SRDs.

b.   Interface CRs (from PPA, and Technical Assessment Processes).

Outputs and Destinations:

a.   ICDs (to CM Process). NOTE: Change to reference ICD changes from DSD, once the MPR is changed.

b.   Approved interface requirement changes (to CM Process).

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

3.3.2.2.1   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 PPA. 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, CE, PPA manager, 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) PPA Plan. (3) Lessons Learned.

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	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 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 CM/DM 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 CM procedures. NOTE: The interface management approach is typically incorporated into the SEMP and baselined in conjunction with the SEMP.

Example

STD/SE-ICD	ICD

3.3.2.2.2   Control Interface Design Solution(s)

Interface design solutions are in response to the interface requirements defined during the TRD 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 ICD and or an Interface Definition Document or Drawing (IDD).

Developing the Interface Control Document

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. 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: 　a. Interface requirements. 　b. LD models and work products. 　c. Applicable trade studies and engineering reports. 　d. Commercial industry and International Standards. 　e. Other specifications. 　f. Figures, tables, schema, or other applicable and supportive information.
Develop an approach to manage the development of the ICD.	a. Develop schedule and identify resources needed to 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: 　　(1) Who is responsible for the content. 　　(2) Expected completion date. 　　(3) The work package that covers the required work to develop it.
Submit the completed ICD for approval.	a. Obtain approval from the PPA set of stakeholders that the ICD has achieved sufficient maturity to be baselined.

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	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 CM 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. 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.	1. a. Flanges. 　b. Bolts. 　c. Welds. 　d. Links. 　e. Fasteners. 　f. Adhesiveness.	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 of elements as mission timeline dictates.	2. a. Pyros. 　b. Springs. 　c. Hydraulics.	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 elements.	1. Duct and flanges.	1. Prevention of leaks with ability to separate as required.
	2. Air flow between elements.	2. Duct and flanges.	2. Prevention of leaks with ability to separate as required.
	3. Control forces/separation forces.	3. Actuators/links.	3. Ability to handle point loads and varying dynamics.

Categories	Functions	Types/Examples	Remarks
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. 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).

The propulsion system requirements to structures:	a. Thrust bearing to transfer thrust load to stage. b. Gimbal capability of engine for control authority (throw angle in degrees). c. Fluid propellant input to engine (flow rate).
Propulsion system description to structures;	a. Induced environments of engine (thermal, acoustic, vibration, thrust). b. Engine dimensions. c. Mass characteristics. d. Flow rates.
Structural requirements to engine:	a. Attach mechanism. b. Induced environments. c. Propellant Lines attachment. d. Electrical attachment.
Structures description to propulsion:	a. Propellant line flex bellows b. Gimbal joint flange description. c. Propellant line flange description. d. Volumetric constraints. e. Detail drawings of interface mating areas.

Developing the Interface Definition Document

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 ConOps 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 (percent 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 PPA, hardware, and software compatibility and interface design formulated during DSD 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 IRD. 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 CM 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 ICP. The need for interface documentation is typically driven by the size and complexity of the PPA. 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 IRD. 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 CM 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 (FCB)[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 ICD.
SSP 42121, Part 2 (ICD)	U.S. On-Orbit Segment Pressurized Mating Adapter – 1 to Russian Segment FGB ICD.
NSTS-21000-IDD-ISS	International Space Station ICD.
SSP 41178-25 Part 1 (IRD)	Software ICD, Internal Multiplexer De-Multiplexer (MDM) to International Space Station Book 25, Node 2-2 MDM Interface
SSP 41178-25 Part 2 (ICD)	Software ICD, Internal Multiple MDM to International Space Station Book 25, Node 2-2 MDM Interface
NSTS 21000-IDD-ISS	International Space Station Interface Definition Document
SSP 30261:001	MDM Standard ICD (IDD)
SSP 30263:002	Remote Power Controller Module Standard ICD (IDD)

3.3.2.3   Technical Risk Management Process

The TRM process focuses on PPA 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 PPA 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 PPA 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 PPA could change this requirement (condition) to mitigate or possibly eliminate the risk.

Technical Risk: This is the risk associated with the evolution of the design and the production of the system of interest effecting the level of performance necessary to meet the stakeholder's expectations and technical requirements.

Programmatic Risk: This is the risk associated with action or inaction from outside the PPA, over which the PPA manager has no control, but which may have a significant impact on the PPA. These impacts may manifest themselves in terms of technical, cost, and/or schedule.

Once a risk strategy is selected, TRM 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.

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 PPA. Identification of risks associated with a low TRL provides justification for proof of concept and development testing as early in the PPA schedule as possible. If the PPA takes the proto-flight approach, the TRM process becomes increasingly important for the identification of unproven technology and designs. Likewise, if the PPA 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 TRM process.

Inputs and Sources:

a. PPA Risk Management Plan (from PPA).

b. Technical risk issues (from PPA and other common technical processes).

c. Technical risk status measurements (from Technical Assessment and Decision Analysis Processes).

d. Technical risk reporting requirements (from PPA and Technical Planning Process).

Outputs and Destinations:

a. Technical risk mitigation and/or contingency actions (to Technical Planning Process for re-planning and/or redirection).

b. Technical risk reports (to PPA and TDM).

c. Work products from TRM activities (to TDM).

3.3.2.3.1 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 PPA. The TRM approach may be captured in the PPA 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 and MWI 7120.6, Program, Project, and Institutional Risk Management. Additional implementation information on RIDM and CRM is contained in Section 4.3.2.3.2.

The following MSFC DRD is applicable to the development of this systems engineering process providing expectations as described:

STD/MA-RMP Risk Management Plan, provides content expectations for developing a contract deliverable for the contractor's Risk Management Plan, in order to satisfy the requirements of NPR 8000.4 and MWI 7120.6. STD/MA-RMP is used to specify requirements for a baseline risk management document and risk reports for planning, management, control, and implementation of the contractor's risk management program.

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

Tasks	Steps
Analyze the TRM activities that will be performed during the system life-cycle.	a. In conjunction with the preparation or revision of the PPA SEMP and/or PPA 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. b. 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 PPA's current authority or purview.
Assign a responsible role or working group for TRM activities.	a. Obtain a PPA organizational chart to support the TRM assignments.

	b. Obtain a PPA working group chart to support the TRM assignments. c. Assign a primary role or working group and supporting role or working group to each of the key top-level and supporting TRM.

Identify key work products that will be used to support the risk management process.	a. Based on the scope of the PPA, analyze the entrance criteria for mandatory technical reviews and key decision points (KDPs) to identify and capture corresponding work products needed to satisfy and comply with the entrance criteria.
	      b. Identify additional work products needed to support TRM that will ultimately support top-level key PPA 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 PPA SEMP and/or PPA Risk Management Plan.	Provide a listing of work products needed to support the risk management process.
	      a. RMP.
	      b. Risk List.
	      c. Analyses.
	      d. Tracking Reports.
	      e. Lessons Learned.
	      b. Metrics.

3.3.2.3.2   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-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 re-baselining of requirements. RIDM is invoked in many different venues, based on the management processes of the implementing organizational unit. RIDM is applicable throughout the PPA 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-576 provides guidance for implementing the RIDM requirements with a specific focus on PPAs 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 PPA. 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 MSFC DRD is applicable to the development of this systems engineering process providing expectations as described:

STD/MA MPR Monthly Progress Report, provides content expectations for developing a contract deliverable for Monthly Progress Reports from the contractor. The Monthly Progress Report provides visibility to contractor and MSFC PPA management of actual and potential problems and progress toward meeting the cost, technical and schedule requirements.

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.

Tasks	Steps
	(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 CM. (13) Unavailable technology. (14) Immature technology. (15) Inadequate planning. (16) Inadequate QA. (17) Other PPA specific risks. c. Write technical risk scenario statements. d. Capture context of the technical risk.
Analyze and assess technical risk.	a. Add new data and "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.

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Tasks	Steps
	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 TRM work products.	a. Prepare and/or update TRM 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 DM requirements.

Examples

NASA Systems Engineering Handbook, NASA/SP-6105	See Figure 25 Continuous Risk Management Representation.
NASA Systems Engineering Handbook, NASA/SP-6105	See Figure 26 The Interface Between CRM and Risk-informed Decision Analysis.
NASA Systems Engineering Handbook, NASA/SP-6105	Risk analysis of decision alternatives.
NASA Systems Engineering Handbook, NASA/SP-6105	See Figure 27 Risk Matrix.
NASA Systems Engineering Handbook, NASA/SP-6105	See Figure 28 Example of a Fault Tree.

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Figure 25. Continuous Risk Management Representation

Figure 26. The Interface Between CRM and Risk-informed Decision Analysis

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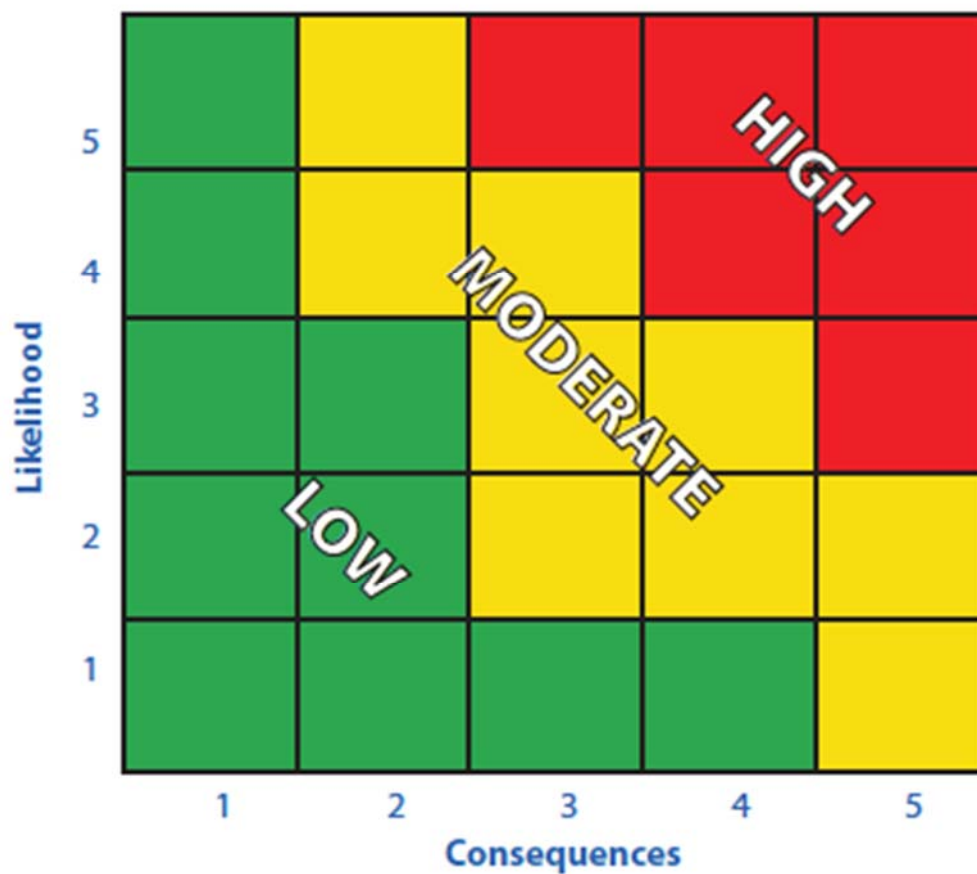
Figure 27. Risk Matrix

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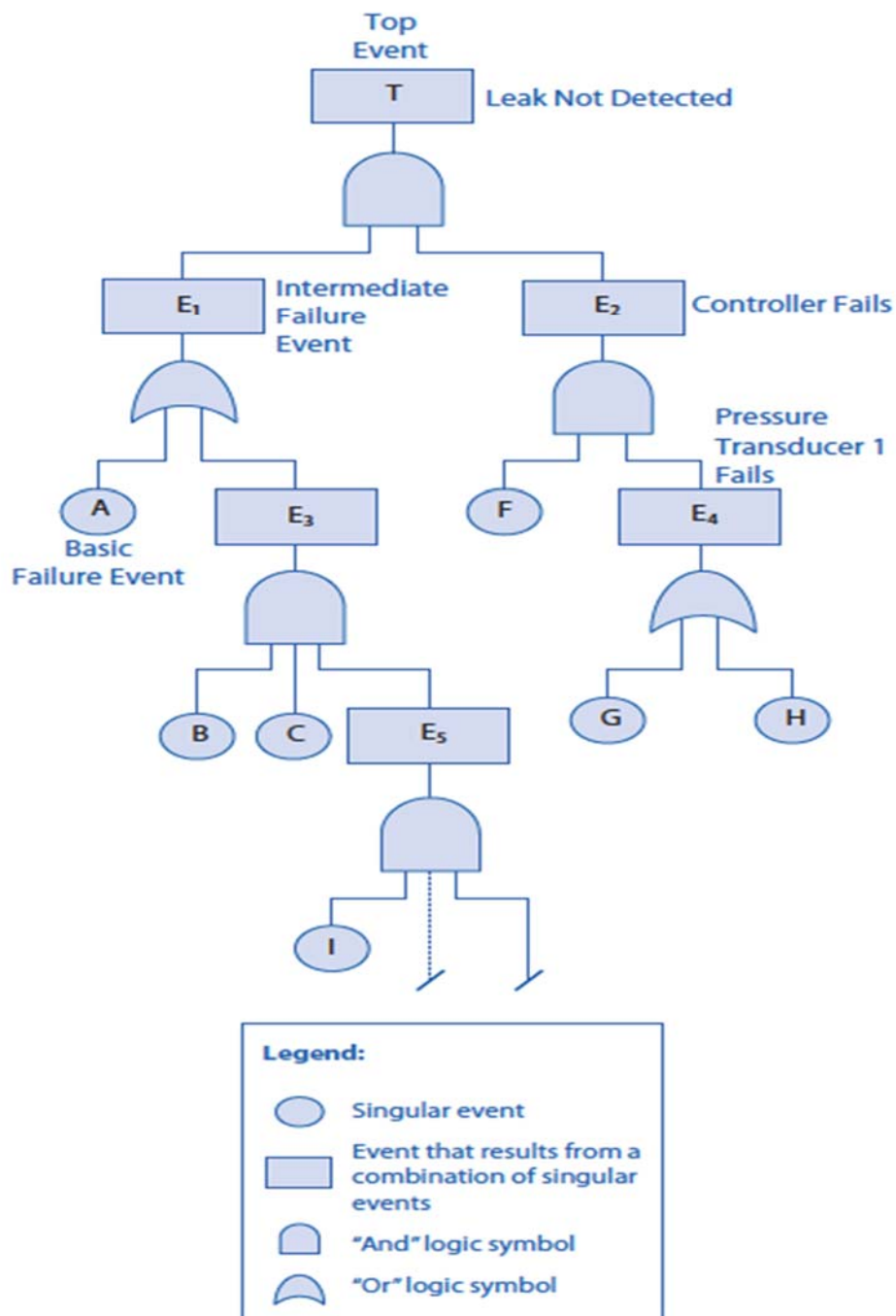
Figure 28. Example of a Fault Tree

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3.3.2.4 Configuration Management

CM is a formal and disciplined process for the establishment and control of the requirements and configuration of HW/SW CIs developed for NASA. The CM activities provide the discipline necessary for the initial establishment and subsequent control of PPA requirements and design evolution.

This CM section of the handbook provides a summary of the guidance and activities for successful implementation of the CM requirements in MPR 7123.1, MSFC Systems Engineering Processes and Requirements, which flows down the NPR 7123.1 requirement for the Center Director to establish and maintain a CM process. Additional detailed CM guidance is provided in MGM 8040.1, MSFC Configuration Management Guidance. Figure 29 shows the MSFC CM requirements and guidance structure.

