NASA/SP-2010-3403

National Aeronautics and
Space Administration

REVISION: 1
EFFECTIVE DATE: 01/30/2020
EXPIRATION DATE: NONE

NASA
SCHEDULE
MANAGEMENT
HANDBOOK

Responsible Office: Office of the Chief Financial Officer (OCFO)

Table of Contents

1 Preface

1.1 Purpose

Schedule Management is an integral part of Program and project (P/p) management, that when effectively performed helps safeguard P/p success. The purpose of Schedule Management is to provide the framework for coordinating, communicating, time phasing, and resource planning the necessary tasks within a work effort in order to manage and optimize the available resources and deliver products on time and within budget. Agency-level NASA Procedural Requirements (NPRs) and NASA Policy Documents (NPDs) referenced throughout this handbook provide the basis of practice for Schedule Management across the Agency. However, the scope of NASA P/p — from research into new ways to extend our vision into space, to designing a new crew vehicle, or exploring the outer reaches of our solar system — is vast. This handbook emphasizes Schedule Management based on P/p life cycles (and Key Decision Points), taking a more detailed look at the principles and best practices associated with effectively implementing high-level requirements and acknowledging the differing levels of complexity and other nuances that exist among NASA's varied set of Programs and projects.

The intent of this handbook is to support the Schedule Management function by providing best practices proven to be successful within the Agency, which will enable continuous improvements Agency-wide that enhance programmatic processes, products, and professional growth (i.e., capabilities). As such, the necessity of this handbook to establish consistent, Agency-wide best practices is threefold:

- The NASA Schedule Management Handbook is necessary to capture recommended schedule management processes, methodologies, and techniques based on NASA-specific needs and lessons learned.
- The NASA Schedule Management Handbook is necessary to define evolving Schedule Management products to be developed during each life cycle phase in accordance with the NASA requirements and policies.
- The NASA Schedule Management Handbook is necessary to support workforce development and professional growth in the programmatic functional area of schedule management through definition of best practices and identification of the planning, development, and analytical skillsets and familiarity of tools associated with producing products that meet NASA requirements.

This handbook also provides recommended practices which are considered supplementary, but secondary, to the Schedule Management best practices.

1.2 Applicability

Schedule Management supports P/p management as a whole and is identified as one of the key functions that aids in decision making in NASA's Project Planning and Control (PP&C) paradigm.[1] This handbook provides Schedule Management guidance for NASA Headquarters, NASA Centers, the Jet Propulsion Laboratory, inter-government partners, academic institutions, international partners, and

---

[1] SP-2016-3424. NASA Project Planning and Control Handbook. Chapter 3.4: Scheduling Function. September 16, 2016.

contractors to the extent specified in the contract or agreement. The authors of this handbook have engaged with personnel associated with the NASA Schedule Community of Practice (SCoPe)[2] in order to capture the best practices of P/p Schedule Management throughout the Agency, thereby providing informed and relevant guidance, as well as continuity of the practices utilized by Agency's expert knowledge base. Providing consistency in guidance for Schedule Management through this handbook supports an efficient and effective decision-making process for NASA management. To facilitate general understanding of the contents of this handbook, supplemental information will be included on the SCoPe website, including a Programmatic Acronym List and a Programmatic Glossary.[3]

The Schedule Management guidance described in this handbook helps to ensure that NASA P/ps are meeting expectations of both internal and external stakeholders. The Government Accountability Office (GAO), which performs routine audits of government agencies, explains this concept as follows:

> "A well-planned schedule is a fundamental management tool that can help government P/ps use public funds effectively by specifying when work will be performed in the future and measuring program performance against an approved plan. Moreover, as a model of time, an integrated and reliable schedule can show when major events are expected as well as the completion dates for all activities leading up to them, which can help determine if the P/p's parameters are realistic and achievable."[4]

Internally, best practice processes and products support not only day-to-day PP&C but also the Independent Assessment (IA) function, which helps to gauge P/p achievability. The alignment of Agency assessment guidelines to Schedule Management best practices, streamlines the life cycle review (LCR) process and provides consistent understanding between NASA's advocate and non-advocate roles.[5] The NASA Office of Inspector General (OIG) also relies on an understanding of NASA's best practices when performing audits that include assessments of P/p schedule estimates. With respect to external stakeholder expectations, this handbook specifies how and when the Schedule Management function supports commitments made to Congress, for example. In addition, the principles, processes, and best practices in this handbook ensure that P/ps are prepared for external audits.

1.3 Authority

As directed by the Associate Administrator, the Office of the Chief Financial Officer (OCFO) is the owner of programmatic standards and policies, as well as the steward of programmatic capabilities, where the

---

[2] The NASA Schedule Community of Practice (SCoPe) is an Agency-level community of practice sponsored by the Office of the Chief Financial Officer's (OCFO) Strategic Investment Division and supporting Agency Programmatic Analysis Capability (APAC) Leadership, given their role of ownership of programmatic standards and policies and stewardship of programmatic competency. SCoPe membership includes both civil servant and contractor schedule management support from NASA Headquarters and all NASA Centers, including component facilities.

[3] SCoPe website, https://community.max.gov/x/9rjRYg

[4] GAO-16-89G. GAO Schedule Assessment Guide. Page 1. December 2015. http://www.gao.gov/assets/680/674404.pdf

[5] OCFO-SID-0002. NASA Standard Operating Procedure Instruction (SOPI) 6.0. Release Date: May 23, 2017. https://www.nasa.gov/sites/default/files/atoms/files/sopi_6.0_final.pdf

term “programmatic” in this handbook refers to program management, resource analysis, scheduling[6], cost estimation, and independent assessment activities.[7] This responsibility includes interpretation of NASA requirements and policy guidance listed below:

NPD 1000.0A, NASA Governance and Strategic Management Handbook

NPD 7120.4C, Program/Project Management

NPD 1000.5, Policy for NASA Acquisition

NPR 7120.5, NASA Space Flight Program and Project Management Requirements

NPR 7120.7, NASA Information Technology and Institutional Infrastructure Program and Project Requirements

NPR 7120.8, NASA Research and Technology Program and Project Management Requirements

Figure 1-1 shows the traceability of requirements to the best practices provided in this handbook, by depicting the flow-down from the highest Agency Policy Directives and Procedural Requirements documents to the PP&C competencies. The remainder of this handbook defines the recommended best practices for fulfilling the Schedule Management requirements set forth in NPR 7120.5, NPR 7120.7, and NPR 7120.8.

---

[6] Per this handbook, “Scheduling” as defined by the Associate Administrator will be taken to mean “Schedule Management.” PP&C guidance will be updated to reflect the change as well, renaming the function from “Scheduling” to “Schedule Management”.

[7] On October 22, 2015, the NASA Associate Administrator, defined the Agency’s Programmatic Capability as consisting of program management, resource analysis, scheduling, cost estimation, and independent assessment activities. The OCFO assumed the role of Agency Programmatic Analysis Capability (APAC) Leadership to provide two critical functions: Programmatic Standards and Policy Owner and Programmatic Capability Steward.