In addition to MSFC internal CM guidance, there are several NASA endorsed standards and guidance publications that may provide useful information for implementing CM processes. These publications include SAE EIA-649, Configuration Management Standard, SAE/EIA-649-2, Configuration Management Requirements for NASA Enterprises, and SAE/GEIA-HB-649, Configuration Management Standard Implementation Guide.
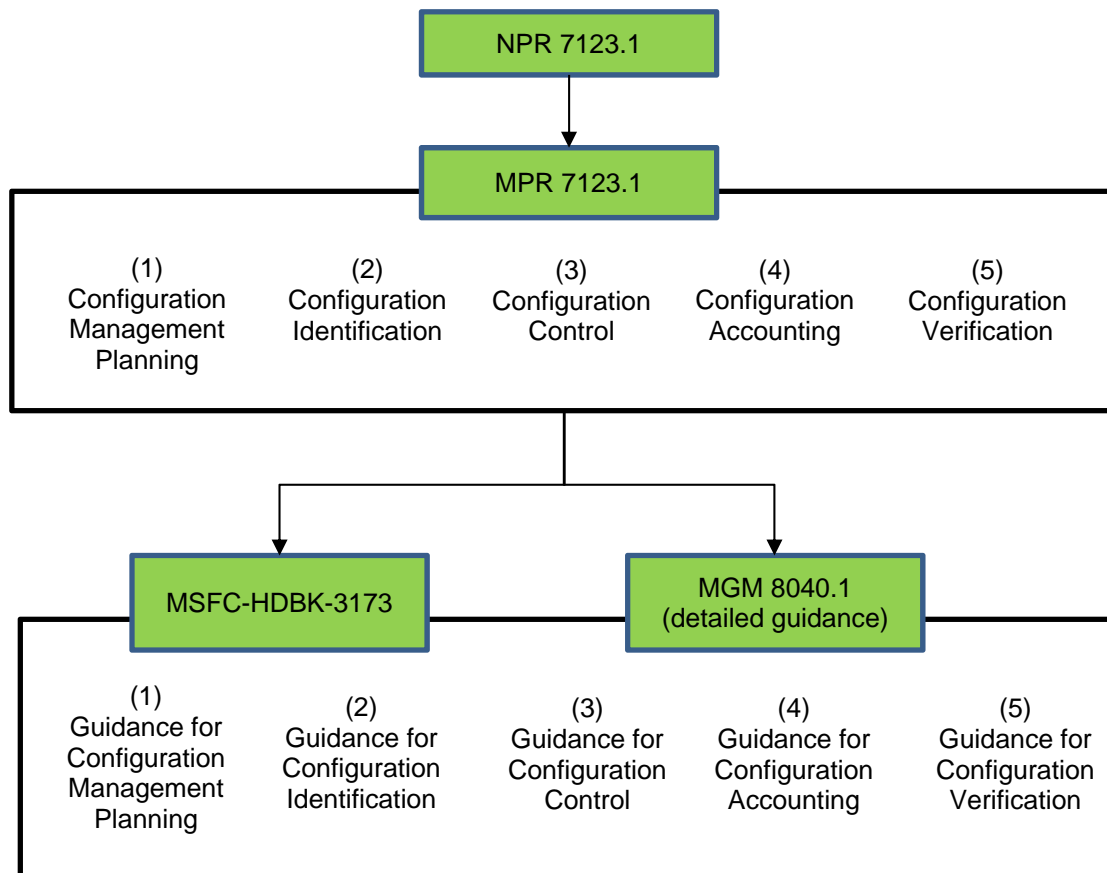
Figure 29. MSFC Configuration Management Requirements and Guidance

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This section identifies activities, tasks and steps for implementing the CM Process. Implementation of this guidance will help the PPA obtain compliance with the requirements contained in MPR 7123.1 and aid the PPA to implement an effective CM system. The following is the minimum set of products resulting from this process:

  a. CMP.
  b. List of CIs.
  c. Baselines of released configuration documentation for each CI.
  d. CRs, Deviations/Waivers and Directives.
  e. Configuration status accounting (CSA) database and reports.
  f. Configuration Audit Records.

Properly executed products will provide the evidence needed to ensure process compliance as part of a process audit.

The CM elements and objectives described within this CM guidance section apply to all PPAs, though the methods of implementation may vary per PPA size and complexity. The data products and formats described are typical of the methods utilized on MPR 7120.1 Mission Type 1, Mission Type 2, and some Mission Type 3 PPAs. For small, higher risk PPAs, CM objectives may be met using less formal and less structured formats and processes, where these processes are known to have cost benefit. For all types of PPAs, use of proven processes and formats that have been verified as meeting PPA CM objectives and that meet the needs of the using organizations will provide technical and resource benefits to the PPA.

3.3.2.4.1   Configuration Management Planning and Strategy

The PPA manager has overall responsibility for ensuring 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 PPA manager should have a knowledgeable CM Lead to guide the PPA in the appropriate tailoring of the PPA CM system for the size, complexity, criticality, and risk of the PPA. The CM strategy should address the five functions of CM: Configuration Planning, Configuration Identification, Configuration Control, CSA, and Configuration Audits.

The CM Strategy is documented in the PPA CMP and contains implementation information as tailored for the specific PPA. This implementation approach is agreed upon by the PPA manager, the CM Lead and the CE of the PPA. MSFC DRD, STD/CM-CMP provides a guidance template for the development of a CMP.

The CMP is written in close coordination with the PPA Plan and the PPA 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 PPA the CMP can be a stand-alone document or be incorporated into the SEMP or the PPA Plan. This decision belongs to the PPA manager.

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

3.3.2.4.1.1 CM Planning Tasks

Tasks	Steps
Develop a CMP.	a. Use STD/CM-CMP as guidance and address the following CM functions. • Configuration Identification (see section 3.3.2.4.2) • Configuration Control (see section 3.3.2.4.3) • CSA (see section 3.3.2.4.4) • Configuration Verification and Audits (see section 3.3.2.4.5) b. The CM Lead coordinates with PPA and CE to tailor the STD/CM-CMP as applicable for specific PPA. c. The CM Lead delivers the CMP to the PPA manager and CE for coordination and implementation.

3.3.2.4.2   Configuration Identification

Configuration identification is the definition and establishment of the technical requirements of a CI or computer software configuration item (CSCI) and encompasses performance and functional requirements as well as the detailed configuration definition. A CI is a deliverable product, (hardware, software, or combination), designated for CM. The term CI is used to refer to both hardware CIs and CSCIs. The selection of CIs is based on criteria established jointly by the PPA manager, CE, CM Lead and the responsible design organization during CM planning. A CI and its component parts are identified with unique identification numbers (i.e., CI number, part numbers, serial and lot numbers) so the CI, its parts, and specific units of those parts can be distinguished from all others.

A CIs configuration baseline consists of the configuration documentation which describes the attributes or characteristics of the CI. Configuration documentation includes requirements documents, specifications, interface definition documents, engineering drawings and models, and software version description documents. It is mandatory that CI configuration documentation be formally defined, authorized, released, and accounted to each CIs baseline throughout the life of the PPA. 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.

NASA has four formal baselines: Functional, Allocated, Product and As-Deployed, which each defines a distinct phase in the evolution of the product design (see NASA/SP-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 baselines are established incrementally as a product of the various PPA reviews as shown in section 3.1.2.2, Table 2, which correlates each baseline to a technical review. The evolution of the configuration baselines are planned and enforced by the PPA. 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.

A complex CI may consist of several CIs with corresponding interfaces, as shown in Figure 30. A baseline authority is assigned to each CI, and that baseline authority is responsible to manage development and deployment of the CI, and to establish a CM system for that CI. Each CI level meets the same fundamental elements of the CM system.
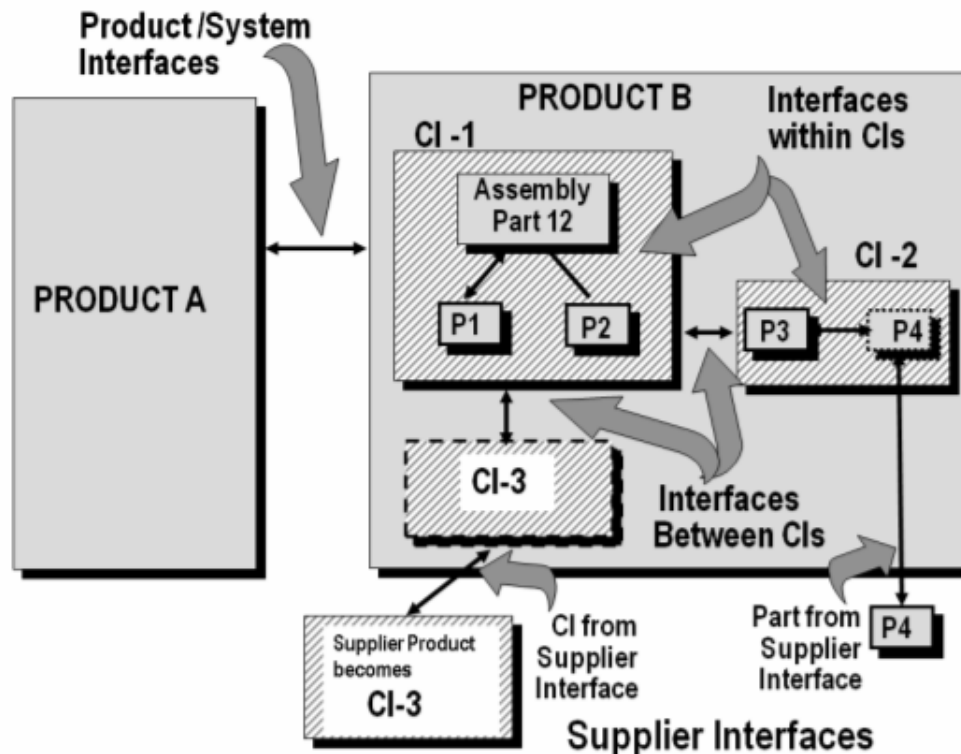
Figure 30. Multiple CI Interface Levels (Ref: SAE EIA-649)

Each CIs 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 CI. Selection and identification of CIs for a particular PPA is the first step in developing an overall architecture of the product from the top down. Each CI is treated as a self-contained unit for the purposes of identification and change control.

3.3.2.4.2.1 Configuration Identification Planning Tasks

Tasks	Steps
Develop CI Selection Criteria and CI identification numbering planning.	Identify PPA specific criteria for the selection of CIs. See CI selection criteria in SAE/EIA-649-2 for guidance.

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Identify CIs and develop an official PPA CI List.	The PPA manager, in coordination with the CE and technical organizations, identify CIs and assign baseline authority for each CI to a management function in the PPA organization. NOTE: Organizations assigned CI baseline authority will establish CM processes and control authorities within their organization.
Identify the configuration documentation associated with each CI.	The PPA and technical personnel, in conjunction with the CM Lead, identify the configuration documentation that will define the functional and physical characteristics of each CI, which includes requirements, specifications, interface documentation, drawings, models, and software version descriptions.
Establish identification schema for CIs, effectivities, control boards, documents, parts, serial numbers, change data.	CM establishes identification schema (numbers, names) to be used for PPA CIs, effectivities, control boards, documents, parts, serial numbers, and change data. NOTE: See MSFC-STD-555 for MSFC numbering schemes for PPA Codes, Board Codes, CI and effectivity identification, part numbers, serial numbers, change package numbers, control board directive numbers, and engineering orders. Document numbers and CRs are typically assigned with PPA-specific or organization-specific IDs.

Identify release function and establish engineering release system.	a. The CM Lead with responsibility for each CI baseline identifies the release function responsible for releasing specific items of configuration documentation.
	   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. The CM Lead should establish the configuration documentation preparation and release requirements to be verified prior to release.
	NOTE 1: The release function is typically associated with the CM function of a PPA, but engineering release is often a centralized release function provided by the engineering organization.
	NOTE 2: 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.

Identify content of CIs baselines to be established at maturity reviews.	a. Identify the configuration documentation content for each CIs baselines (Functional, Allocated, Product, and As-Deployed) and map those baselines to the CI/PPA schedules. NOTE: Official baselines are the primary exit products resulting from successful completion of major reviews (SRR, PDR, CDR, and ORR).

3.3.2.4.2.2 Configuration Identification Implementation Tasks

Tasks	Steps
Generate and maintain the PPA CI List.	CM Lead coordinates with PPA manager, CE and Design Organizations to assign CI IDs for the primary CIs and lower level CIs, and generate the PPA CI List. See MSFC-STD-555 for recommended content of the CI and Effectivity List. The CI-Effectivity List will be updated over the PPA lifecycle to add new CIs and update CI-related information.

3.3.2.4.2.2 Configuration Identification Implementation Tasks

Tasks	Steps
Release CI configuration documentation through the release function	The PPA or engineering release function implements the following release activities: a. Receive direction to release from the CI baseline authority's CCB. b. Verify release requirements for the configuration documentation are met and PPA-engineering planned approvals and authorities have been obtained. c. Ensure product structure relationships are established for CI parts and associated data d. Capture configuration documentation identification (e.g., number, revision, name) CI effectivity and release approval authority in the release accounting for every configuration documentation item released. e. Release the configuration documentation, ensure integrity, security, and availability of the released data, and send notification of release to the affected users.
Capture the CI baseline from each milestone review or audit	The CM Lead ensures that the CI baseline established by a milestone review or audit is captured as a product of the review-audit.

3.3.2.4.3   Configuration Control

Configuration control is the formal process used to establish and control the baselines. It begins with the establishment of initial configuration baselines and continues through the PPA life-cycle. The Configuration Control process is used by the PPA to establish, track and control proposed engineering changes or deviation/waivers to the affected CIs and baselined configuration documentation. Through this process, the proposed change or deviation/waiver is identified, the justification and impact of the proposed change or deviation/waiver is reviewed and dispositioned, and the approved changes are incorporated into the baseline, and approved deviation/waivers are tracked against the baseline. Implementation of the change is then tracked to determine if changes resulted in the intended outcome.

The primary objectives of formal Configuration Control are to:

a.   Provide a systematic process for managing configuration changes and deviation/waivers throughout the life-cycle of a system.

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.

Configuration Control begins with the preparation of a CR or deviation/waiver, which includes complete justification for the change or deviation/waiver and any impacts to the design, interfaces, performance, safety factors/margins as well as cost, schedule and safety. CRs are evaluated and approved or disapproved by the CCB based on overall impact to the

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PPA. Evaluations are obtained from all impacted baseline areas, which includes interfacing or lower level baseline authorities. All approved changes are reviewed and implemented into PPA requirements and the design. Depending on the size and complexity of the PPA, additional processes and/or feedback loops may be added, including one for adjudication.

Configuration control is typically implemented through a hierarchy of formal CCBs that are established at each level of HW/SW management responsibility. Figure 31 depicts an example multilevel CCB structure, and Figure 32 shows an example of documentation control allocated to different levels in a multi-level PPA. Figure 33 is a generalized representation of a flow for a typical change.

The Level I CCB resides at NASA Headquarters and is responsible for the overall program/system level I requirements. The Level II CCB resides at the NASA Center assigned the Program Office or Lead Center and is responsible for program/system level requirements allocated from Level I. 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 by the PPA Office to control its element's/PPA's requirements and interfaces. The Level IV CCBs are established at the contractor or subsystem level. For in-house design, the Level IV CCB may be the controlling change authority for detailed design and subsystem derived requirements, 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.

Each board level can make decisions within its own authority, so long as it does not violate the cost, schedule, technical, or programmatic baselines established by a higher level CCBs. MGM 8040.1 provides additional guidance on the configuration control process including establishment of CCBs.

NOTE: For small projects or limited scope agreements, CCBs may not be established. In lieu of a CCB, approval authority may reside in an equivalent committee, group, or individual, for example, a Project Control Board or PPA Manager.

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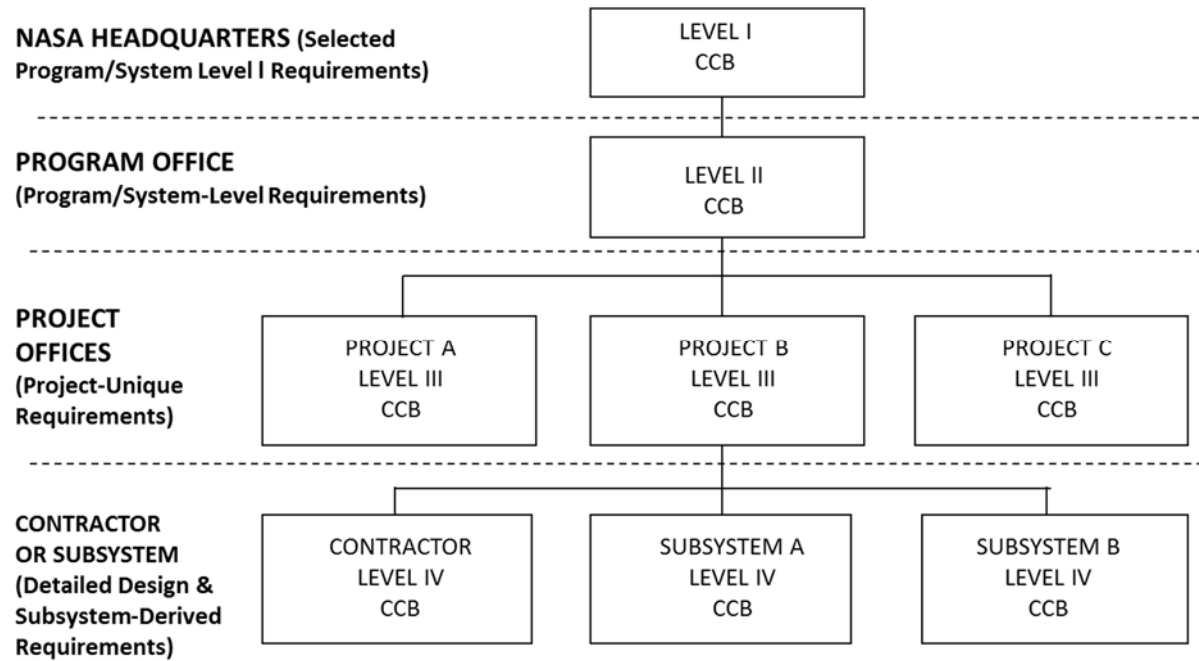
Figure 31. Configuration Control Board Hierarchy
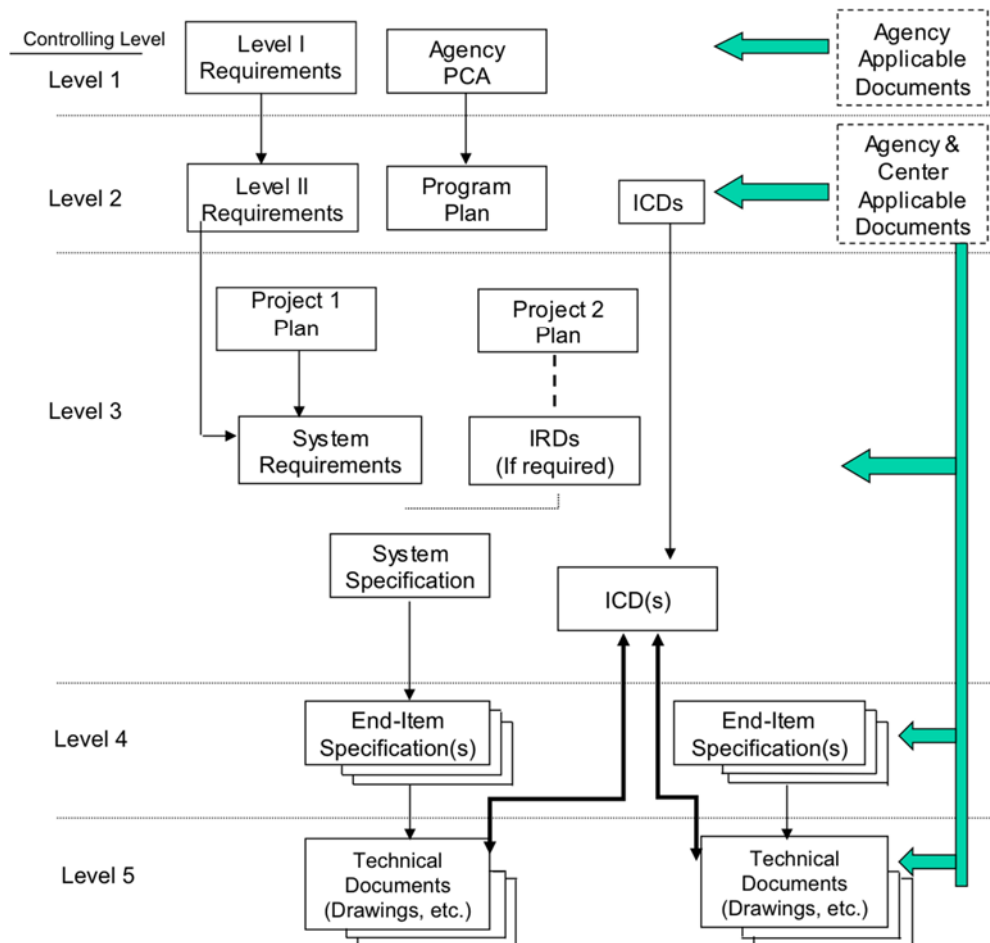
Figure 32. Example of Multi-level Documentation Control Allocation

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Figure 33. Change Process Flow
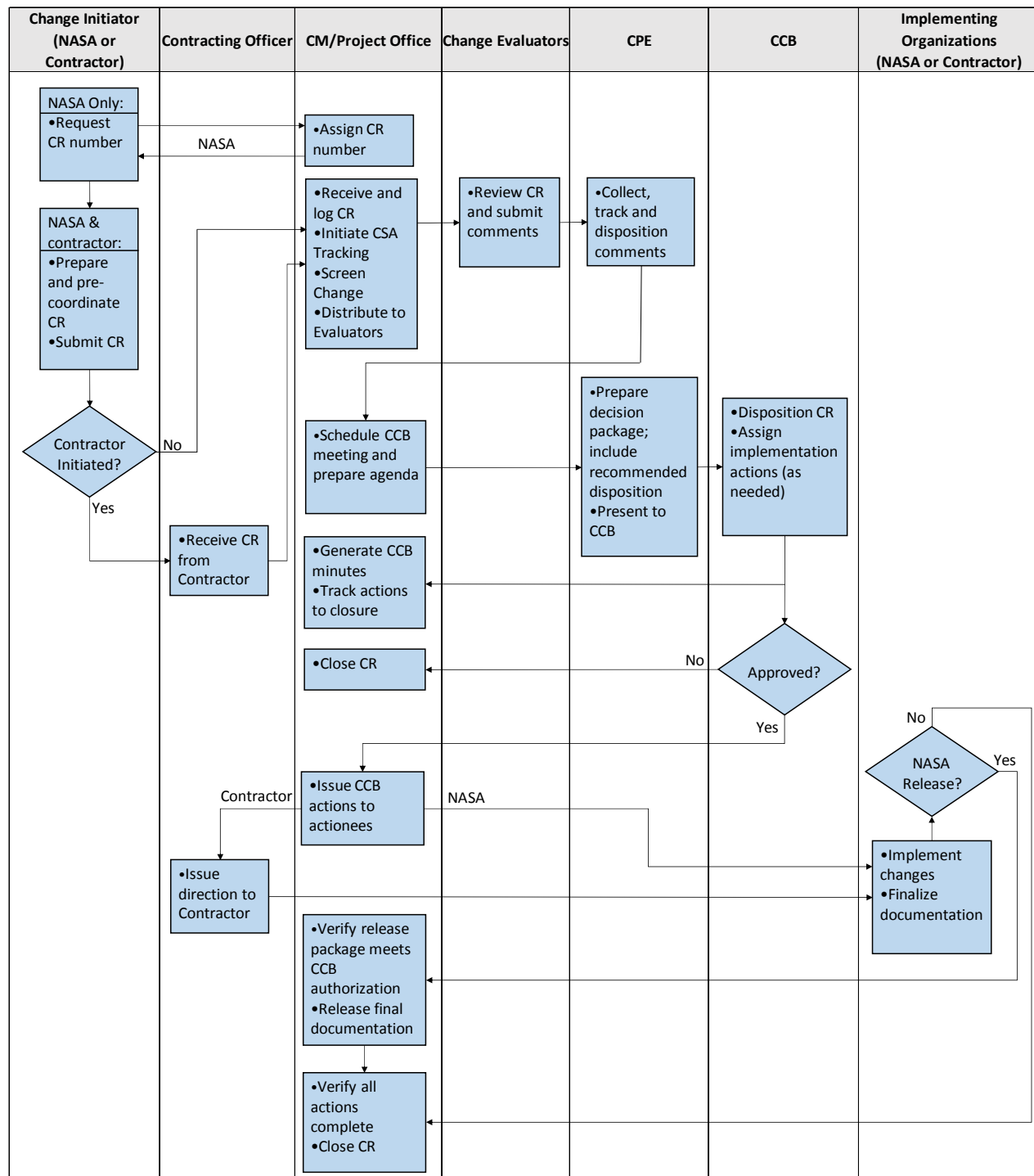
NOTES:

1. If higher level requirements are impacted by a change, the change must be submitted to the appropriate CCB for disposition.

2. Change Evaluators and Implementing Organizations should include interfacing organizations, lower level CCBs, and contractors that may be impacted by the change.

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

3.3.2.4.3.1 Configuration Control Planning Tasks

Tasks	Steps
Establish CCB(s) (or equivalent approval authority)	a. Charter one or more CCBs or identify equivalent approval authority(ies). For a multilevel board structure define authority at each level. b. Identify the specific CI baseline authority, responsibilities, and membership roles for each authorized CCB. c. Establish CR and Control Board Directive (CBD) numbering schemes to ensure unique identification of changes and CCB dispositions.
Establish a change initiation process.	a. Develop a change initiation process and document in the CMP, addressing items b through f below. The process should address processing of different types of changes, such as CR, Engineering Change Requests (ECR), Deviation and Waiver Requests (DAR), interface changes, etc. b. Identify criteria to be met prior to submittal of a change. c. Identify change classifications to be used in the configuration control process (see SAE/EIA-649 and SAE/EIA-649-2 for guidance; also see MPR 8730.3 for requirements related to non-conformance classifications). d. Identify information required for the preparation and submittal of a change (see MGM 8040.1 and SAE/EIA-649 for guidance). e. Identify any pre-approvals that are required for submittal of a deviation/waiver (e.g., SMA) or other types of change documentation if applicable. f. Identify the interrelationship between the Material Review Board nonconformance disposition process and the configuration control process.
Establish change evaluation, disposition, and implementation processes	a. Develop evaluation and disposition processes and document in the CMP. Identify any variations in process based on classification or type of change documentation. b. Include a change process flow diagram (see Figure 31 for a sample CR flow change flow). c. Address method of documenting and tracking change information from initiation through implementation of authorized changes.

3.3.2.4.3.2 Configuration Control Implementation Tasks

Tasks	Steps
Prepare a Change	a. Identify the need for a change; assess and document the associated benefits, impacts and risks. b. Prepare the applicable change documentation (e.g., CR, ECR, DAR) and submit the change per the PPA CMP. Initiation of a change should be a coordinated effort between the initiating organization and the PPA CM Lead. c. Prior to submitting a DAR, obtain any required pre-approval or concurrences.
Evaluate and disposition a Change	a. Identify change evaluators and a Change Package Engineer (CPE). The CPE is the technical coordinator assigned to consolidate and disposition evaluator comments. NOTE: Evaluators should include any interfacing or lower level baseline authorities whose CIs may be affected by the change that need to take action to implement the change if it is approved. The cost, schedule, and technical impacts of the change at each level must be identified to ensure the baseline authority is aware of all integrated change impacts. b. Evaluators review the change package and document comments per the process defined in the CMP. Evaluations are provided to the CPE for consolidation. c. CPE presents the change and provides a recommendation to the CCB. d. CCB dispositions the change and directs implementation actions for approved changes. NOTE: typically the CCB chair has sole disposition authority. Members are responsible for advising and concur/nonconcur as required by the chair. e. CM documents change disposition on a CBD. f. For disapproved changes, document rational for disapproval.
Track change implementation	a. CM notifies CBD actionees of their actions and due dates b. Actionees complete assigned actions to implement approved changes c. CM tracks actions and change implementation to completion.

3.3.2.4.4   Configuration Status Accounting

CSA is the process of creating and organizing the knowledge base necessary to perform CM. 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 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 HW/SW.

The following are recommended activities to create this knowledge base:

     a. Capture and maintain accounting data that defines the currently approved configuration for each CI.

     b. Capture and maintain accounting data that defines the historical information throughout the CI life-cycle.

c. Record and report the status of both proposed and approved configuration changes.

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.

f. Describe the differences between successive baselines and capture the revision history of each CI.

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 MGM 8040.1 for additional guidance on CSA system data elements. Also, SAE/EIA-649 contains typical information sources and outputs of the CSA system over the product life-cycle.

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

3.3.2.4.4.1 CSA Planning Tasks

Tasks	Steps
Develop a CSA strategy	a. Identify methods for collecting, recording, processing, and maintaining data necessary to provide status accounting information and document in the CMP. b. Identify data items needed to provide status accounting information. c. Describe required CSA reports, including reports accessible through a CSA database or tool. d. Identify recipients of standard CSA reports. e. Develop processes for requesting CSA data. f. Identify methods of accessing information in the status accounting system and/or frequency of reporting.

3.3.2.4.4.2 CSA Implementation Tasks

Tasks	Steps
Implement the CSA system.	a. Train PPA team on the use of the selected CSA tool, if applicable. b. Communicate process for requesting Status of CIs and related configuration documentation. c. Identify Constraints to the CSA (i.e., what and when will information be captured, agreements (provisions) between the PPA and supporting organizations, identification of the PPA life-cycle phases, agreements on tasks to be performed and the organization (including contractors) tasked to perform them). d. Perform the CSA activities listed in paragraph 4.3.2.4.4, as applicable. e. Generate outputs from the CSA system (i.e., status of the CIs, CM information related to every CI, performance measurement of CM processes) and make available to PPA users per CM planning and/or agreement with PPA manager. CSA reporting

	may be immediately available to users as updates occur, performed as part of periodic reporting (e.g., monthly, for a specific activity, etc.) or upon request.

3.3.2.4.5   Configuration Verification and Audits

Configuration verification and audits processes are used to ensure that the CIs design and performance requirements have been met and properly documented in compliance with NASA and Program requirements. There are two types of configuration audits, the Functional Configuration Audit (FCA) and the Physical Configuration Audit (PCA), which are described below. Additionally, a best practice is to periodically perform CM System Audits to ensure that PPA CM processes, both contractor and in-house, are effective and meet MSFC requirements.

The configuration 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. MGM 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 PPA. That is, the configuration baseline is correctly defined, controlled, accounted for and verified, and any required corrective actions resulting from the audit are implemented. MGM 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 PPA 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 CIs 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 PPA 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 FCA is used to perform this verification that the CI 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 PCA is the review utilized to perform this verification. For MSFC in-house design and manufacture, the "as-designed" configuration is contained in the design release system, and the "as-built" is provided from the manufacturing or quality systems.

The following tasks and steps are provided to assist with satisfying the Configuration Verification requirements contained in MPR 7123.1 and to perform recommended CM System Audits.

3.3.2.4.5.1 Configuration Verification and Audit Planning Tasks

Tasks	Steps
Plan for FCA/PCA	a. Select CIs to the audited and describe the planned FCA/PCAs in the CMP.
Plan for a CM System Audit	a. Describe the planned CM System Audits in the CMP. b. Determine the number and frequency of audits. Audits should be planned early in the program life-cycle. NOTE: Best practice is to perform at least one CM System Audit prior to CDR.

3.3.2.4.5.2 Configuration Verification and Audit Implementation Tasks

Tasks	Steps
Conduct an FCA/PCA.	a. CM Lead coordinates with Systems Engineer to develop the FCA/PCA plan for the specific CIs being audited. b. Develop Review Data Package. c. Develop schedule. d. Develop the entrance briefing. e. Perform audit activities f. Present findings and mitigation strategies. g. Sign certificates of completion. NOTE: For additional guidance, MGM 8040.1 and STD/CM-AD.
Conduct a CM System Audit.	a. PPA manager coordinates with CM Lead to develop a CM System Audit plan. b. Perform audit to the audit plan. c. Document any discrepancies as findings and observations. d. Submit an Audit Report. NOTE: For additional guidance, see MGM 8040.1 and STD/CM-CMA.