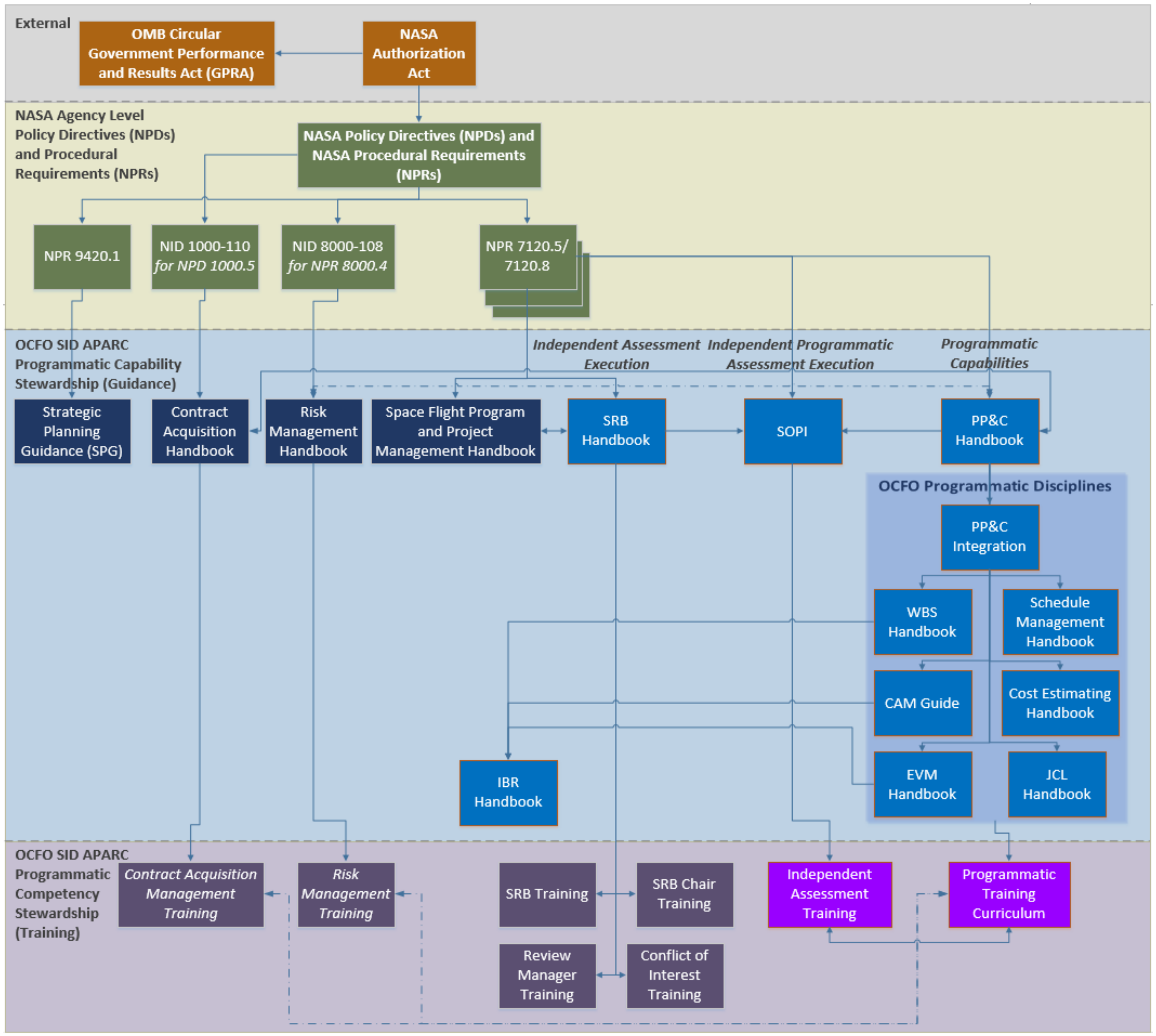


Figure 1-1. Agency requirements flow down to this Schedule Management Handbook.

This handbook will be updated as needed to enhance Schedule Management, to be more effective and efficient, across the Agency. It is acknowledged that most, if not all, external organizations participating in NASA P/ps will have their own “corporate” Schedule Management policy, procedures, and guidance. Issues that arise from conflicting schedule guidance will be resolved on a case-by-case basis as contracts and partnering relationships are established. It is also acknowledged and understood that all P/ps are not the same and may require different levels of schedule visibility, scrutiny, and control. P/p type, value, and complexity are factors that typically dictate the breadth and depth of Schedule Management practices employed.

1.4 References

The following are related NPRs and NASA-specific guidance documents, as well as other non-NASA references used as source material for this document.

NPD 1000.0, NASA Governance and Strategic Management Handbook

NPD 7120.4, Program/Project Management

NPD 1000.5, Policy for NASA Acquisition

NPR 7120.5, NASA Space Flight Program and Project Management Requirements

NPR 7120.7, NASA Information Technology and Institutional Infrastructure Program and Project Requirements

NPR 7120.8, NASA Research and Technology Program and Project Management Requirements

NPR 8000.4, Agency Risk Management Procedural Requirements

NPR 8705.4, Risk Classification for NASA Payloads

NASA/SP-2010-3404, NASA Work Breakdown Structure (WBS) Handbook

NASA, Cost Estimating Handbook V.4.0

NASA/SP-2016-3708, Earned Value Management Project Control Account Managers (P-CAM) Reference Guide

NASA/SP-2012-599, NASA Earned Value Management (EVM) Implementation Handbook

NASA/SP-2016-3406, Integrated Baseline Review Handbook

NASA/SP-2016-3424, NASA Project Planning and Control (PP&C) Handbook

NASA/SP-2011-3422, NASA Risk Management Handbook

Academy of Program/Project & Engineering Leadership (APPEL)[8]

Chief Financial Officer University (CFO-U) [9]

1.5 Acknowledgments

Primary points of contact include: Michele T. King, Office of the Chief Financial Officer, NASA Headquarters and Robin K. Smith, Office of the Chief Financial Officer, NASA Headquarters. The following individuals were active participants in the NASA Schedule Community of Practice working group efforts and are recognized as core contributors to the content of this handbook:

Juan Atayde, NASA Kennedy Space Center
Erica Beam, Jet Propulsion Laboratory
Jose Camacho, NASA Kennedy Space Flight Center
Christopher Chromik, NASA Headquarters
Zachary Dolch, NASA Goddard Space Flight Center/Lentech Inc.

---

[8] Academy of Program/Project & Engineering Leadership (APPEL), http://appel.nasa.gov.

[9] CFO University, https://community.max.gov/pages/viewpage.action?spaceKey=NASA&title=CFO+University.

Jon Fleming, NASA Marshall Space Flight Center/Manufacturing Technical Solutions, Inc. (MTS)
Nancy Fleming, NASA Johnson Space Flight Center
Louis Fussell, NASA Johnson Space Flight Center
Richard Greathouse, NASA Headquarters
Arnold Hill, NASA Headquarters
Justin Hornback, NASA Headquarters/Aerospace Corp.
Charles Hunt, NASA Headquarters
James Johnson, NASA Headquarters
Jerald Kerby, NASA Headquarters
Kristen Kehrer, NASA Headquarters
Walter Majerowicz, NASA Goddard Space Flight Center/ Walter Majerowicz Consulting
Kelly Moses, NASA Headquarters/Aerospace Corp.
Bonnie Lahiff, NASA Langley Research Center
Barney Roberts, NASA Headquarters/ Reed Integration, Inc.
Jeffrey Slade, NASA Goddard Space Flight Center/X3M Systems, LLC
James Taylor, 4DRisk/NASA Headquarters
Stephanie Terrell, NASA Marshall Space Flight Center
Wallace Willard, NASA Headquarters
Steve Wilson, NASA Johnson Space Flight Center

A special acknowledgement goes to the following individuals who were primary contributors to the prior iterations of the Schedule Management Handbook and the “Scheduling Best Practices Guide” previously created at the Marshall Space Flight Center. These documents served as the foundation for much of the content contained in this handbook.

Jimmy W. Black, NASA Marshall Space Flight Center
Anthony R. Beaver, NASA Marshall Space Flight Center
Lynne Faith, NASA Dryden Flight Research Center
James H. Henderson, NASA Kennedy Space Center
Almond H. Kile, NASA Ames Research Center
Cheryl A. Kromis, MEI – Boeing/NASA Marshall Space Flight Center
John A McCarty, SAIC/NASA Marshall Space Flight Center
Michael W. Norris, Jacobs Engineering Group/NASA Marshall Space Flight Center
Steven O. Patterson, NASA Marshall Space Flight Center
Kenneth W. Poole, NASA Marshall Space Flight Center
Donnie E. Smith, MTS/ NASA Marshall Space Flight Center
James G. Smith, Smith & Associates LLC/NASA Marshall Space Flight Center
Anita M. Thomas, NASA Headquarters
Jeanette C. Tokaz, Jacobs Engineering Group/NASA Marshall Space Flight Center
Lynn L. Wyatt, ASRC InuTeq/NASA Goddard Space Flight Center

2 NASA Schedule Management: Life Cycle, Requirements, and Best Practices

This chapter provides an introduction to key elements of NASA's strategic framework for Schedule Management, tying best practices to Agency P/p life cycle requirements that are established in NPR 7120.5 *NASA Space Flight Program and Project Management Requirements,* NPR 7120.7 *NASA Information Technology and Institutional Infrastructure Program and Project Requirements,* NPR 7120.8 *NASA Research and Technology Program and Project Management Requirements, and* NPD 1000.5 *Policy for NASA Acquisition*. Subsequent chapters deal with defining and describing best practices on how to most effectively administer and satisfy the Schedule Management life cycle requirements that pertain to each sub-function of Schedule Management.