3.3.2.4.6   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 CM. 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 R&R 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 5 identifies a list that can be used as criteria for defining CM tool requirements:

Table 5. CM Tool Selection Criteria

Tool Selection Criteria
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 CSA 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 flow.
The ability to customize work flow.
The ability to customize forms.
The ability to customize field names, attributes, data views, etc.

Tool Selection Criteria
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.

3.3.2.4.7   Training the Technical and Program/Project/Activity Team

A well-trained and knowledgeable PPA and technical team is the key ingredient to implementing a successful CM Plan. Since each PPA 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 CRs, while PPA leadership may not).

At a minimum training should address the following three areas tailored to the PPA:

a. CM Strategy, such as:

    (1) Change Control Board Structure.

    (2) CRs Process.

    (3) Release system.

    (4) Baselining.

b. CM Procedures, such as:

    (1) Initiate CR

    (2) Approval Process.

    (3) Accessing Baselines.

c. Tool usage, such as:

    (1) Electronic folder access.

    (2) Input and access libraries.

    (3) Search for CIs and contents.

3.3.2.5   Data Management

This section provides a summary of the guidance and activities for successful implementation of MPR 7123.1, TDM Section, in conjunction with the detailed guidance provided in MGM 7120.3, MSFC Data Management Guidance. For the purposes of this section, data management generally refers to TDM which is a subset of all program, PPA, or activity (referred to henceforth as a PPA) data. Technical data is data produced in support of technical activities as defined by the PPA WBS. However, PPA data management planning and implementation is not generally focused solely on technical data. Processes and guidance for non-technical data are addressed in other MSFC guidance documentation such as the MPR 7120.1 and MSFC-HDBK-3684, MSFC Program Planning and Control Handbook. Configuration information and baselines are a subset of technical data and are addressed in detail by the CM function. The data management planning and implementation should integrate seamlessly with both non- TDM and CM planning and implementation.

At MSFC, Data Management is defined as: *The timely and economical identification/definition, preparation, control, and disposition of documents and data required by a PPA*. Each PPA manager or Data Management (DM) Lead develops a Data Management Plan during the PPA formulation phase that describes the specific PPA 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 PPAs and activities, the data management processes may be included as part of the PPA Plan or SEMP as long as the requirements identified in MPR 7123.1 are satisfied.

ANSI/GEIA-859, Data Management is an international consensus standard for Data Management that identifies a number of enablers for effective development of data management implementation strategies and provides a framework for comprehensive data management planning and implementation.

The following is the minimum set of artifacts for compliance with DM requirements at MSFC:

    a. Data storage plan and procedures.

    b. Data distribution procedures.

    c. Data security plans, instructions, and audits.

    d. Records retention planning for PPA Data.

    e. Data request report.

    f. Data Requirements Report.

    g. DRD.

    h. Data Procurement and Exchange Documents.

    i. Data Master List(s).

CHECK THE MASTER LIST – VERIFY THAT THIS IS THE CORRECT VERSION BEFORE USE

These are used to provide the artifacts needed to ensure process compliance during a process audit. They are derived from the original requirement for the Center Director or designee to establish and maintain a Data Management process found in NPR 7123.1, NASA Systems Engineering Processes and Requirements.

Lead Systems Engineers, DM Leads and CEs use this document to support the estimating and scheduling of the work that will be required to produce the data work products for the PPA 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, MPR 7120.3, and NASA/SP-6105.

The development of this section of the Handbook was based on the following assumptions:

a. Each PPA office needs a minimum number of DM requirements accompanied by proven and accepted guidance used by industry and government.

b. The PPA utilizes a DM Lead knowledgeable of data management processes with a demonstrated capability to guide the PPA in the appropriate tailoring and customizing for the size and complexity of the PPA.

c. Approval of the plans such as the Data Management Plan (and other important guiding documents such as the SEMP) follows a governance process similar to the one outlined.

The TDM elements and objectives described within this TDM guidance section apply to all PPAs, though the methods of implementation may vary per PPA size and complexity. The data products and formats described are typical of the methods utilized on MPR 7120.1 Mission Type 1, Mission Type 2, and some Mission Type 3 PPAs. For small, higher risk PPAs, TDM objectives may be met using less formal and less structured formats and processes, where these processes are known to have cost benefit. For all types of PPAs, use of proven processes and formats that have been verified as meeting PPA TDM objectives and that meet the needs of the using organizations will provide technical and resource benefits to the PPA.

3.3.2.5.1 Developing a Technical Data Management Strategy

The intent of the data management strategy is to define how data management will be implemented for any given PPA. This strategy is documented in the Data Management Plan (DMP) and tailored and customized according to the size and complexity of the PPA. The implementation approach is agreed upon by the PPA manager, the DM Lead and the CE of the PPA. The reason for this agreement is that the implementation can be different for each PPA based on the PPA organizational structure, operational culture, and the communications approach between the PPA 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 MSFC DRD STD/DM-DMP, Data Management Plan, also contains additional

information on DMP development. Like the CMP, the DMP may be combined with the PPA Plan or the SEMP as determined by the PPA manager.

Traditional TDM 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 are associated with DM execution. However, in addition to DM execution, new contemporary methods of TDM also include DM strategy and architecture development, DM 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 provides a framework of enablers that support these methods. PPAs consider an overall data architecture definition as part of the DM strategy to ensure data interoperability across teaming organizations and contractors.

3.3.2.5.2   Developing a Technical Data Management Plan

The first step in developing and documenting a DM strategy and process is for the PPA manager to appoint a DM Lead in the formulation phase of the PPA life-cycle. During this phase, the DM Lead will coordinate with the PPA manager and CE to develop the Data Management Plan (DMP). The DMP addresses the same functions as described by the DM key execution functions above. Sections 3.3.2.5.2 through 3.3.2.5.6 of this document are used as guidance to help populate the sections in the DMP. The following tasks and steps can be used as guidance for the initial steps during the development of the DMP:

Tasks	Steps
Assigning the Data Management Function. Establish General Requirements for Technical Data.	a. PPA manager assigns the DM support function during the PPA formulation life-cycle phase. b. DM Lead reviews the PPA Plan to determine general needs for data delivery and access throughout the PPA life-cycle. (1) A practical way to proceed is to review data requirements from similar PPA in coordination with NASA and Industry Subject Matter Experts (SMEs) including the Center Data Requirements Manager (CDRM). (2) Consider 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 PPA life-cycle.) (4) Identify a process to perform periodic audits of generated technical data to ensure correctness and completeness of all

> data quality. (data quality attributes include, precision, date/time, accuracy, completeness, consistency, and others based on PPA needs.)
>
> (5) Include a process for managing the security and access control of data.
>
> (6) Data views include presentation of data by technologies such as digital images, geographical information systems, graphical user interfaces, multi-dimensional tables and graphs, virtual reality, 3-D presentations, and animation.
>
> c. Anticipate the form in which the data will be required and determine if access to data or delivery of data is more appropriate. The general requirements will be used to develop inputs to the DMP.
>
> d. The DM function is responsible for developing the DMP.
>
> e. Use MPR 7120.3 and DRD STD/DM-DMP as guidance for developing a DMP.
>
> f. Additional guidance is also found in ANSI/GEIA-859.
>
> g. The DM Lead coordinates with PPA manager and CE to identify the "Applicable" sections of the MPR 7120.3, template based on size and complexity of the PPA.
>
> h. Deliver to PPA manager and CE for coordination and implementation.

3.3.2.5.3   Data Identification/Definition

The identification and definition of data requirements is one of the most important components in the formulation and planning of any PPA. 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.

Once the data needs of the PPA life-cycle have been identified in the DMP, then data types are defined in standard documents. NASA and MSFC directives sometimes specify the content of these documents which are used for in-house data preparation but the standard description of the data can be modified based on the PPA size, complexity and unique needs. There are different types of data that can be used in a MSFC PPA. These types of data applicable to MSFC PPAs for approval and delivery are documented in STD/DM-DRD, Data Requirements Description. NASA/SP-6105 identifies different types of data that might be utilized within a NASA PPA. The following tasks and steps can be used as guidance in identifying and defining PPA data:

Tasks	Steps
Develop and Maintain Standard DRDs.	a. The DM Lead develops the DRL and/or the DPD. MPR 7120.3 offers instructions respectively for the development of DRLs and DPDs. It is advisable to coordinate with the CDRM when developing the PPA DRL/DPD. b. 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 DM process, access privileges may take the place of recipients and number of copies. c. 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). MPR 8070.1, identifies guidance for a Standard DRD Development.

3.3.2.5.4   Acquire and Prepare Data

Preparation of data deals primarily with developing and implementing standardized formats and is critical accuracy. Data developed for the PPA is prepared according to the document preparation process identified in the PPA DMP.   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 data:

Tasks	Steps
Establish a Standard approach for preparing data.	a. The DM Lead, in coordination with PPA manager and CE, defines the data preparation requirements and documents them in the DMP. b. Instructions and guidance for identifying data preparation can be found in MPR 7120.3. c. The DM Lead informs the PPA of the data preparation procedures.

3.3.2.5.5   Data Control

Since data is central to all successful PPA 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., PPA manager, DCB, CCB, Contracting Officer's Representative (COR), OPR, 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 PPA Master List(s).

Data Control is essentially the application of a change management to PPA data to ensure its integrity and timeliness. Change management is the primary function of this process. However, not all data requires board change management process. Other forms of DM change management are receipt and release processes. It is important to identify the body of data that requires some level of control, when the data is ready to be placed under 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 data that makes control meaningful and productive. ANSI/GEIA-859 provides guidance for establishing a control process for data. Maturity d-states for NASA data are addressed in MGM 7120.3. 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:

  a. Develop General Data Control Process Requirements.

  b. Identify the responsibilities of the OPRD. The OPRD is assigned based on the data developed.

  c. Identify a Data Review Process.

  d. Identify data to be placed under configuration control.

  e. Establish and implement a consistent change control process.

   (1) Identify a formal change control approval process.

   (2) Identify a data authorization and capture process.

  f. Establish a process for control of contractor-produced data.

The CM section of this handbook identifies the guidelines for the configuration change control process. Data management processes can integrate the CM change management process for efficiency and unambiguous control of PPA data. However, technical and configuration baselines must be clearly identified and addressed when using an integrated process. Figure 34 provides a simplified overview of the Data Change Management process.
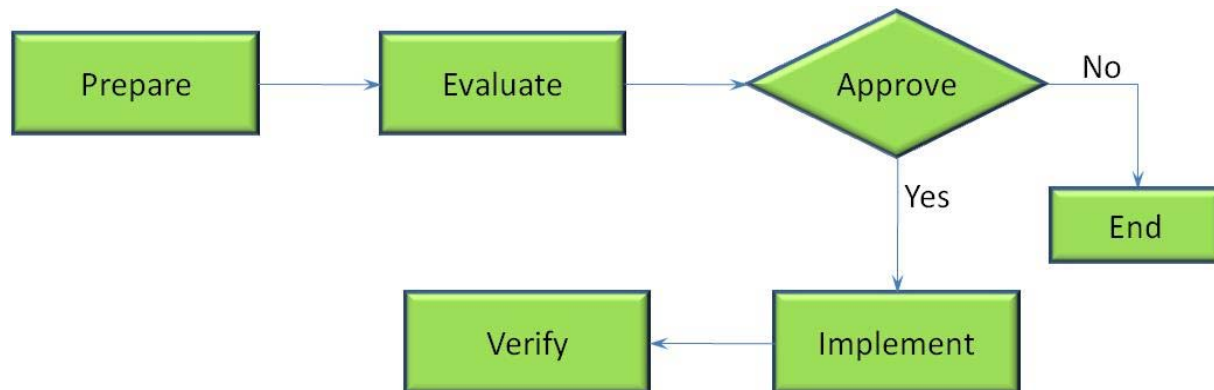
Figure 34. Data Control Process

The following tasks and steps offer guidance for effective data change management:

Tasks	Steps
Establish a Change Control Board function, Operations and Hierarchy	a. The DM Lead, CM Lead, PPA manager, and CE coordinate to determine the data and Configuration Change Control Board relationship (some PPAs may choose to run one change control board for data and configuration). b. The DM Lead uses the CM process section of this Handbook to select appropriate tasks and steps for the data control process.

3.3.2.5.6   Data Disposition (Access and Records)

Data disposition includes storage, data access, and maintenance of records. NASA record management requirements are defined in NPR 1441.1, NASA Records Management Program Requirements, and record retention and disposition requirements are defined in NRRS 1441.1, NASA Records Retention Schedules. MSFC records management requirements are defined in MPR 1440.2, MSFC Records Management Program. PPAs identify the records they are producing and ensure they are stored appropriately. Records and data are available for current use, stored so that records may be retrieved and utilized on future PPAs, 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 PPA ensures there is a process to provide adequate retention and preservation of data assets that are of value to the PPA and effectively disposing of data assets that are no longer of value. Once this process has been developed, data is evaluated regularly to assure it is of sustained value to the PPA. Since PPAs generally produce both paper and electronic data. a process for electronic conversion of paper data considered sustained value should be developed and implemented. The PPA communicates the retention and disposition requirements to all supporting organizations that generate PPA technical data. This is done to assure the appropriate technology is used at the right time in the PPA life-cycle and data assets with historic or valuable attributes are accessible and readable. ANSI/GEIA-859 provides guidance for effective archival and disposition of data.

Tasks	Steps
Establish Data/Document Disposition Process	a. The DM Lead coordinates with PPA manager to define a records plan and records management requirements, including a records/retention schedule for the PPA. See NPR 1441.1 for typical retention schedules and MPR 1440.2 for typical records management requirements. b. The DM Lead coordinates with PPA manager and CE to identify a process for long-term temporary and permanent data management within the MSFC repository. The process includes indexing of archives. c. Them DM Lead coordinates with Program/Manager and CE to establish a process for dissemination (publication and making available) of data produced by the PPA. d. All data disposition processes are documented in the PPA DMP.

3.3.2.5.7   Training the Data Management and Program/Project/Activity Team

A well-trained and knowledgeable PPA and TDM team is the key ingredient to implementing a successful DM Planning. Since each PPA team may have a specific DM process the training is customized accordingly. It is suggested that DM training be role-based to meet the needs of the trainees (i.e., Engineering organizations may need training on Technical Data preparation, while PPA leadership may not).

This section of the Handbook can be used as a "How to" training resource on implementing a DM process. However, it is up to the PPA manager and DM Lead to assess and determine any unique training needs. At a minimum it addresses the following three areas tailored to the PPA:

    a.   DM Strategy, such as:
       (1) Data access process.
       (2) Data classification.
       (3) Change Control Process.
       (4) Baselining.
    b.   DM Procedures, such as:
       (1) Data Review Process.
       (2) Data Approval Process.
       (3) Control of Contractor-Produced Data.
    c.   Tool usage, such as:
       (1) Electronic folder access.
       (2) Input and access libraries.
       (3) Search for CIs and contents.

3.3.2.5.8   Defining Requirements for Applications That Support DM

In today's environment automated tools are essential for effective and efficient data management. They can automate many aspects of the data change management process, provide reports and metrics, and provide document control and other essential functionality.

When reviewing use-cases and process integration for applications that support the DM functions within a PPA, inputs from both the DM practitioners and the data developers are essential. The R&R of the data developer and the DM practitioner are significantly different. Identifying simple user and tool interfaces commensurate with their respective roles will have a significant impact on how well the tool is accepted and utilized.

3.3.3 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, NASA/SP-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 PPA 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 DM'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 CEs 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 KDPs. 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 systems engineering) status reporting, metadata assessment, and top-level technical readiness; 2) intermediate level formal technical assessment, including DGA 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 systems engineering). 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 PPA 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 PPA 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 TRM Decision Analysis, and Technical Planning. These processes provide input to or receive output from the Technical Assessment process. Other systems engineering engine processes also interact with Technical Assessment. Additional guidance and detail is given in Appendix E.

Review Plan Outline:
- 1.0 Introduction and Background
- 2.0 Review Objectives

CHECK THE MASTER LIST – VERIFY THAT THIS IS THE CORRECT VERSION BEFORE USE

- • 2.1 Entrance/Exit Criteria
- • 3.0 Review Organization
  - • 3.1 Review Team Membership
  - • 3.2 Pre-Board Membership
  - • 3.3 Board Membership
  - • 3.4 R&R
- • 4.0 Review Procedures
- • 5.0 Technical Data Products
- • 6.0 Review Schedule
- • 7.0 RID Forms

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

<u>Inputs and Sources</u>:

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 PPA).

d. Technical cost and schedule status reports (from PPA).

e. Product measurements (from Product Verification and Product Validation Processes).

f. Decision support recommendations and impacts (from Decision Analysis Process).

<u>Outputs and Destinations</u>:

a. Assessment results and findings including technical performance measurement estimates of measures (to Technical Planning, TRM, and Requirements Management Processes).

b. Analysis support requests (to Decision Analysis Process).

c. Technical review reports (to PPA and TDM).

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 TDM).

3.3.3.1   Mishap and Failure Investigations

The NASA mishap investigation process is governed by NPR 8621.1 NASA Procedural Requirements for Mishap and Close Call Reporting, Investigating, and Recordkeeping.

At a glance, the NPR: (1) specifies how to prepare for the possibility of and respond to mishaps/failures. (2) Contains requirements for classifying mishaps, establishing investigating authorities, and performing investigations. (3) Describes R&R.

For flight PPAs, the NPR requires that a pre-mishap plan be established by the PPA, which provides direction on how the PPA will implement NASA policy, and in many cases, there will need to be an interface with a prime contractor.

For Research and Technology (R&T) PPAs, there are provisions for the hardware owner/PPA to conduct an independent failure investigation, is warranted to prevent recurrence of any test induced damage that may occur during R&T testing. Per NPR 8621.1, test induced damage is not considered a mishap, providing the following:

   a.   There are no injuries, illness or fatalities.

   b.   There is no damage to public property, other Government agency property, or private property (e.g., a privately owned vehicle) regardless of the property's location. This includes debris which left the test range/test cell (unless there was a close call).

   c.   Damage is limited to test articles or test facilities, and the risk of damage was formally documented and accepted by signature before the test, such as during the TRR.

3.3.3.1.1   MSFC Guidance and Best Practices

The MSFC implementation of this NPR is outlined in MCP 8621.1, MSFC Mishap Preparedness and Contingency Plan, and MWI 8621.1, Mishap and Close Call Reporting and Investigation Program.

At MSFC, the NPR 8621.1 requirements and guidance flowed down to the contractors through the following MSFC DRDs: STD/SA-SHP off Off-site Safety, Health, and Environmental (SHE) Plan, and/or STD/SA-SHP on On-site Safety, Health, and Environmental (SHE) Plan.

If a mishap/failure occurs at MSFC, the responsible engineer will either call for emergency services, or if there is only hardware damage, the engineer will report the mishap to SMA, and other engineering/PPA personnel as directed. An example of an immediate response plan is outlined in ET01-PRO-OWI-023, Initial Mishap Response during Test Operations.

The hardware/facility is secured as soon as it is safe to do so, usually with the assistance of Protective Services, and SMA will impound the associated records until an investigation authority is determined at which time the records are turned over to that authority.

In either case, whether a flight or R&T PPA, it is imperative that the investigation and analysis be thorough and unbiased. A Fault Tree Analysis (FTA) will serve as a framework to identify and track all possible areas of investigation and analysis. SMA provides this service. The fault tree is a symbolic logic diagram showing the cause and effect relationship between a top undesired event (i.e. a failure) and one or more contributing causes. For a less complicated failure, another tool is an Ishikawa Diagram, commonly known as a "Fishbone.".

The investigation team takes a forensic approach to the analysis. Remaining hardware, whether flight article, test article and facility/GSE are thoroughly examined visually, dimensionally and through NDE or other materials tests as appropriate. In many cases, flight hardware may not be available. "Build paper" is examined for compliance with drawings, specifications, and critical processes; and test or launch constraints; waivers, deviations and non-conformances are closely examined; as well as Hazard Analysis and FMEA/CIL. Test data is examined for similar failures or out-of-tolerance conditions. Software programs and recorded data are analyzed for sequence of events, control system parameters, and indications of out-of-tolerance conditions. Processes such as precision cleaning, maintaining cleanliness, foreign objects and debris controls, impact damage controls, electrostatic discharge controls are examined as applicable for evidence of compliance. A timeline of events is established. Any photo/video evidence should be closely examined, since there may be evidence or data captured there that does not show up anywhere else. Witness statements, which are collected by SMA, are another source of important information. Testing is often done to duplicate the failure and validate the suspected cause. Again, for a complicated scenario, a FTA serves to organize the lines of investigation and to facilitate organization of the evidence. It is important to examine the data in advance of developing conclusions, so that nothing is overlooked and the appropriate solutions can be determined.

3.3.3.2 Technical Assessment Approach

The formulation of the technical assessment approach is done in conjunction with the development of the PPA's SEMP. Development and subsequent revisions to the PPA's SEMP are performed as part of the Technical Planning process. The scope of the PPA will ultimately determine the resources and schedule needed to complete the PPA 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 PPA 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) PPA 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 PPA's technical assessment strategy and approach.

	b. Provide an overview on how the planning team is organized and description of R&R. 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 PPA stakeholders.
Submit for concurrence and/or approval.	Submit the final technical assessment planning information for concurrence and/or approval to the proper DGA.
Maintain the Technical Assessment Approach.	Update the technical assessment strategy and approach, as required, based on: a. Major program milestone review. b. Major technical reviews.

3.3.3.3   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 PPA stakeholders is key to any successful PPA. 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-3403	NASA Schedule Management Handbook
NASA/SP-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 DGA 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.

3.3.3.4   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 measurable progress and intermediate quality checks to ensure a quality product is on track to meet cost, schedule, and technical requirements for the final deliverable.

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 DGA 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.

3.3.3.5   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 PPA management, but typically, reviews are conducted as identified in MPR 7120.1 and MPR 7123.1. For information relative to Entrance and Success criteria for MSFC applicable technical reviews see, MPR 7123.1.

3.3.3.6   Conducting Technical Reviews

Planning and preparation for a technical review is critical. Significant time and effort is needed to prepare and coordinate with key stakeholders.

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 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:

      a.   Definition of the technical products required and the required maturity level for the review data package.

      b.   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 at which key stakeholders decide and certify adequate progress has made to proceed to the next PPA phase. If sufficient progress has not been made, additional outcomes can include (1) approval for continuation to the next 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 PPA (Phases B, C, D, and E only); direction to continue in the current phase; or redirection of the PPA.

Several NASA and MSFC 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-6105	NASA Systems Engineering Handbook
MSFC 7123.1	MSFC Systems Engineering Processes and Requirements
NASA/SP-3706	NASA Standing Review Board (SRB) Handbook, 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 DGA 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.

3.3.4 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 DM 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 PPA.

b. Selecting and testing evaluation methods and tools against sample data.

c. CM processes for major CRs or problem reports.

d. Design processes for making major design decisions and selecting design approaches.

e. KDP reviews or technical review decisions (e.g., PDR, CDR) as defined in MPR 7120.1 and MPR 7123.1.

f. Go or No-Go decisions (e.g., FRR).

g. PPA 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.

k. Miscellaneous decisions (e.g., whether to intervene in the PPA 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:

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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 TDM).

3.3.4.1   Decision Analysis Approach

Decisions are made at all levels of the PPA and throughout a system's life-cycle. The PPA SEMP will describe the importance of a thorough, rigorous, and disciplined decision analysis process because decisions can have far reaching impacts to a PPA'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 PPA.

Authority to make decisions can be delegated to specific organizations or single representatives of those organizations, taking into account the R&R 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 HW/SW 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.

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    (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-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 PPA'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.

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.

    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 PPA 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 PPA'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 a PPA organizational chart to support the decision making assignments. b. Obtain a PPA 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 PPA, analyze the entrance criteria for mandatory technical reviews and KDPs 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 PPA decisions.
Provide output of the decision analysis process in support of the preparation or revision of the PPA 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.

3.3.4.2 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 LCCs.
	    (8) Schedule impact.
	b. Define the acceptable range and scale of the criteria.

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	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.
	    a. Systems analysis, simulation and performance.
	    b. Weighted tradeoff matrices.
	    c. Engineering, manufacturing, cost, and technical opportunity trade studies.
	    d. Cost-benefit analysis.
	    e. Decision matrix.
	    f. Decision trees.
	    g. Influence diagram.
	    h. Multi-criteria decision analysis.
	    i. 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-6105	Figure 35, Example of Decision Matrix.
NASA Systems Engineering Handbook, NASA/SP-6105	Figure 36, Typical Information to Capture in a Decision Report.
NASA Systems Engineering Handbook, NASA/SP-6105	Figure 37, Trade Study Process.
NASA Systems Engineering Handbook, NASA/SP-6105	Figure 38, Example of a Decision Tree.
NASA Systems Engineering Handbook, NASA/SP-6105	Figure 39, Risk-informed Decision Analysis Process.

Decision Matrix Example for Battery			ENTER SCORES	Extend Old Battery Life	Buy New Batteries	Collect Experiment Data With Alternative Experiment	Cancelled Experiment
CRITERIA	Mandatory (Y=1/N=0)?	Weight	SCALE				
Mission Success (Get Experiment Data)	1	30	3 = Most Supportive 1 = Least Supportive	2	3	3	0
Cost per Option	0	10	3 = Least Expensive 1 = Most Expensive	1	2	3	1
Risk (Overall Option Risk)	0	15	3 = Least Risk 1 = Most Risk	2	1	2	3
Schedule	0	10	3 = Shortest Schedule 1 = Longest Schedule	3	2	1	3
Safety	1	15	3 = Most Safe 1 = Least Safe	2	1	2	3
Uninterrupted Data Collection	0	20	3 = Most Supportive 1 = Least Supportive	3	1	2	1
WEIGHTED TOTALS in %		100%	3	73%	60%	77%	0%
			SCALE 1-3				

Figure 35. Example of a Decision Matrix

#	Section	Section Description
1	Executive Summary	Provide a short half-page executive summary of the report: • Recommendation (short summary—1 sentence) • Problem/issue requiring a decision (short summary—1 sentence)
2	Problem/Issue Description	Describe the problem/issue that requires a decision. Provide background, history, the decisionmaker(s) (e.g., board, panel, forum, council), and decision recommendation team, etc.
3	Decision Matrix Setup Rationale	Provide the rationale for setting up the decision matrix: • Criteria selected • Options selected • Weights selected • Evaluation methods selected Provide a copy of the setup decision matrix.
4	Decision Matrix Scoring Rationale	Provide the rationale for the scoring of the decision matrix. Provide the results of populating the scores of the matrix using the evaluation methods selected.
5	Final Decision Matrix	Cut and paste the final spreadsheet into the document. Also include any important snapshots of the decision matrix.
6	Risk/Benefits	For the final options being considered, document the risks and benefits of each option.
7	Recommendation and/or Final Decision	Describe the recommendation that is being made to the decisionmaker(s) and the rationale for why the option was selected. Can also document the final decision in this section.
8	Dissent	If applicable, document any dissent with the recommendation. Document how dissent was addressed (e.g., decision matrix, risk, etc.).
9	References	Provide any references.
A	Appendices	Provide the results of the literature search, including lessons learned, previous related decisions, and previous related dissent. Also document any detailed data analysis and risk analysis used for the decision. Can also document any decision metrics.

Figure 36. Typical Information to Capture in a Decision Report

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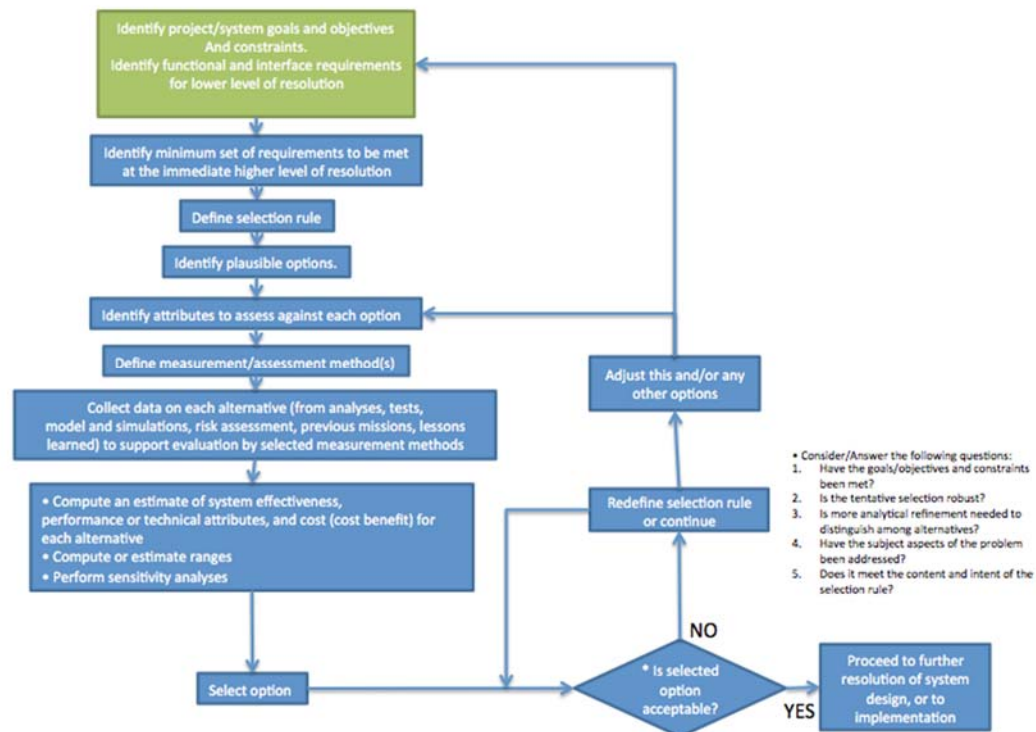
Figure 37. Trade Study Process
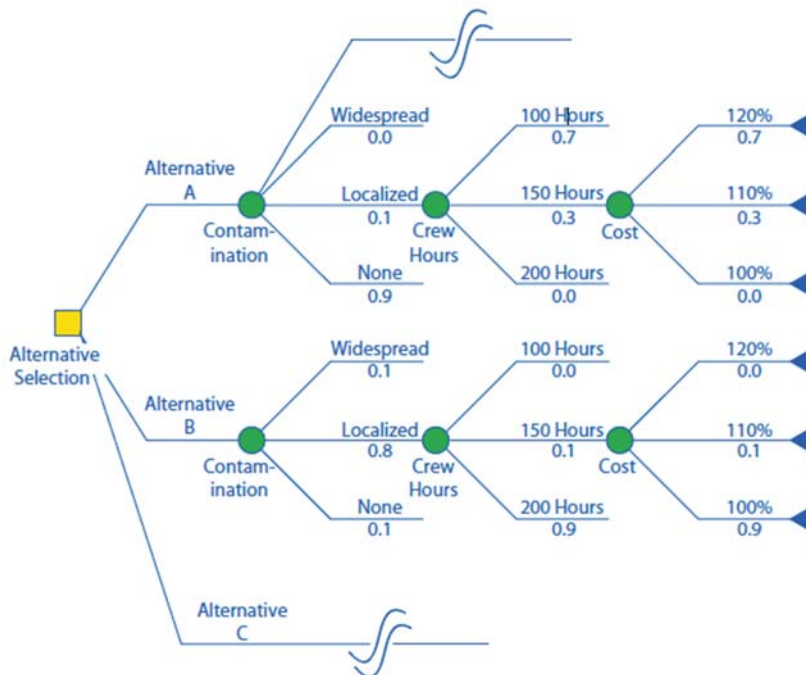
Figure 38. Example of a Decision Tree