2.1 NASA's Program/Project Life Cycle

Space flight P/ps flow from the implementation of national priorities, defined in the Agency's Strategic Plan, through the Agency's Mission Directorates as part of the Agency's general work breakdown hierarchy. Although this hierarchical relationship of Programs to projects demonstrates that P/ps may vary significantly in scope, complexity, cost, and criticality, and their management involves different activities and focus, all have a life cycle that is divided into the following four-part management process:

- ***Formulation*** – The identification of how the Program or project supports the Agency's strategic needs, goals, and objectives; the assessment of feasibility, technology and concepts; risk assessment, team building, development of operations concepts and acquisition strategies; establishment of high-level requirements and success criteria; the preparation of plans, budgets, and schedules essential to the success of a Program or project; and the establishment of control systems to ensure performance to those plans and alignment with current Agency strategies.
- ***Approval (for Implementation)*** – The acknowledgment by the Decision Authority that the Program/project has met stakeholder expectations and formulation requirements and is ready to proceed to implementation. By approving a Program/project, the Decision Authority commits the budget resources necessary to continue into implementation. Approval (for Implementation) must be documented.
- ***Implementation*** – The execution of approved plans for the development and operation of the Program/project, and the use of control systems to ensure performance to approved plans and continued alignment with the Agency's strategic needs, goals, and objectives.
- ***Evaluation*** – The continual, independent (i.e., outside the advocacy chain of the P/p) evaluation of the performance of a Program or project and incorporation of the evaluation findings to ensure adequacy of planning and execution according to plan.

For most NASA P/ps, Formulation and Implementation are further divided into incremental phasing that allows management to periodically assess P/p progress. Figure 2-1 and Figure 2-2 illustrate how the level of schedule detail required in space flight P/ps changes with respect to the particular phase of Formulation or Implementation; more specifically, it increases as the P/p moves through its life cycle. The same is true for 7120.8 P/ps as shown in Figure 2-3 and Figure 2-4. These figures further illustrate the LCRs that comprise independent reviews, which provide assessments of a P/p's technical and programmatic status and health at key points in the P/p's life cycle. NPR 7120.5 requires the use of a single, independent review team called the Standing Review Board (SRB) to conduct certain LCRs.[10] For smaller projects that are not governed by NPR 7120.5, LCRs may be conducted by Center-led, independent review teams (IRTs). P/p assessments, or special reviews, may also be conducted at other times during the P/p life cycle not specifically shown in these figures, such as when a rebaseline occurs. This means that for effective P/p Management in support of P/p life cycle requirements, it is critical for Schedule Management to be initiated early in P/p Formulation all the way through to Closeout.

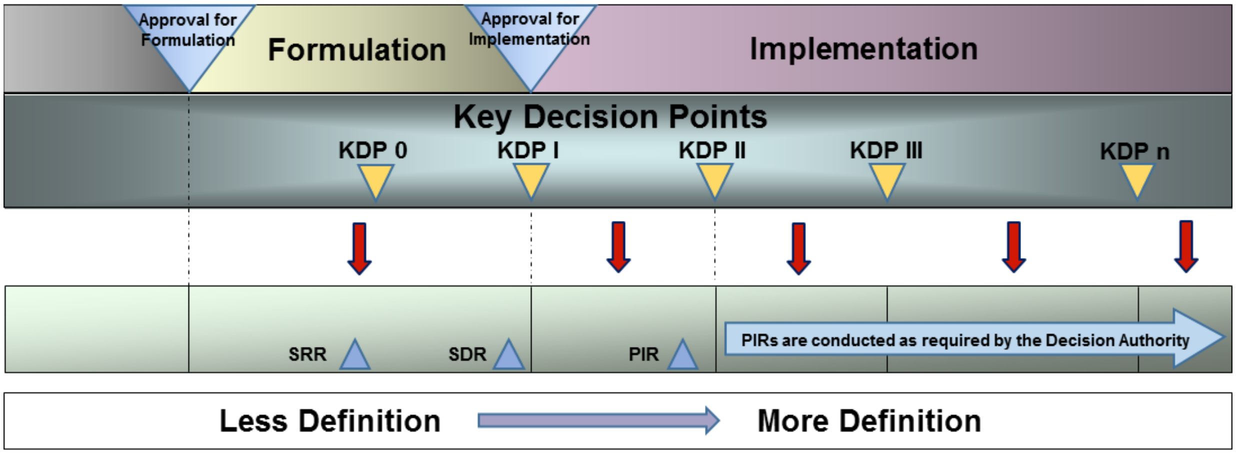


Figure 2-1. NASA Space Flight Tightly-Coupled, Loosely-Coupled and Uncoupled Program Life Cycle Phase/Schedule Detail Relationship.

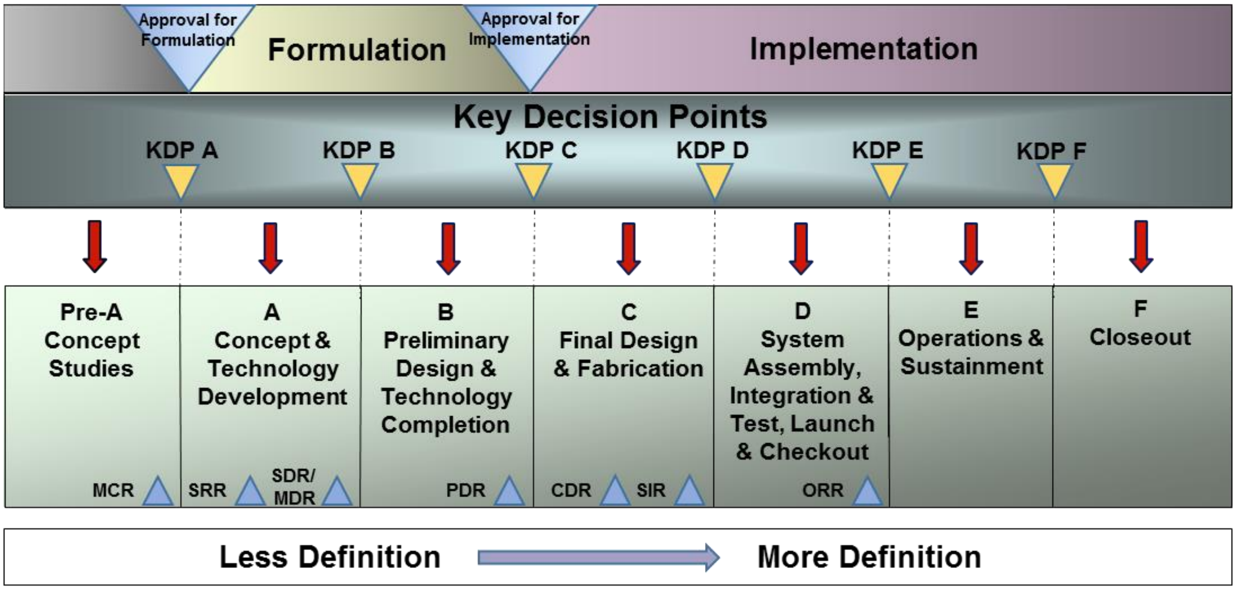


Figure 2-2. NASA Space Flight Single-Project Program and Project Life Cycle Phase/Schedule Detail Relationship.

---

[10] For P/p's that adhere to NPR 7120.5, "all LCRs must assess both the program's or project's technical maturity and its alignment with the Agency's six assessment criteria identified in NPR 7120.5, NASA Space Flight Program and Project Management Requirements, Section 2, and described in Section 5.1 of the NASA Standing Review Board Handbook." NASA/SP-2016-3706 REV B.

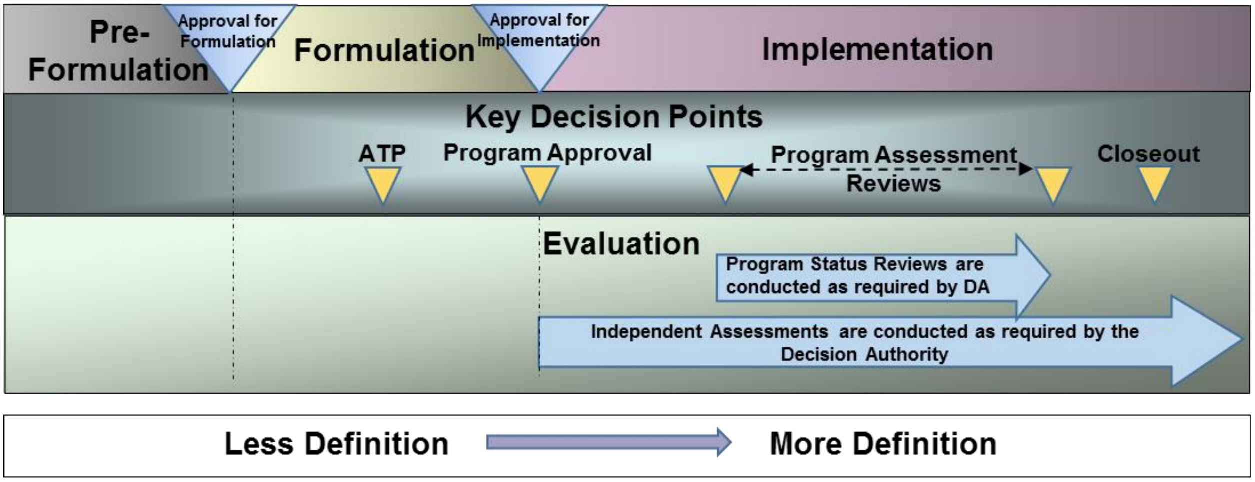


Figure 2-3. NASA R&T Program Life Cycle Phase/Schedule Detail Relationship.