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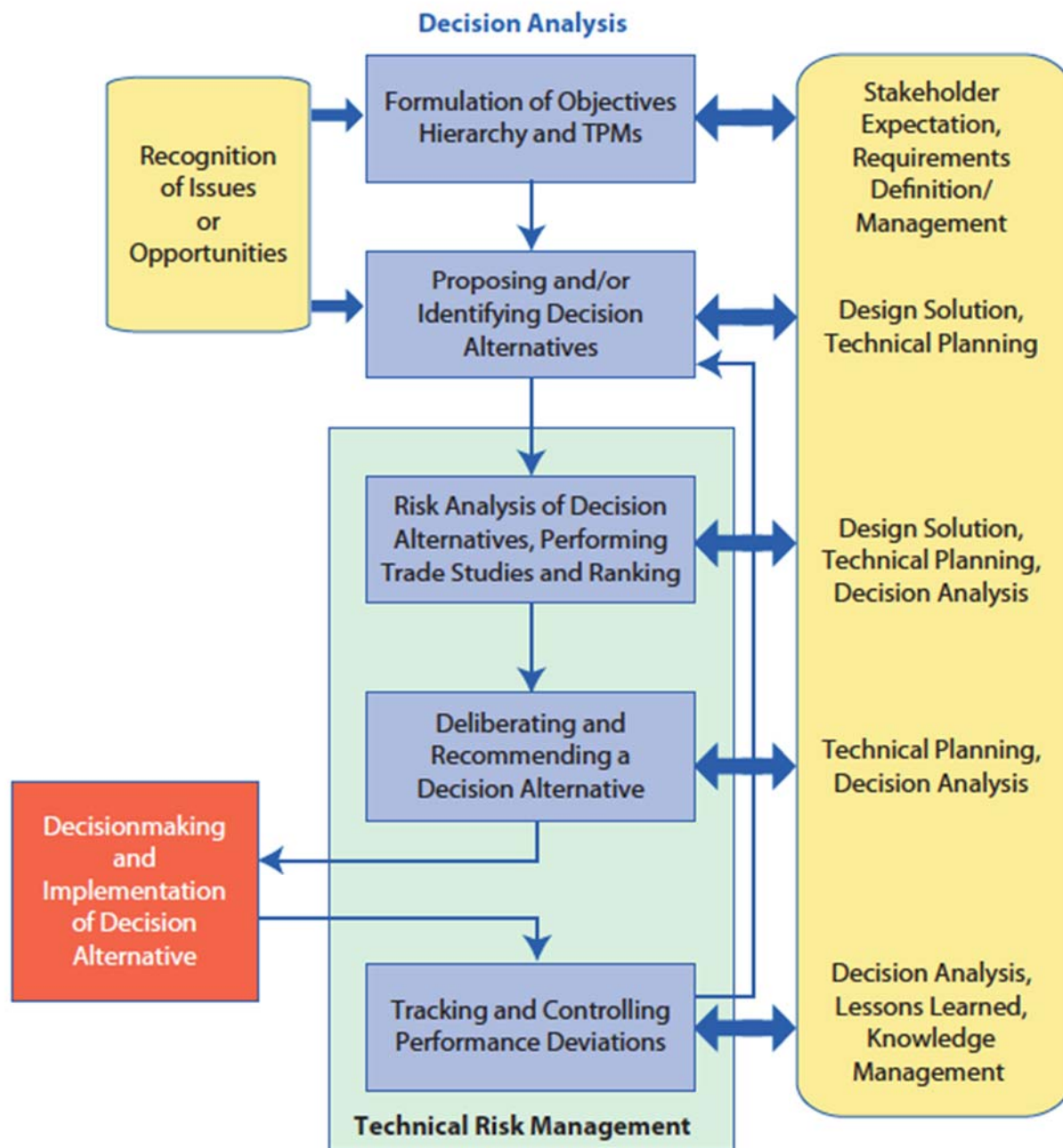
Figure 39. Risk-informed Decision Analysis Process

3.4   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 PPA implementation, system design, development, and operations. Throughout PPA development, existing lessons learned/best practices are reviewed. Reviewing lessons learned from past PPAs 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 PPAs. 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

ALERT	Acute Launch Emergency Restraint Tip
ANSI	American National Standards Institute
AO	Announcement of Opportunity
BAR	Basic and Applied Research
CAM	Cost Account Manager
CCB	Configuration Control Board
CDR	Critical Design Review
CDRM	Center Data Requirements Manager
CE	Chief Engineer
CER	Center Export Representative
CERR	Critical Events Readiness Review
CI	Configuration Item
CIL	Critical Items List
CM	Configuration Management
CMC	Center Management Council
CMP	Configuration Management Plan
CofF	Construction of Facilities
COFR	Certification of Flight Readiness
ConOps	Concept of Operations
COR	Contracting Officer's Representative
CPU	Computer Processing Unit
CR	Change Request
CRM	Continuous Risk Management
CSA	Configuration Status Accounting
CSO	Chief Safety and Mission Assurance Officer
CSR	Customer Support Representative
DCB	Document Control Board
DCR	Design Certification Review
DFI	Developmental Flight Instrumentation
DGA	Designated Governing Authority
DID	Data Item Description
dm	direct measurements
DM	Data Management
DoD	Department of Defense
DR	Decommissioning Review
DRD	Data Requirements Description
DRL	Data Requirements List
DRM	Design Reference Mission
DRR	Disposal Readiness Review
DSD	Design Solution Definition
ECR	Engineering Change Request

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EEE	Electrical, Electronic, and Electromechanical
EMC	Electromagnetic Compatibility Engineering Management Council
EMI	Electromagnetic Interference
ERD	Environmental Requirements Documents
ETA	Engineering Technical Authority
EVMS	Earned Value Management System
FS&GS	Flight Systems and Ground Support
FAD	Formulation Authorization Document
FAR	Federal Acquisition Regulation
FCA	Functional Configuration Audit
FDF	Flight Data File
FFBD	Functional Flow Block Diagrams
FGB	Functional Cargo Block
FMEA	Failure Mode and Effects Analyses
FRR	Flight Readiness Review
FTO	Flight Test Objectives
FTA	Fault Tree Analysis
GN&C	Guidance Navigation & Control
GEIA	Government Electronics & Information Technology Association
GPMC	Governing Project Management Council
GSE	Ground Support Equipment
HW/SW	Hardware/Software
HQ	Headquarters
I&T	Integration and Test
IA	Independent Assessment
ICD	Interface Control Document Interface Control Drawing
ICP	Interface Control Plan
ICWG	Interface Control Working Group
ID	Identifier
IDD	Interface Definition Document or Interface definition Drawing
ILS	Integrated Logistics Support
ILSP	Integrated Logistics Support Plan
IMP	Integrated Master Plan
IMS	Integrated Master Schedule
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
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 Information System
LSE	Lead System Engineer
LT/PI	Lead Technologist / Principal Investigator
MAP	Manufacturing and Assembly Plan
MCR	Mission Concept Review
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
MP	Materials and Processes
MPR	Marshall Procedural Requirements
MRR	Mission Readiness Review
M&S	Models and Simulations
MSFC	Marshall Space Flight Center
MWI	Marshall Work Instruction
N^2	N-squared diagrams
NASA	National Aeronautics and Space Administration
NFS	NASA FAR Supplement
NGO	Needs, Goals, and Objectives
NPD	NASA Policy Directive
NRA	NASA Research Announcement
OBS	Organizational Breakdown Structure
OCD	Operational Concept Document
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
PA	Process Assessment
PBS	Product Breakdown Structure
PCA	Program Commitment Agreement
PCA	Physical Configuration Audit

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PCH	Program Critical Hardware
PDR	Preliminary Design Review
PFAR	Post-Flight Assessment Review
PFD	Power Flux Density
PHA	Preliminary Hazard Analysis
PHS&T	Packaging, Handling, Storage and Transportation
PIRN	Preliminary Interface Revision Notification
PLAR	Post-Launch Assessment Review
PMA	Pump Module Assembly
PMB	Performance Measurement Baseline
PMC	Project Management Council
POC	Point of Contact
PPA	Program/Project/Activity
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
QA	Quality Assurance
RAM	Responsibility Assignment Matrix
REMP	Requirements Engineering Management Plan
REQSPEC	Requirement Specification
RF	Radio Frequency
RID	Review Item Discrepancy
RIDM	Risk-Informed Decision Making
RM	Risk Management
RMP	Requirements Management Plan Risk Management Plan
ROM	Rough Order Magnitude
R&M	Reliability and Maintainability
R&R	Roles and Responsibilities
SMA	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
SED	Stakeholders Expectations Definition
SE&I	Systems Engineering and integration
SEMP	Systems Engineering Management Plan
SIR	System Integration Review

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SMAR	Safety and Mission Assurance Review
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
TA	Technical Authority
TAS	Technical Analysis System
TBD	To Be Determined
TDM	Technical Data Management
TDP	Technical Data Package
TLYF	Test Like You Fly
TPM	Technical Performance Metric Technical Performance Measures
TRD	Technical Requirements Definition
TRL	Technology Readiness Level
TRM	Technical Risk Management
TRR	Test Readiness Review
UFE	Unallocated Future Expenses
V&V	Verification and Validation
WBS	Work Breakdown Structure

APPENDIX B. GLOSSARY

Activities. (1) A set of tasks that describe the technical effort to accomplish a process and help generate expected outcomes. (2) A set of tasks that support the execution of, or provide a product to a program or project.

Agency. Term referring to NASA.

Baseline (noun). The authorized and identified data that defines an item (e.g., cost, schedule, requirements, design, configuration, or other technical data item) at a specific point in time where changes from that point forward are controlled through a traceable approval and implementation process.

Baseline (verb). To authorize and identify data that defines an item (e.g., cost, schedule, requirements, design, configuration, or other technical data item) where changes from that point forward are controlled through a traceable approval and implementation process.

Bidirectional Traceability. An association between two or more logical entities that is discernible in either direction.

Center Management Council (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 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 PPA representatives who recommend approval or disapproval of proposed engineering changes to, and proposed deviations/waivers from, a CIs, or a baseline's, current approved configuration documentation.

Configuration Documentation. The PPA-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 CM. Configuration items are typically referred to by an alphanumeric ID which also serves as the unchanging base for the assignment of serial numbers to uniquely identify individual units of the CI.

Cost Risk. The risk associated with the ability of the PPA to achieve its LCC 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. 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 PPA.

Data Interoperability. The ability for two or more systems to exchange data and use the data that has been exchanged.

Data Requirements Description (DRD). A detailed description of a required data item, including purpose, contents, format, maintenance requirements, and submittal requirements.

Data Requirements List (DRL). 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 (DM). The timely and economical identification/definition, preparation, control, and disposition of documents and data required by a PPA.

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

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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 PPA 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 LD 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 CIs 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. PPA 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 PPA 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.

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Formulation Authorization Document (FAD). The document issued by the Mission Directorate Associate Administrator (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 PPA.

Gantt Chart. Bar chart depicting start and finish dates of activities and products in the WBS.

Integrated Master Schedule (IMS). An integrated set of schedule data that reflects the total PPA 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 PPA 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 virtue of position, has responsibility for the use and control of MSFC product and/or CSP (MPR 6410.2).

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 PPA.

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 V&V 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 V&V 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 V&V 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 PPAs. 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 PPA, over which the PPA manager has no control, but which may have significant impact on the PPA. 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 LCC, a beginning, and an end. A project yields new or revised products that directly address NASA's strategic needs.

Review Item Discrepancy (RID). 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 PPA 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 PPA 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 TRM 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,

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the National Space Council, scientists, PPA 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 PPA 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 R&R 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.

Tailoring. The process used to adjust or seek relief from a prescribed requirement to accommodate the needs of a specific PPA.

Technical Assessment Process.   The crosscutting process used to help monitor technical progress of a PPA 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 PPA. 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 PPA objectives and life-cycle-phase success criteria within the cost, schedule, and risk constraints of the PPA.

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 (TRM) 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 PPA.

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 PPA's end product(s) structured according to the way the work will be performed, reflecting the way in which PPA 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 PPA 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 GOOD REQUIREMENTS

C.1   Developing Requirements

The "system of interest" NGOs are often contained in the parent documents. The need is often found in the announcement of opportunity (AO) or proposal. The need explains why the PPA is developing the product from the stakeholders' points of view (What problem do the stakeholders want to solve?). The NGOs are generally found in the PPA Plan, proposal, or a NGOs 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?

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    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 PPA's Risk Management process.

Requirements Documents are only to contain requirements relative to the product(s) to be developed. Requirements relative to the PPA or personnel/contractor actions are to be captured in a Statement of Work (SOW) or PPA 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 PPA's template and style rules.

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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.

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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")?

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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 PPA glossary?

c. Is the terminology consistently used throughout the document?

d. Are the key terms included in the PPA'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?

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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?

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C.2   Requirements Analysis Metrics

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 PPA's risk profile Acute Launch Emergency Restraint Tips (ALERTs) systems engineering management for the need to take appropriate action.

Systems engineers are familiar with the capabilities of the systems engineering tool software. Systems engineering 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 systems engineering 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 systems engineering tool software to establish and maintain metrics. PPA specific metrics are identified and implemented to ensure a complete assessment can be made on the PPA status.

The following short list of metrics that can be used to gauge the progress and completion of a typical requirements analysis activity:

      a. Number or percent of requirements defined, allocated, and traced.
      b. Time to issue draft technical requirements specification.
      c. Number of meetings held.
      d. Number and trends of TBD, TBR, and TBS requirements.
      e. Number of requirement issues identified (e.g., requirements not stated in a verifiable way).
      f. Number and frequency of changes (additions, modifications, and deletions).

APPENDIX D. MANAGING REVIEWS AND DISCREPANCIES

D.1 Introduction

This appendix addresses descriptions, 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 PPAs. The RID generation, tracking, and resolution process describes a robust system for managing the primary activities of a technical review. Individual PPAs 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 systems engineering 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 PPAs is specified in MPR 7120.1, and the minimum types of major milestone reviews to support required PPA phases, KDPs, and phase transitions are further specified in MPR 7123.1. In addition MPR 7123.1 describes the different major milestone reviews, and provides guidance for developing and specifying entrance and exit criteria for major milestone reviews.

Technical reviews enable PPA 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 PPA objectives, and to obtain approval to proceed to the next level of activity.

D.3.2 Inter-related Technical Assessment and Review Responsibilities

PPA Management is responsible for managing the budget, schedule, and satisfaction of predominantly external stakeholders needs, including system performance for the entire PPA. PPA Management control the direction of all work and have ultimate authority for controlling PPA funds. CEs or LSEs 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 DGA. It is reiterated that in general, at MSFC, CEs and LSEs do not have final authority to direct action on PPA work or to control budget and schedule-impacting major decisions. The role of CEs 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 PPA objectives and execute technical work guidance in compliance with the PPA 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, PPA management, the lead systems engineer, and the CE evaluated the program objectives captured in the Program Plan, and specified in the SEMP the major milestone review/KDPs to be conducted, and at what maturity the PPA products are to be at each of the major milestone reviews. Output from Decision Analysis System 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.

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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 are recorded and follow-up activities are tracked and resolved as quickly as possible.

Clear guidelines are in place for elevation of dissenting opinions to allow understanding and assessment of the issue(s) and achieve resolution at the appropriate level.

D.3.3.2   Program/Project/Activity 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 in MPR 7123.1.

Ensuring adequate PPA maturity is crucial to the successful completion of the review. Conducting the review before the PPA 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 PPA manager 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 PPA need to be up-to-date on the PPA activities and direction, and be proactive in resolving format and content deficiencies well before the review is conducted.

The PPA manager 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 PPA 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. PPA 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, 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 TDM 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 2.2.10 Technical Planning and Appendix 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 and providing training to the team on review processes as appropriate.

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 Success Criteria

Each of the Technical Reviews defined in section 3.3.3.5 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 one PPA to another. The tables provided in MPR 7123.1 assist the Systems Engineers to focus their attention on the specific programmatic and technical requirements and product maturity level expectations for each review. Criteria may be tailored to meet the specific needs of PPAs as appropriate.

D.4.7 Obtaining Review Plan Approval.

The PPA CE, LSE, and/or Governing Technical Authority approves the review plan.

The PPA's CCB 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 prior to the Review Kick-off meeting.

D.5   Conducting Major Program Technical Reviews

D.5.1 Review Kickoff Meeting

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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. Any remaining open action items or RIDs from previous reviews should be presented along with status and closure plans. In addition, any pre-declared RIDs or action items for the review should be identified and discussed.

Kick off meeting attendance is mandatory for the Review Committee, Review Team, and review team leads. Consideration should also be given to inviting Pre-Board and Board membership to the Kick-off meeting as appropriate.

The PPA manager 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, M&Ss, 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.

h. Status and closure plans for remaining open action items or RIDs from previous reviews.

i. Identification of Pre-declared RIDs for the Review, if any.

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D.5.1.2   *Agenda*

A typical agenda for a design review kickoff:

Introduction/Welcoming Remarks	PPA manager
Safety Procedures (protected areas/evacuation routes, etc.)	Review Lead or PPA Designee
PPA Overview	" "
Review Scope and Objectives	" "
Review Teams/Responsibilities	" "
Review Process/Ground rules	" "
RID Criteria and other Ground rules	" "

Schedule, Open action items/RIDs from previous reviews, Pre-declared RIDs

System Overview	CE designee
Requirements/Verification Flow	
Design Overview	
Interfaces, Integration and Test (I&T)	
Issues/Concerns	

Subsystem A	CE designee
Requirements/Verification	
Design Overview	
Interfaces	
Manufacturing, I&T	
Issues/Concerns	

Other Subsystems as Applicable	CE designee

Operations	Lead Operations Engineer
Requirements/Verification	
Concept/Planning Overview	
Training	
Issues/Concerns	

Safety and Mission Assurance	CSO or designee

Concluding Remarks	PPA manager

D.6   Review Item Discrepancy Legacy Process

The following process describes the formal RID process as used in the past at MSFC. This process may be used for future PPAs 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 PPA reviews. This process documented here provides guidance on

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how good reviews are conducted, including identifying, tracking, and resolving action items, discrepancies in review items, and dissenting opinions. PPA may tailor this process to their needs.

D.6.1 Overview

Specific technical reviews for each program and PPA are defined in the individual PPA Plans and/or in the SEMP for each PPA.

Narrative statements describe the entrance criteria and success criteria for each review.

In addition to entrance criteria, the NASA LLIS 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 PPA 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 PPA test or operational readiness reviews detailed below, at the discretion of the PPA 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 PPA 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 PPA manager 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 PPA plan and/or the SEMP.

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    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) Pre-board meeting date/time and location.

        (8) Board meeting date/time and location.

        (9) Definition of approach to support the life-cycle reviews.

    f.   Ensuring that the PPA uses this MSFC directive for entrance and success criteria associated with life-cycle and technical 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 PPA manager or designee to initiate the selection of a Chairperson for the SRB, as appropriate.

    i.   The PPA manager 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.
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D.6.2.2   Appointing a Review Committee

The PPA manager or designee appoints a review committee:

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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 PPA personnel, SMA 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.   SMA 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 PPA manager or designee organizes the review committee into teams based on functional areas, disciplines, subsystems, organizations or other categories.

h.   If the PPA manager or designee organizes the review committee into teams, review team leads are appointed to manage each team's review:

(1) Team leads are functional/technical team leads or senior level engineers;

(2) 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.

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     m. PPA document developers provide support and clarification to review committee/team members in order to facilitate an effective review.

D.6.2.3   Pre-RID Screening

The PPA manager or designee may commission the review committee/teams to provide technical evaluations/assessments of Pre-RIDs prior to Pre-RID screening:

If a Pre-RID 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.

     c.   If it is not modified/resubmitted or withdrawn by the initiator, it proceeds to the Pre-RID screening process where it is classified (editorial/technical), simplified (one discrepancy per form), and/or consolidated (merged/combined with other Pre-RIDs), as appropriate.

If a Pre-RID is considered technically acceptable, it proceeds to the Pre-RID screening process where it is classified (editorial/technical), simplified (one discrepancy per form), and/or consolidated (merged/combined with other Pre-RIDs), as appropriate.

Screening is a crucial element of a successful review. Pre-RIDs may be screened by a Screening Committee to ensure that they meet the criteria/ground rules as defined in the Review Plan. An accepted Pre-RID becomes a RID and is assigned a RID tracking number and is forwarded to the Review Committee/Teams for disposition.

The PPA CE or designee appoints a Pre-RID screening lead. The PPA manager 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 PPA manager 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.

D.6.2.3.1 Pre-RIDs That Fail 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 PPA.

Pre-RIDs that meet the criteria are promoted as RIDs to the Pre-board or Board.

D.6.2.4 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) PPA 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 PPA 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.6.2.5   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   Guidelines for a Pre-Board Meeting

     a.   The PPA CE or designee chairs the Pre-board.

     b.   The RID system coordinator presents a summary of the RID status to the Pre-board.

     c.   The summary includes a complete list of all RIDs, the recommended dispositions, and associated cost and schedule impacts, if possible.

     d.   A total of the cost impacts for all approved RIDs is presented, if possible.

e.   RIDs forwarded to the Pre-board for review and action are presented individually in sufficient detail to facilitate Pre-board disposition and recommendations.

D.6.4 Pre-board Process

Typically, the Board Chairperson is the PPA manager, 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 PPA.

(4) RIDs are revaluated to see if it is within the scope of the Pre-board to implement.

c.   The PPA manager 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 PPA manager.

(2) Schedule thresholds for Pre-board and Board reviews are based upon the schedule reserve available to the PPA manager.

d.   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.

d.   The CE or designee publishes the Pre-board meeting minutes and distributes to the PPA manager, 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 PPA manager for concurrence and implementation.

(3) A description of RIDs requiring Board review and disposition.

e.   A list and status of all open RIDs from previous reviews.

f.   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 PPA with the next stage of development.

g.   If the Pre-board finds that the entrance and success criteria have been met, that the PPA 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.

D.6.4.1 Review Data Package

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 MPR 7123.1. 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.

D.6.4.2 Pre-board and Board Members

The PPA manager 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 PPA team.

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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 PPA manager 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 SMA 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.6.5   Conducting a Board Meeting

D.6.5.1   Program/Project/Activity Manager Board Responsibilities

The PPA manager or designee chairs the 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.

D.6.5.2   Board Responsibilities

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.

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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 Governing Project Management Council (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 PPA manager 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 PPA manager 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 PPA manager designates, in the Review Plan, any concurrences required for RID closure. The PPA manager 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, has been met, and whether to recommend that the PPA proceed to the next stage of development.

    (1) If the success criteria have not been met, or the PPA is not ready to proceed, then the Board documents required corrective actions.

g.   The PPA does not proceed further until the conditions established by the Board have been fulfilled.

h.   Publishes Board meeting minutes and distributes to the PPA manager, 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 PPA to proceed to the next stage of development. If the stated criteria have not been met, or the PPA 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 PPA is ready to proceed to the next stage of development. A suggested Pre-board/Board certification sheet format is included in Appendix D.6.7.

D.6.6   Documentation of Review Results

The PPA manager 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 PPA 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.

D.6.6.1   What a Review Result Includes

As a minimum, review results include the following:

  a. PPA ID 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.

D.6.6.2 What a Review Schedule Includes

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.6.7 Template for Pre-board/Board Certification

PPA Name – Name of Review – Pre-board or Board Findings - Date

The Pre-board/Board Chair recommends the following:

_____ The PPA has demonstrated successful completion of the Entry Criteria defined in the Review Plan.

_____ The PPA 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 PPA 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

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_____ 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.6.8 RID Tracking

Tracking RID closure is a valuable TPM that PPA manager s are encouraged to utilize as part of the regular PPA 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 WBS is an effective means of determining technical areas that require management attention.

D.6.9 Post-Board, Post-Review Presentations of Results

a. The PPA manager or designee prepares, delivers, and presents the Review Report to the EMC/SRB, if required.

b. The summary package includes summary of trades, open requirements, V&V Plan, cost estimates, schedule, margins, and specific ToR defined for the review.

c. If generated, the EMC/SRB Review Report becomes a formal record.

d. All EMC/SRB records, reports, and findings protect SBU information.

e. The PPA manager, CE and Lead SMA representatives attend the presentation of the Review Report at the EMC/SRB, if held.

D.6.9.1 CMC Briefing

a. The PPA manager, CE, and SMA provide a status to the CMC on the results of the review and any EMC/SRB recommendations to be carried forward to the GPMC prior to the GPMC meeting.

b. The CMC Briefing becomes a formal record.

c. The Review Board Chairperson, the EMC/SRB, and the CMC report their findings to the GPMC.

d. Any EMC/SRB findings that are not agreed to by the PPA manager are discussed at the CMC Briefing.

e.   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.

f.   The GPMC Briefing becomes a formal record.

D.7   RID Criteria and Ground Rules

a.   Clear and effective RID criteria and ground rules are crucial to the success of the review.

b.   Each Review Plan clearly defines the RID criteria and ground rules for RIDs for that specific review.

c.   Ambiguous RID criteria results in a large number of RIDs of limited value to the PPA.

d.   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.

e.   Editorial comments are not technical discrepancies and therefore not RIDs.

f.   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.

g.   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.

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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 PPA maturity, review scope, objectives and entrance criteria).

h. PPA planning is inadequate or incompatible with PPA 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 PPA.

k. The content of the 'forward work' is forwarded to the appropriate 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 PPA 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 PPA action item tracking system to submit an Engineering Change Request (ECR) can accomplish this.

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  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 PPA. 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 PPAs 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

(See Figure 40, Example of a 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/time-stamped - 2000 characters max.)

32. Screening Lead's Approval: (Signature will promote the RID to the next status level)

33. Date:

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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:

Figure 40. Example of a RID Form

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 PPA technical performance objectives, schedule, budget, and risk constraints. Three levels of technical assessment (TAS) are defined- life-cycle phase transition major milestone KDP 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 CEs. 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 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 systems engineering engine 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. V&V systems engineering 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, PPA management, the LSE, and/or the CE evaluated the program objectives captured in the Program Plan, and specified in the SEMP the major milestone review/KDPs 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,

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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 PPA 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 PPA progress. Typically, Program management will monitor the measurement of actual work performed, expected system maturity and cost and schedule as a primary PPA management responsibility. Technical performance metric assessment by systems engineers 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 systems engineering engine process of Technical Requirements Management.

Technical Assessment is also closely tied to the Verification, Validation, and Design Solution systems engineering 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 PPA provides risk reports and technical cost and schedule reports that Systems Engineers may utilize in maintaining alignment with technical work activities and PPA constraints. The logical flow of activities supporting verifying and ensuring the validity of the system being designed and realized evolves from the V&V 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.

PPA Management is responsible for managing the budget, schedule, and satisfaction of predominantly external stakeholders needs, including system performance for the entire PPA. Project Management control the direction of all work and have ultimate authority for controlling program or project funds. CEs 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 DGA. It is reiterated here that in general, at MSFC, CEs and Lead Systems Engineers do not have final authority to direct action on PPA work or to control budget and schedule-impacting major decisions. The role of CEs 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 PPA objectives and execute technical work guidance in compliance with the PPA plan and SEMP.

E.2.3   Levels and Types of Technical Assessment

Technical reviews enable PPA 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 PPA objectives, and to obtain approval to proceed to the next level of activity.

CEs 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 PPA 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 TPM, WBS, Inputs to Earned Value Management System (EVMS), Program metrics, Process metrics, Integrated Master Schedule (IMS), SEMP and/or Software Development Plan (SDP), CMP, and Trade-off Analysis Technical Reports.

E.2.4.1   TAS Tasks

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 PPA 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 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 PPA performance correlates with improvement in potential customer satisfaction.

E.2.4.2   TAS Potential Outcomes

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 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-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 PPA 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 KPPs and 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. V&V plans will be executed and directed at this level, and the results evaluated and validated. It is essential that the logic underlying the V&V plans be well understood by the whole team, and that the lead DGA 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 PPA plan and SEMP is really controlled. Boards and pre-milestone review preparation at this level is essential to the sufficiently mature a system through KDPs at major milestone reviews. Integration of technical work and the execution of technical analyses and assessments, done with integrity, competence, and alignment with PPA 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 likelihood 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 systems engineering processes in a different context than NASA's, but with basically the same activities and products.

More detailed descriptions of systems, discipline, operations, and PPA 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 systems engineering processes from the systems engineering 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 systems engineering 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 PPA 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 PPA requirements. These analyses analytically confirm design performance in their application. Key analyses common to many PPAs 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 PPA. 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.

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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 PPA 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.

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E.3.2 Program/Project/Activity 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 SMA and other Center engineering organizations provide supporting technical rationale to aid the PPA 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 PPA life-cycle. Risk assessments are conducted continuously to identify the risks to a PPA 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 PPA. Therefore, the Standards Watch List and Alerts Function is in place to mitigate risks by providing notification as requested by the PPA when standards products change.

E.3.2.3   Cost Analyses

Costs are estimated during the formulation phase of a PPA. 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 PPA 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 PPAs, 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 PPA 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 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.

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E.3.3.2.3   Electromagnetic Compatibility/Electromagnetic Interference Analyses

EMC / 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 PPA will perform, the objectives of the PPA 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 PPAs 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 PPAs 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 PPA 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 PPA manager and LSE 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 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

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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.*

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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 PPA 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

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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 HW/SW 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 PPA 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 PPA 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).

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E.3.3.2.24.2.1 Design Reference Mission

During the late formulation and early implementation phase, the study team assembles numerous design reference missions (DRMs). The PPA 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 (PPA 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 PPA, 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 PPA 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 PPA responsible for systems engineering and for operations implementation (preparation and execution), with final approval by the PPA manager. The specific analysis tasks and products required will be PPA-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. PPA 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 PPA and shows the relationship between ground operations activities and PPA milestones and relates the schedule of support and engineering teams to the PPA. 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 6410.2, Identifying, *Handling, Storage, Packaging, Handling, and Moving Program Critical Hardware*, and MWI 6430.1, *Lifting Equipment and Operations*, are management guidelines and instructions that apply to PPA ground operations. The specific ground operation elements applicable to a PPA are a function of the ground processing flow for that PPA. 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 systems engineering 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: Systems Engineering 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: Characterization, 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 DiMarzio, "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 DM.

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.

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 DMs 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 DM 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 DM.

F.2   Reference Documents

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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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)

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[1] "Decision analysis", wikipedia, http://en.wikipedia.org/wiki/Decision_analysis, accessed 27 February 2012

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 DM 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 DMs 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 systems engineering 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 systems engineering 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 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 supersede 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 DM 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 DM; 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 DM for the types of challenges he or she may encounter.

F.4.1 Multi-criteria Decision Analysis

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 Systems engineers doing systems engineering 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 NPR 7123.1, the Process Traceability Matrix includes the following expected process activities. The Process Traceability 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 systems engineering 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 iterations include 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 the following:
      A. An effectiveness assessment.
      B. A technical tradeoff.
      C. A problem needing to be solved.
      D. Response to a risk exceeding the acceptable threshold.
      E. Verification failure.
      F. Validation failure.
      G. Make-buy choice.
      H. Evaluating a solution alternative.
      I. Resolving a requirements conflict.

    (2) What needs to be documented.

    (3) Who will be the DMs, 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:
   A. Technology limitations.
   B. Environmental impact.
   C. Safety.
   D. Risks.
   E. Total ownership.
   F. LCCs impact.
   G. Life-cycle schedule impact.
   H. Capabilities ("ilities", for example, affordability, reliability, robustness).
   I. 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 following:

(1) Method.
(2) Procedure.
(3) Technique.
(4) Tool.
(5) 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 probability 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 the following:

(1) Documenting the information that justifies the recommendations.

(2) 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.

Trade Studies

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:

    a.   Minimum requirements that have to be achieved by definition.

    b.   Visible alternatives that satisfy requirements.

    c.   Selection criteria such as cost, schedule, technical.

    d.   Metrics for evaluating alternatives.

    e.   Weighting factors for each criteria.

    f.   Ranking/scoring process.

A general trade study process is shown in Figure 37.

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 sustainability or affordability may also be identified 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.