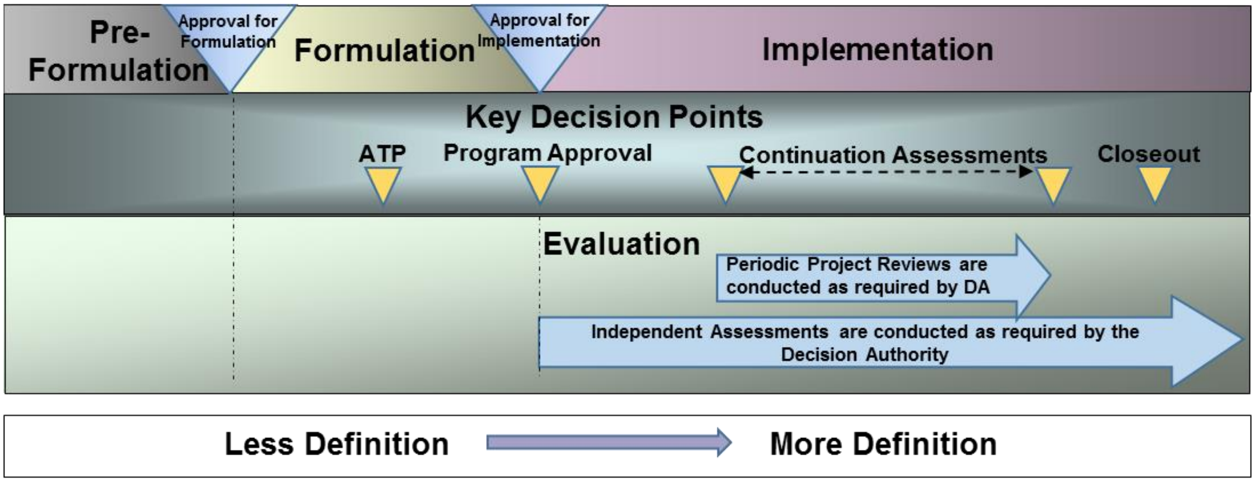


Figure 2-4. NASA R&T Project Life Cycle Phase/Schedule Detail Relationship.

Because the scientific and exploration goals of Programs vary significantly, different Program implementation strategies are required, ranging from very simple to very complex. To accommodate these differences, NASA categorizes space flight Programs into four distinct types. Definitions of space flight (7120.5) and research and technology (R&T, 7120.8) Programs and projects are as follows:

- **Programs (7120.5 and 7120.8).** Strategic investments by a Mission Directorate or Mission Support Office that has a defined architecture and/or technical approach, requirements, funding level, and a management structure that initiates and directs one or more projects. A program defines a strategic direction that the Agency has identified as needed to accomplish Agency goals and objectives.
    - **Single-Project Programs (7120.5).** Programs that tend to have long development and/or operational lifetimes, represent a large investment of Agency resources, and have contributions from multiple organizations/agencies. These Programs frequently combine Program and project management approaches, which they document through tailoring.

  - **Tightly-Coupled Programs (7120.5).** Programs with multiple projects that execute portions of a mission(s). No single project is capable of implementing a complete mission. Typically, multiple NASA Centers contribute to the Program. Individual projects may be managed at different Centers. The Program may also include other agency or international partner contributions.
  - **Loosely-Coupled Programs (7120.5).** Programs that address specific objectives through multiple space flight projects of varied scope. While each individual project has an assigned set of mission objectives, architectural and technological synergies and strategies that benefit the Program as a whole are explored during the Formulation process. For instance, Mars orbiters designed for more than one Mars year in orbit are required to carry a communication system to support present and future landers.
  - **Uncoupled Programs (7120.5).** Programs implemented under a broad theme and/or a common Program implementation concept, such as providing frequent flight opportunities for cost-capped projects selected through an Announcement of Opportunity (AO) or NASA Research Announcements. Each such project is independent of the other projects within the Program.
- **Projects (7120.5 and 7120.8).** A specific investment identified in a Program Plan having defined requirements, a life cycle cost (LCC), a beginning, and an end. A project also has a management structure and may have interfaces to other projects, agencies, and international partners. A project yields new or revised products that directly address NASA's strategic goals.

As with Programs, projects vary in scope and complexity and therefore require varying levels of management requirements and Agency attention and oversight. For example, projects may consist of primarily “in-house” work, they may be a mix of “in-house” and “out-of-house”, or contracted work, or they may be composed of partnerships with other Agencies, universities, research institutions, or international entities. Consequently, project categorization defines Agency expectations of PMs by determining both the oversight council and the specific approval requirements.

Space Flight projects are Category 1, 2, or 3 and shall be assigned to a category based on guidelines established in NPR 7120.5. Space flight projects are also assigned a risk classification of Class A, B, C, or D, based upon on guidance per NPR 8705.4. Specific Space Flight project types include:

- **In-House Observatory Projects.** In-house observatory projects are those in which a NASA Center is the system integrator. Typically, the Center develops the spacecraft, procures and/or builds the science instruments in house, procures or develops the ground system, and integrates and tests the observatory. In-house observatory projects may also include contributions from other international or domestic partners, including other NASA Centers.
- **Out-of-House Observatory Projects.** Out-of-house observatory projects are those in which a NASA Center manages a prime contractor who serves as the system integrator. The NASA Center may also manage one or more non-prime instrument contractors whose instruments are provided as government-furnished equipment (GFE) to the prime. Out-of-house observatory projects may also include contributions from other international or domestic partners, including other NASA Centers. The mission’s ground systems may be developed in-house, be a part of the

prime contractor's scope of work or may be managed as a stand-alone special project within the NASA Center.

- **Out-of-House Flight or Ground System Projects (single prime contractor).** For some flight or ground systems, a single prime contractor is responsible for the entire flight or ground system effort including that of their subcontractors.
- **In-House Instrument/Payload Projects.** In-house instrument/payload projects are those in which the project is managed by a NASA Center, and the work is primarily performed by in-house organizations/directorates. The instrument/payload may be delivered to the Center's in-house observatory project, an out-of-house observatory project, an external partner, or another NASA Program Office or Center.
- **Out-of-House Instrument/Payload Projects.** Out-of-house instrument/payload projects are those in which the project is managed by a NASA Center, and the work is primarily performed by industry contractors or other external organizations. The instrument/payload may be delivered to an external partner or another NASA Center or Program Office.
- **In-House Component/Subsystem Projects.** In-house component/subsystem projects are those in which a NASA Center manages the development and delivery of a unique component, subsystem, or other element as a "supplier" to an external organization such an international partner, other NASA center, the Jet Propulsion Laboratory, another federal agency, etc.
- **Special Projects.** A special project is any project that cannot be classified in one of the categories described above.

Research and Technology project types include:

- **Technology Development Projects.** Technology Development projects characterize or enhance performance and mature a technology or set of related technologies. These projects attempt to solve a specific problem or address a practical need. They advance investigations, experiments, and prototyping to higher level of maturity. TD projects typically focus their activities on fully establishing their approach and techniques, answering all pertinent questions on the theory or hypothesis, developing the simulations, prototypes, and models that demonstrate the capability, and testing, verifying and validating the capability with the intended customer or beneficiary. Usually, TD projects have an identified or targeted beneficiary who is the intended user of the technology being developed and who is involved throughout the development process.
- **Research Projects.** Research projects perform either basic research or applied research. Basic research addresses the need for knowledge through investigation of fundamental principles and interactions, and result in research papers, presentations, or articles. For applied research, once an idea is defined enough to start thinking about practical application, single prototypes are designed and tested, or a simulation or model is developed to demonstrate the potential of the research. The results of this basic or applied research may provide fundamental discoveries, expand the knowledge base, provide scientific and technological breakthroughs that are immediately applicable, or evolve into more advanced technology development. Research

projects are characterized by unpredictability of outcome. Funding may be at a fixed level on a yearly basis.

Regardless of the type, category, or class of P/p being implemented, the fundamental processes for implementing best practices described in this handbook serve as the basis for the management of any NASA P/p schedule according to its life cycle requirements; although, *in some cases*, the breadth and depth of the implementation of the best practices may be tailorable.

2.2 Requirements

A sound, integrated, logic network-constructed schedule, developed using the Critical Path Method (CPM), serves the basis for planning and performance, and is the primary source for all schedule data provided to management for critical P/p decisions. This logic network schedule, or *Integrated Master Schedule (IMS)*, constitutes the framework for time phasing and coordinating all P/p efforts into a master plan to ensure that objectives are accomplished within approved commitments. *As such, NASA requirements pertaining to the "schedule" are in fact written with respect to the IMS.* This handbook heavily leverages several NASA requirements documents in order to support consistency and rigor across the NASA Schedule Management community. The requirements that dictate Schedule Management Planning, Development, Assessment/Analysis, Maintenance/Control, and Documentation/Communication are found in NPR 7120.5, NPR 7120.7, NPR 7120.8, NPR 7123.1, NPR 7150.2 and NPD 1000.5.

Comprehensive Schedule Management requires the establishment, utilization, and control of a schedule baseline, or baseline *IMS*, and its derivative schedules. It is the responsibility of each Program or Project Manager (PM) and P/p team to ensure that these Schedule Management requirements are adhered to, not only during initial schedule planning and development, but also in the on-going updating, maintenance, and control. In addition, on-going evaluation of the *IMS* through assessment and analysis should be made available to the appropriate levels of management to aid in decision making, as indicated by P/p life cycle requirements.

Requirements in NASA Procedural Requirements (NPRs), technical standards, and specifications are identified by using the word "shall" and denote mandatory compliance by P/ps. Rationale for why the requirement is necessary is typically available to the user in each parent/requirement-originating document. To facilitate requirements selection and verification by NASA P/ps, a Requirements Compliance Matrix is provided as an appendix in each NPR. The Requirements Compliance Matrix should be used in coordination with the best practices, explanations, and guidance text in the body of this NASA handbook to ensure the P/p is meeting the required objectives. Figure 2-5 below maps the best practices discussed in this handbook according to the Schedule Management sub-function they support to the NASA requirement document(s) from which they originate.

Schedule Management Sub-Function	Requirement Statement	Requirements Document
Schedule Management Planning	◆ Shall base acquisitions on realistic schedules.	1000.5B
	◆ Shall plan schedules for all P/p effort	1000.5B 7120.5E 2.4.2 7120.5E 2.4.4 7120.8A 3.2.4.3.2 7120.8A 4.2.7.1
Schedule Development	◆ Shall develop planned schedules (@70% confidence level, *conditional*) for all P/p effort	7120.5E 2.4.2 7120.8A 4.2.5.1
	◆ Shall develop the basis of estimate in retrievable P/p records	7120.5E 2.4.3
	◆ Shall demonstrate plans are sufficiently mature	7120.5E 2.2.4
	◆ Shall demonstrate adequacy of schedule at key points in the LC	7120.5E 2.2.6
	◆ Shall demonstrate critical paths	7150.2B 3.3.1 c
	◆ Shall have vertical and horizontal integration	7150.2B 3.3.1 a 7150.2B 3.3.1 b
Schedule Analysis and Assessment	◆ Shall establish a target schedule range at KDP 0/KDP B	7120.5E 2.4.1 7120.5E 2.4.3 7120.5E 2.2.8.2 JCL Requirements Update Memo (2019)
	◆ Shall develop a cost- or resource-loaded schedule and perform a risk-informed probabilistic analysis that produces a JCL at KDP I/KDP C (*conditional*). Projects and single-project programs with LCC of $1B or more: - KDP-B: Shall develop a JCL informed by probabilistic analysis of development cost and schedule duration (parametric and bivariate methods are acceptable) - CDR: Shall update their KDP C JCL - KDP-D: Shall update their JCL, if current development costs have exceeded their development Agency Baseline Commitment (ABC) cost by 5% - Rebaselines: Tightly-coupled, single-project programs, or projects with an estimated LCC greater than $250M shall recalculate the JCL as part of the rebaselining approval process	
	◆ Shall have management processes in place to conduct project-level EVM	
Schedule Maintenance and Control	◆ Shall track planned and actual schedule metrics	7150.2B 2.1.3.12.b
Schedule Documentation and Communication	◆ Shall develop appropriate documentation to implement the requirements of NPR 7120.5E	7120.5E 1.1.2 7120.5E 2.2.6 7120.5E 2.4.1 7120.5E 2.4.3 Corrective Action Plan (2018) Enhanced EVM and Schedule Repository Guidance (2019)
	◆ Shall generate the appropriate documentation in preparation for LCRs to demonstrate maturity	
	◆ Shall describe in the Decision Memo the constraints and parameters within which the P/p will operate and the supporting data (e.g., the cost and schedule data sheet)	
	◆ All NPR 7120.5E space flight projects and single-project programs and all NPR 7120.8 research and technology projects with a Life Cycle Cost of $50M or greater shall submit integrated master schedules in their native scheduling tool formats to the Agency Schedule Repository on a quarterly basis, beginning at SRR (7120.5)/Project Approval (7120.8) through completion of Launch Readiness Review (7120.5)/Closeout of Activities (7120.8)	
	◆ Shall have management processes in place to conduct project-level EVM	
	◆ Shall submit monthly EVM reports, integrated program management report (IPMR), or the contract performance report submittals to a central repository (incl. Format 6-IMS in the native format)	

Figure 2-5. Mapping of Schedule Management Best Practices to NASA Requirements Documents.

NPR 7120.5 further defines the expected maturity of P/p products and control plans at each LCR. P/ps are expected to have achieved these maturities, unless the requirements have been tailored and approved. The same expectation is typically true for P/ps that fall under other requirements documents, such as NPR 7120.7 or 7120.8, although product maturity matrices may not be defined. It is important to note that according to NPR 7120.8, "R&T projects that directly tie to the space flight mission's success and schedule are normally managed under NPR 7120.5" and would therefore adhere to standard NASA best practices as described in this handbook.

2.3 Best Practices

The guidance in this handbook is not "self-imposing;" in other words, it is not mandatory for use by a P/p unless it is required by U.S. law or NASA directive, or invoked by other NASA requirements documents (e.g., contracts, including but not limited to: the JPL (FFRDC) contract, P/p documents, grants, and agreements). However, the best practices identified in this handbook are methods and techniques that have consistently shown results superior to those achieved by other means, and are supported by various principles, processes, and lessons learned. This document will capture and communicate the Schedule Management best practices across and for the entire Agency according to each Schedule Management sub-function. In Figure 2-6 and Figure 2-7, the Schedule Management sub-functions are mapped against the NASA space flight and R&T P/p life cycles, respectively, in order to provide the community with a guide as to where the best practices supporting each Schedule Management sub-function should be focused and when.