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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

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 Program Management Study is shown in Figure 41 and for the Mars Rover see Figure 42 that follows.
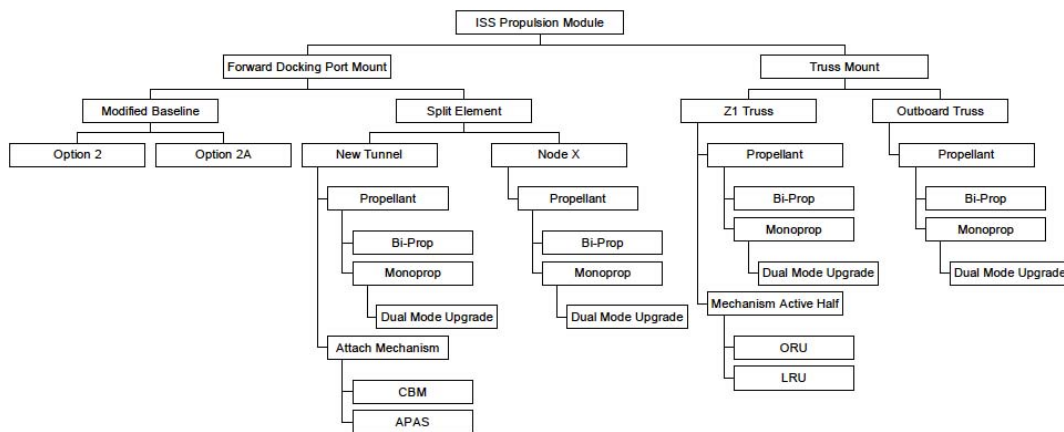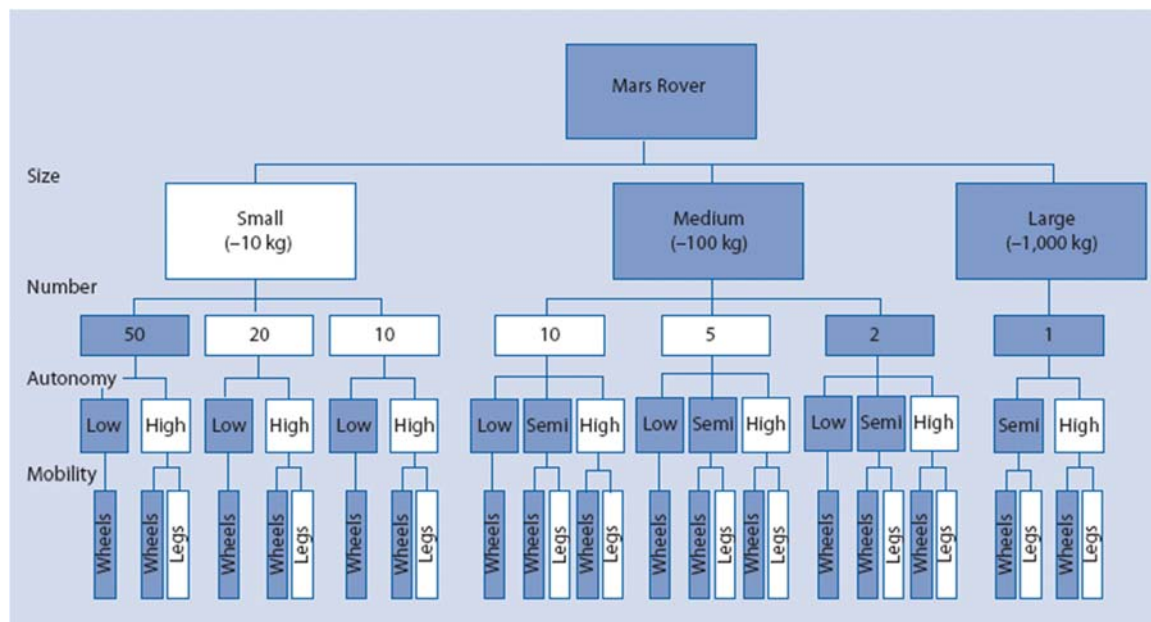

Figure 41. Example of the ISS PM Study Trade Tree

Figure 42. Example of a Trade Tree

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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. See figure 43.

Relative Ranks of Options

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.)

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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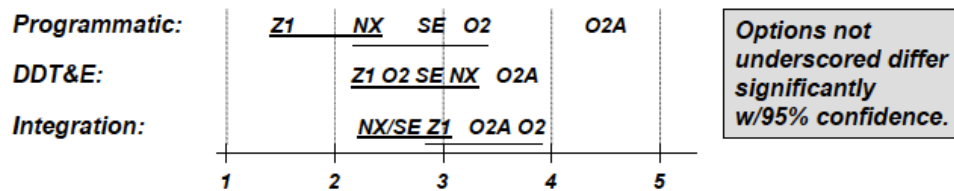**Figure 43. Relative Ranks of Options**

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 Analysis of Variance (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 ANOVA by Ranks within each category, and uses key discriminant analysis. See figure 44.

Comparative Rankings of Options

ANOVA Results

Programmatic:	Z1	NX SE O2	O2A
DDT&E:		Z1 O2 SE NX O2A	
Integration:		NX/SE Z1 O2A O2	

1   2   3   4   5

Options not underscored differ significantly w/95% confidence.

Sums of Weighted Ranks

	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

• The Z1 Truss Option has the overall lowest weighted rank sum.

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Figure 44. Comparative Rankings of Options

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 DMs.

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. Identify 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 DMs.

11. Sensitivity Analysis: Perform a sensitivity analysis to gage the robustness of the model to the grade and weight value changes.

Axioms of SMART (Assumptions):

"Axioms" means a set of postulates that may be regarded as reasonable. If a DM is rational (behaves consistently in relationship to the principle) and if a DM accepts the axioms, the DM 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.

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[3] Jung, Karl Gustav, 1905

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 percent 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 a Rank 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   Decision Analysis Methods and Reference Sources

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

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[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

FTA
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
PRA
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
Reliability 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 DMs 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 Figure 45 below.

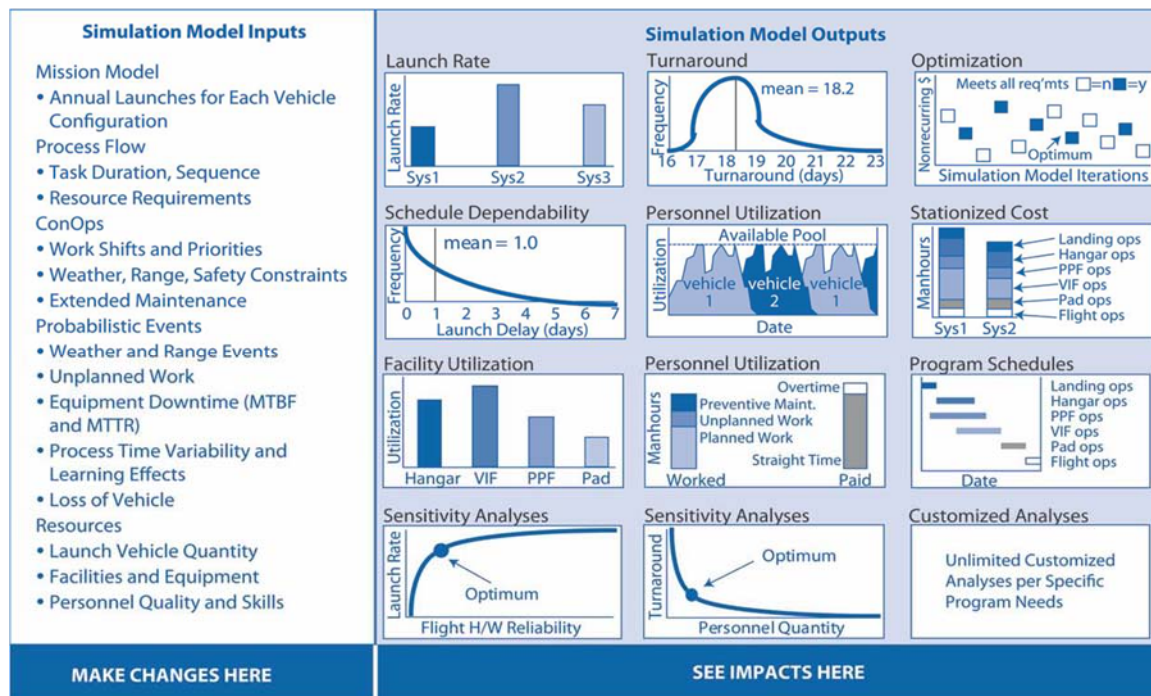CHECK THE MASTER LIST – VERIFY THAT THIS IS THE CORRECT VERSION BEFORE USE

Figure 45. Example of a Modeling and Simulation Analysis

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

An example of a notional cost-benefit analysis tree is shown in Figure 46 below.

MSFC Technical Standard EE10		
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Figure 46. Example of a Notional Cost-benefit Analysis Tree

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Value Tree
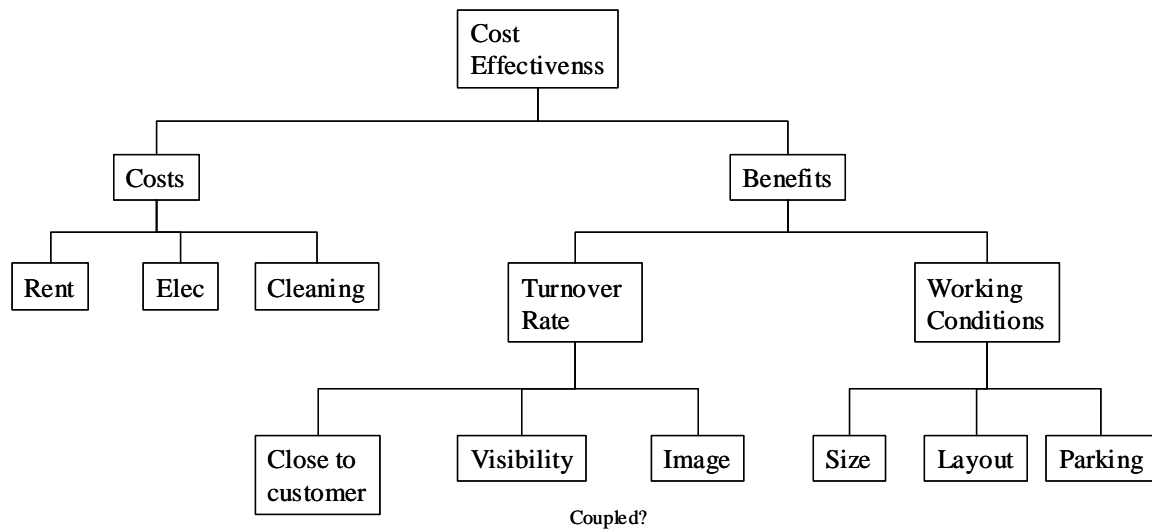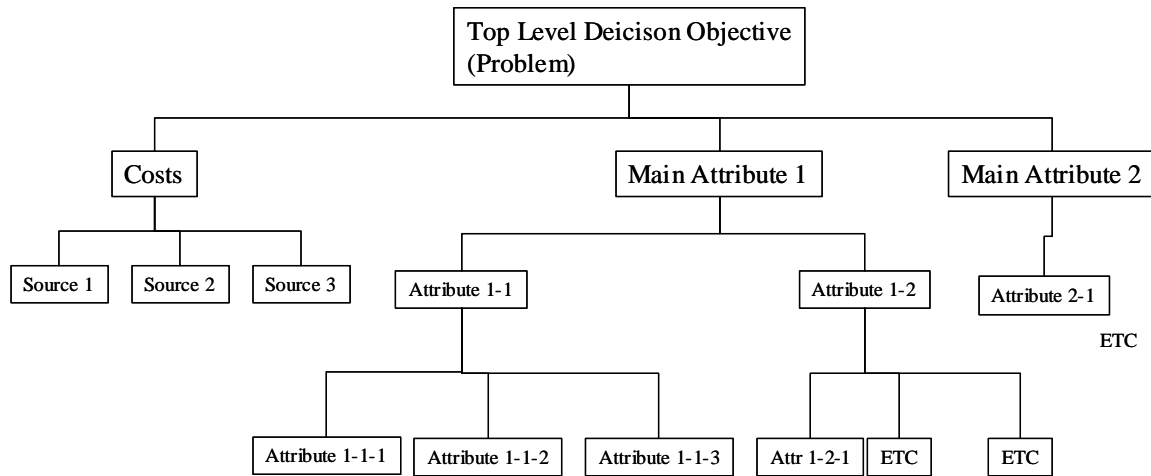

Figure 47. Example of a Value Tree

Developing a Value Tree (see figure 47 above):

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 independent, so you can't use an additive model. You need to look at the delta or difference between the option grades to gauge 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.

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    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 (i.e., 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.

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      1. An increase from lowest to 50%=an increase from 50% to highest.
         a. i.e., 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 i.e.: the weights are very nearly equal, ordinal Rank Weight would over exaggerate differences (the deltas). If the actual Range Very Large i.e.: a nonlinear dispersion of weights, then ordinal Rank Weight would minimize and underestimate 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

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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, i.e.: 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 initial = 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.

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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 importance 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).

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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.

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    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 you 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 attributes, those whose contributions does not change the final decision result, i.e., if attribute scores are all the same, eliminate the attribute from calculations.

    c. Regression.

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      d.   Not more than 4 or 5 significant 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 direct measurements (dm's) judgmental 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 DMs 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 DM does not have to select the recommendation resulting from a requisite decision model, but the model provides sufficient information such that the DM has confidence in selecting a course of action.

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[6] "Decision support system", wikipedia, http://en.wikipedia.org/wiki/Decision_support_system, accessed 27 February 2012

APPENDIX G. REFERENCE DOCUMENTS

G.1   NASA Documents

Number	Title
NPR 7120.8	NASA Research and Technology Program and Project Management Requirements
NPR 1441.1	NASA Records Management Program Requirements
NRRS 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-6105	NASA Special Publication: Systems Engineering Handbook
NASA/SP-3403	NASA Special Publication: Schedule Management Handbook
NASA/SP-3404	NASA Special Publication: Work Breakdown Structure (WBS) Handbook
NASA/SP-569	Bayesian Inference for NASA Probabilistic Risk and Reliability Analysis
NASA/SP-576	NASA Risk Informed Decision Making Handbook
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
NASA/SP-3706	NASA Standing Review Board (SRB) Handbook
	NASA Cost Estimating Handbook
NPR 7150.2	NASA Software Engineering Requirements
NASA-HDBK-2203	NASA Software Engineering Handbook

G.2   MSFC Documents

Number	Title
MCP 8070.2	MSFC Technical Authority Implementation Plan
MGM 8040.1	Configuration Management Guidance
MGM 7120.3	Data Management Guidance
MPR 1440.2	MSFC Records Management Program
MPR 6410.2	Identifying, Packaging, Handling, and Moving Program Critical Hardware
MPR 7120.1	Space Flight Program/Project Planning
MPR 7123.1	MSFC Systems Engineering Processes and Requirements
MWI 6430.1	Lifting Equipment and Operations
MWI 7100.1	Proposal Review and Signoff Process

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Number	Title
MWI 7120.6	Program, Project, and Institutional Risk Management
MPR 8070.1	Administration of MSFC's Technical Standards
MSFC-HDBK-3684	MSFC Program Planning and Control Handbook
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
MSFC Form 2327	MSFC Engineering Change Request (ECR)

G.3   Other Documents

Number	Title
ANSI/AIAA/G-043-1992	Guide for Preparation of Operational Concept Documents
ANSI/GEIA-859	Data Management Standards
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
ISO/IEEE 15288	Systems and Software Engineering – System Lifecycle Processes
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
MIL-HDBK-520	Systems Requirements Document Guidance
MIL-STD-31000	Technical Data Packages
MIL-HDBK-520	Systems Requirements Document Guidance
SAE/EIA-649	Configuration Management Standard
SAE/EIA-649-2	Configuration Management Requirements for NASA Enterprises
SAE/GEIA-HB-649	Configuration Management Standard Implementation Guide