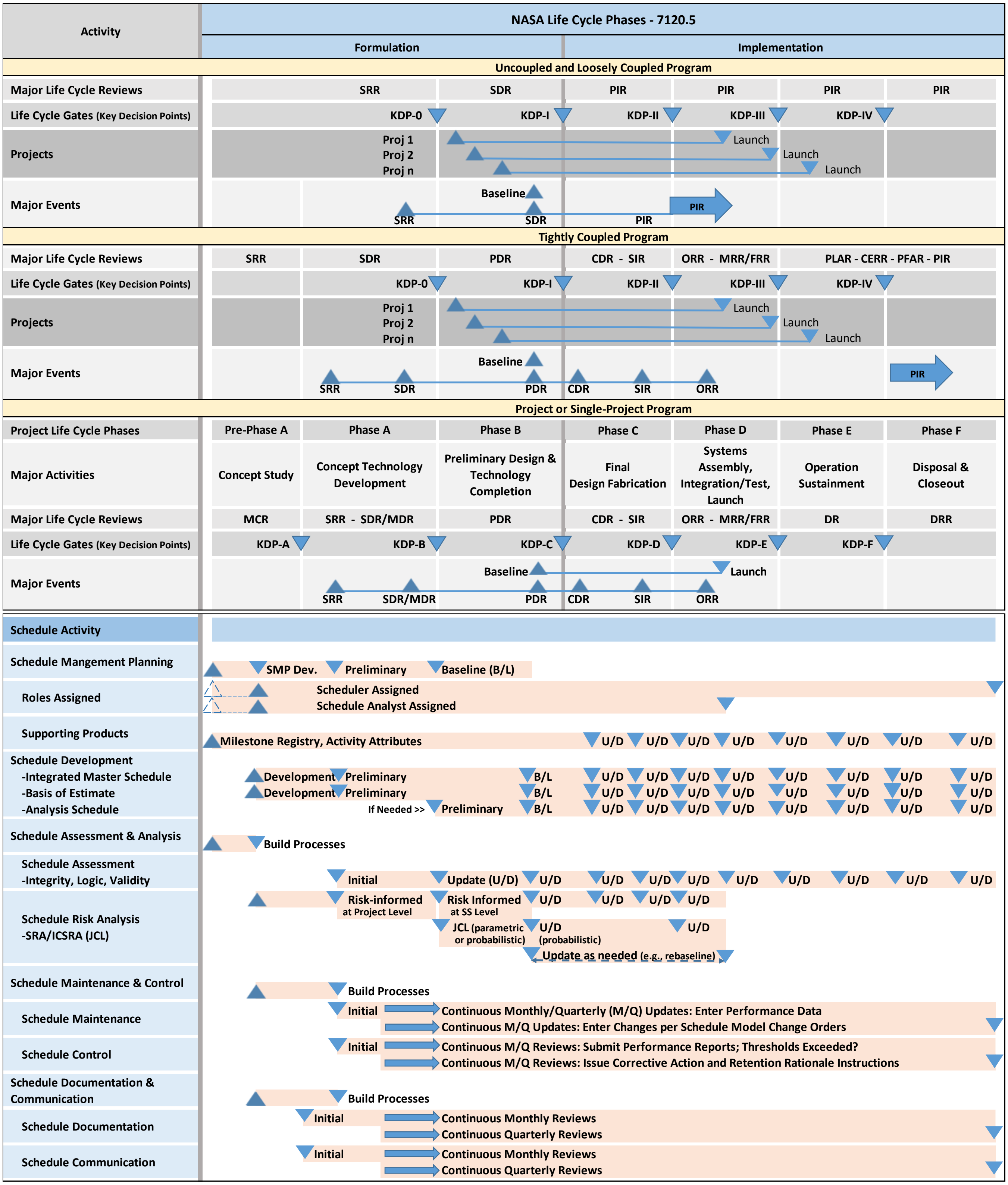


Figure 2-6. The relationship of the NASA Space Flight P/p life cycle to the Schedule Management sub-functions guides the development of Schedule Management products, which are supported by adherence to best practices.

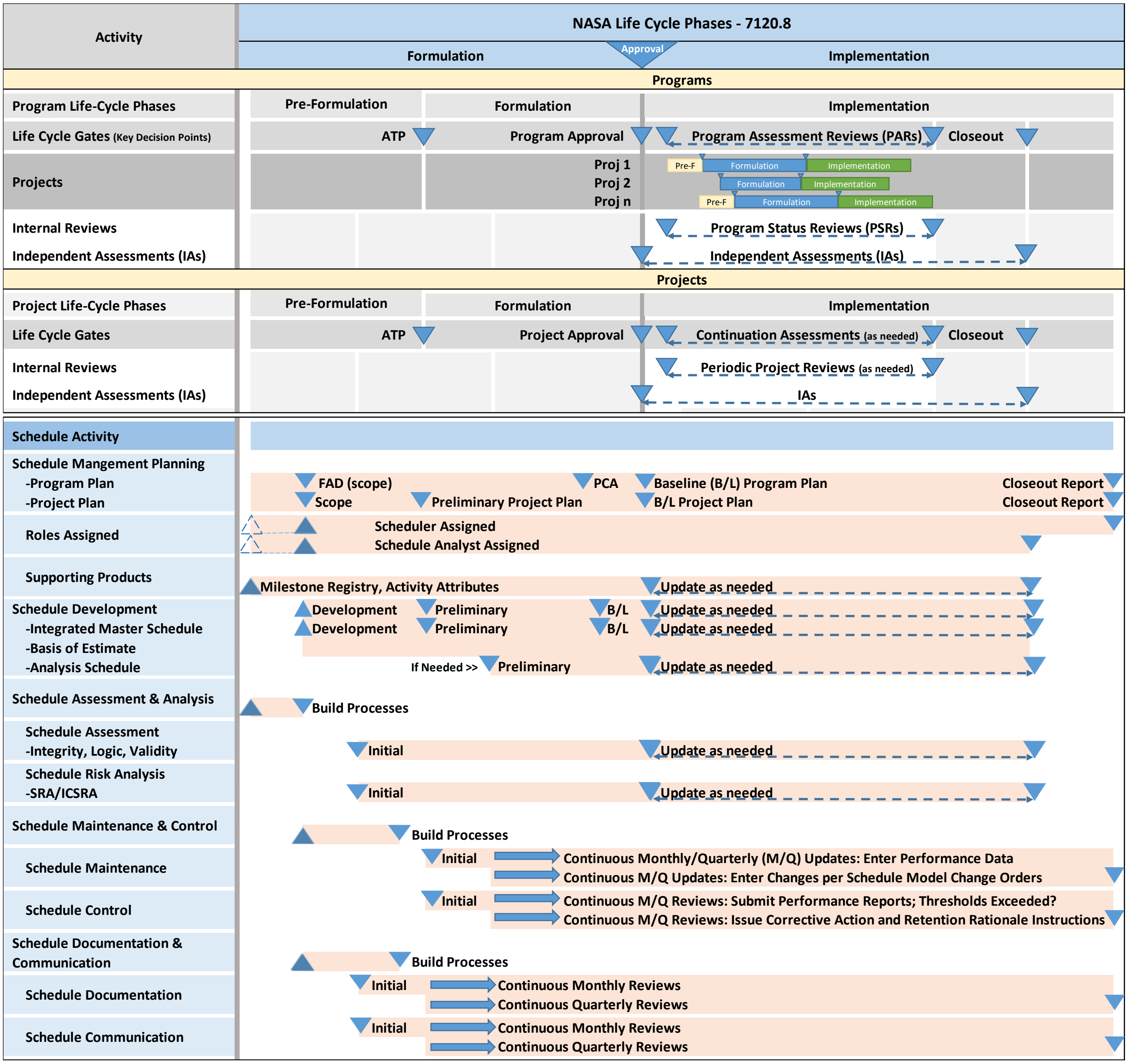


Figure 2-7. The relationship of the NASA Research and Technology P/p life cycle to the Schedule Management sub-functions guides the development of Schedule Management products, which are supported by adherence to best practices.

Although the processes described in this handbook can be tailored as needed to better fit the P/p scope, when feasible the intent of the best practice should be followed. Consistent Schedule Management utilizing best practices and supporting the overall P/p life cycle is important to the Agency for many reasons including, but not limited to:

- Strengthening the Agency's Schedule Management capability
- Enhancing programmatic excellence and continual improvement of P/p management at NASA
- Increasing the quality of planning and thus P/p success

- Ensuring the appropriate, required maturity of Schedule Management practices and products throughout the P/p's life cycle
- Capturing schedule data, narrative, and lessons learned to improve the NASA programmatic community knowledge base, as well as to provide a rationale for recommendations and requirements, or to share success factors across the Agency
- Facilitating coordination between PP&C communities
- Providing a common base for communication and data exchange
- Preventing conflict and duplication of effort
- Complying with internal Agency "down and in" (P/p) as well as external "up and out" (Congress, GAO, etc.) requirements
- Adhering to programmatic requirements or specifications in contracts, grants, and other types of agreements to ensure contractors are held accountable for delivering the products or services to achieve P/p needs, goals, and objectives
- Enabling the career growth and development of the Schedule Management community as a recognized and rigorous career field at NASA

3 Introduction – An Overview to the Schedule Management Function

NASA requires specific types of P/p to execute the Schedule Management function. While not required in totality for execution by some types of small-scale projects, it is strongly encouraged as a proven management practice that increases effectivity and efficiency of P/p performance. The Schedule Management function is illustrated by the framework shown in Figure 3-1 that comprises the following sub-functions:

1. Schedule Management Planning: The design, development and implementation of all Schedule Management processes, tools, reporting forms, and formats.
2. Schedule Development: Initiated early in formulation of a P/p with the objective to develop the *Schedule BoE* and *IMS*, as well as to define, develop, and deploy a scheduling capability that can export specific outputs as required for the other Schedule Management sub-functions.
3. Schedule Assessment and Analysis: Initiated early in formulation and utilized routinely to determine the validity and integrity of the schedule, and evaluating the magnitude, impact, and significance of P/p uncertainties and risks associated with meeting P/p and Agency commitments.
4. Schedule Maintenance and Control: The routine updating of progress, the tracking and monitoring of schedule performance, and the execution of corrective actions as determined from the *Schedule Performance Measures* needed for schedule baseline control to maintain internal and external commitments.
5. Schedule Documentation and Communication: The recording and dissemination of schedule information and required products at varying levels of maturity, using established configuration

and data management (CM/DM) processes, as well as communication aids and tools throughout the P/p life cycle.

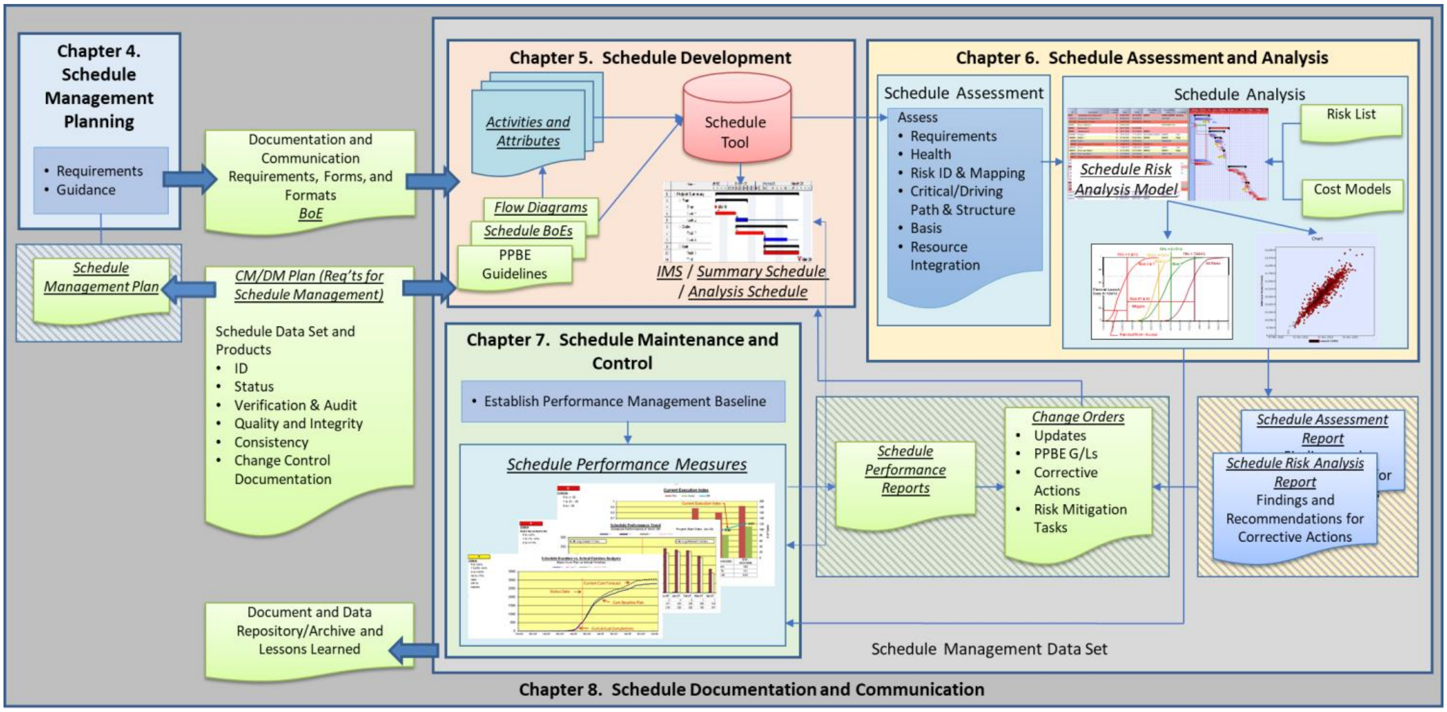


Figure 3-1. The Schedule Management function is composed of five main sub-functions: Schedule Management Planning, Schedule Development, Schedule Assessment and Analysis, Schedule Maintenance and Control, and Schedule Documentation and Communication.

The figures in this Chapter define the Schedule Management sub-functions and relate them to subsequent Chapters within this handbook. Each Chapter further discusses the principles and best practices associated with effectively implementing each of the sub-functions. Schedule Management products to be developed are identified throughout this document as italicized and underlined phrases.

3.1 Schedule Management Planning

Schedule Management Planning establishes the principles, processes, and best practices of the how the schedule will be developed and managed throughout the P/p life cycle to meet requirements. An overview of the Schedule Management Planning and Schedule Development sub-functions are shown in Figure 3-2 and further defined in Chapters 4 and 5 of this document.

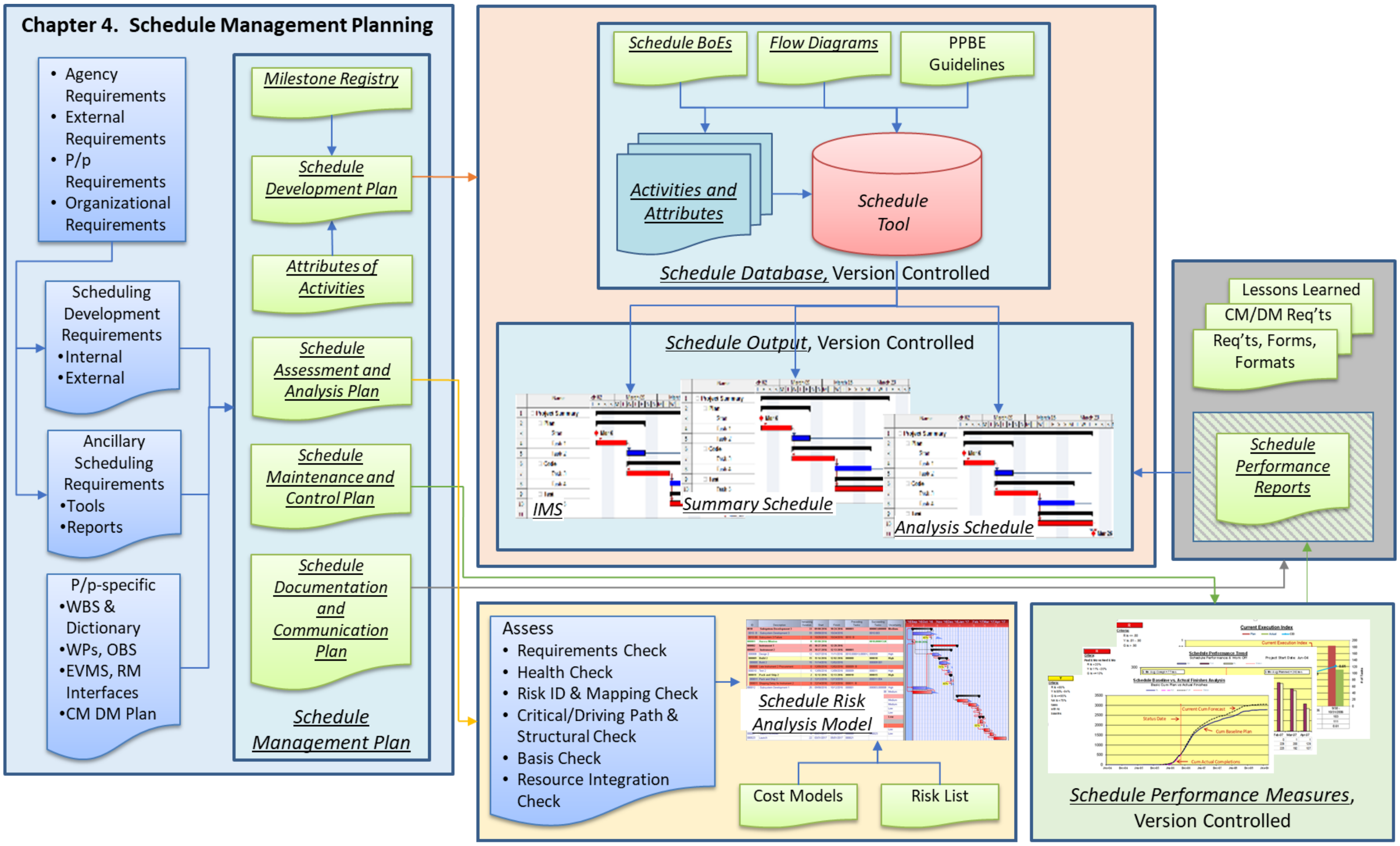


Figure 3-2. Schedule Management Planning compiles all specifications needed to build the complete set of Schedule Management tools and processes. Schedule Development is the implementation of those specifications and results in the IMS and all Schedule Performance Measures. Included in the figure are references to the Sections herein where details are provided.

The left-hand side of Figure 3-2 illustrates the Schedule Management Planning (Chapter 4) sub-function. This sub-function consists of collecting all the requirements needed to completely plan the development of the *IMS*, the assessment and analysis of the schedule, schedule performance measurement and control, and the documentation and communication of the schedule information. The Schedule Management Planning sub-function produces the product: *Schedule Management Plan*, abbreviated as the *SMP*, which is the definitive instruction that guides the development, implementation, and execution of all Schedule Management sub-functions.

3.2 Schedule Development

Schedule Development is the sub-function initiated early in the Formulation of a P/p with the objective to develop the Schedule *BoE* and *IMS*. This includes the following Schedule Development activities: ensure scheduling tool capabilities, implement the scheduling method, establish field codes, determine schedule hierarchy, determine activity naming convention, capture all scope, develop schedule detail, logically link activities, estimate activity durations, establish and allocate margin, perform resource or cost loading, and time-phase the schedule to align with available resources. Figure 3-3 illustrates the physical scheduling products and the schedule performance measurement and control products that result from the Schedule Development sub-function (Chapter 5). The following paragraphs briefly describe these products.

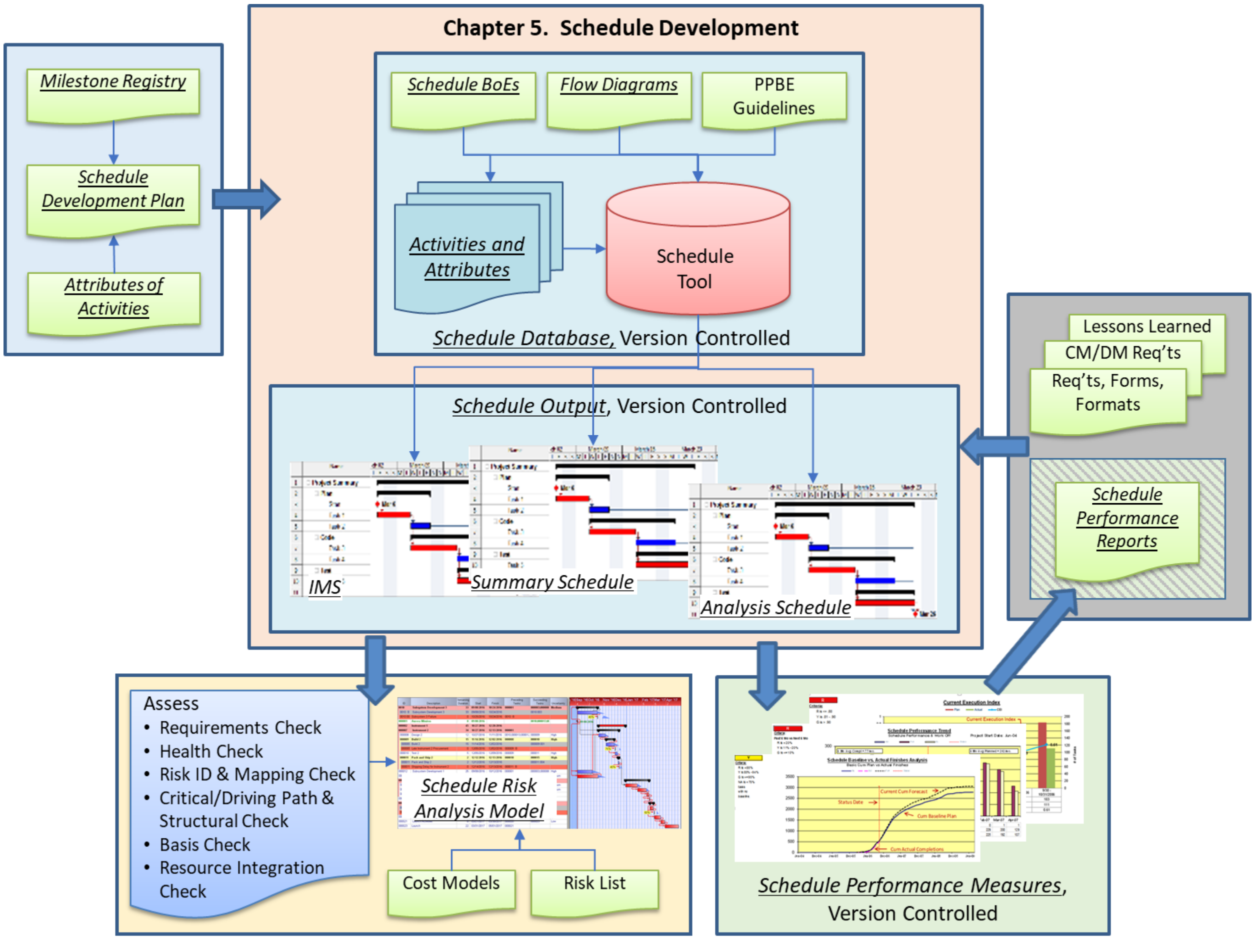


Figure 3-3. Schedule Development is carried out according to the Schedule Development Plan. It requires the collection of data that affect how the schedule is built, the documentation of the data into a Schedule BoE, along with an appropriate scheduling tool to develop Schedule Outputs, such as an IMS. Schedule Development also produces Schedule Performance Measures from which Schedule Performance Reports can be generated.

A *Schedule Database* consists of the entire database of all schedule data used to develop the *IMS* and document the *Schedule BoE*. It includes all the *Activity Attributes*, as well as any directly related supporting documentation such as the Flow Diagrams, Planning Programming Budgeting and Execution (PPBE) Guidance, etc. The *Schedule Database* captures the original baseline, as well as any revised baselines (i.e., "replanning") or official rebaselines, the current *IMS*, and also saved copies of each monthly *IMS* update. All data products within the *Schedule Database* are clearly identified and archived following the version control requirements within the configuration control process.

A *Schedule Output* is a product of the *Schedule Database* that is used for various management activities, such as analysis or control, and is repeated at pre-determined intervals, usually monthly. It may include at least one or some combination of the following:

- An *IMS* is the complete, end-to-end, time-phased, logically-linked network of all P/p effort that is required to ensure that all objectives are met within approved commitments. The use of the word "integrated" implies the incorporation of all activities, even contractor and subcontractor efforts, necessary to complete the P/p. The *IMS* is utilized as the P/p management tool that integrates the planned work, the resources necessary to accomplish that work, and the associated budget.[11] The *IMS* is the backbone for managing the P/p successfully, which includes establishing the integrated performance baseline or Performance Measurement Baseline (PMB), measuring and forecasting performance, controlling the baseline, and communicating the overall progress against the plan.
- A *Summary Schedule* is a high-level roll-up of the *IMS* and is used for management reporting. It is a direct derivative of the *IMS* and should mimic the critical path(s) within the *IMS*.
- When needed for schedule risk analysis, the *Schedule Database* is the basis for the development of an *Analysis Schedule*. An *Analysis Schedule* should be directly traceable to the *IMS*, should replicate the critical paths, and should emulate the *IMS*; however, it may have additional tasks to model the impact of discrete risks.
- *Schedule Performance Measures* are produced by incorporating current performance data with the planned performance in the *IMS*. *Schedule Performance Reports* are typically created monthly. All are clearly identified and archived following the version control requirements within the configuration control process. Sections 7.3.2 and 7.3.3 further discuss updating the schedule with current performance and measuring performance and monitoring trends.

3.3 Schedule Assessment and Analysis

Schedule Assessment and Schedule Analysis are two complementary sub-functions that are initiated early and operated routinely throughout the P/p life cycle. Schedule Assessment is the sub-function for determining the validity and integrity of the schedule and Schedule Analysis is the sub-function for evaluating the magnitude, impact, and significance of actual and forecast variances to the schedule and/or baseline. Figure 3-4 illustrates the sub-functions of Schedule Assessment and Schedule Analysis. All requirements for Schedule Assessment and Schedule Analysis are specified in the *Schedule Management Plan* along with the analysis and reporting frequency, and all forms and formats for reports. Chapter 6 in this document further defines these sub-functions.

---

[11] GAO-16-89G. GAO Schedule Assessment Guide. December 2015. Page 5. https://www.gao.gov/assets/680/674404.pdf

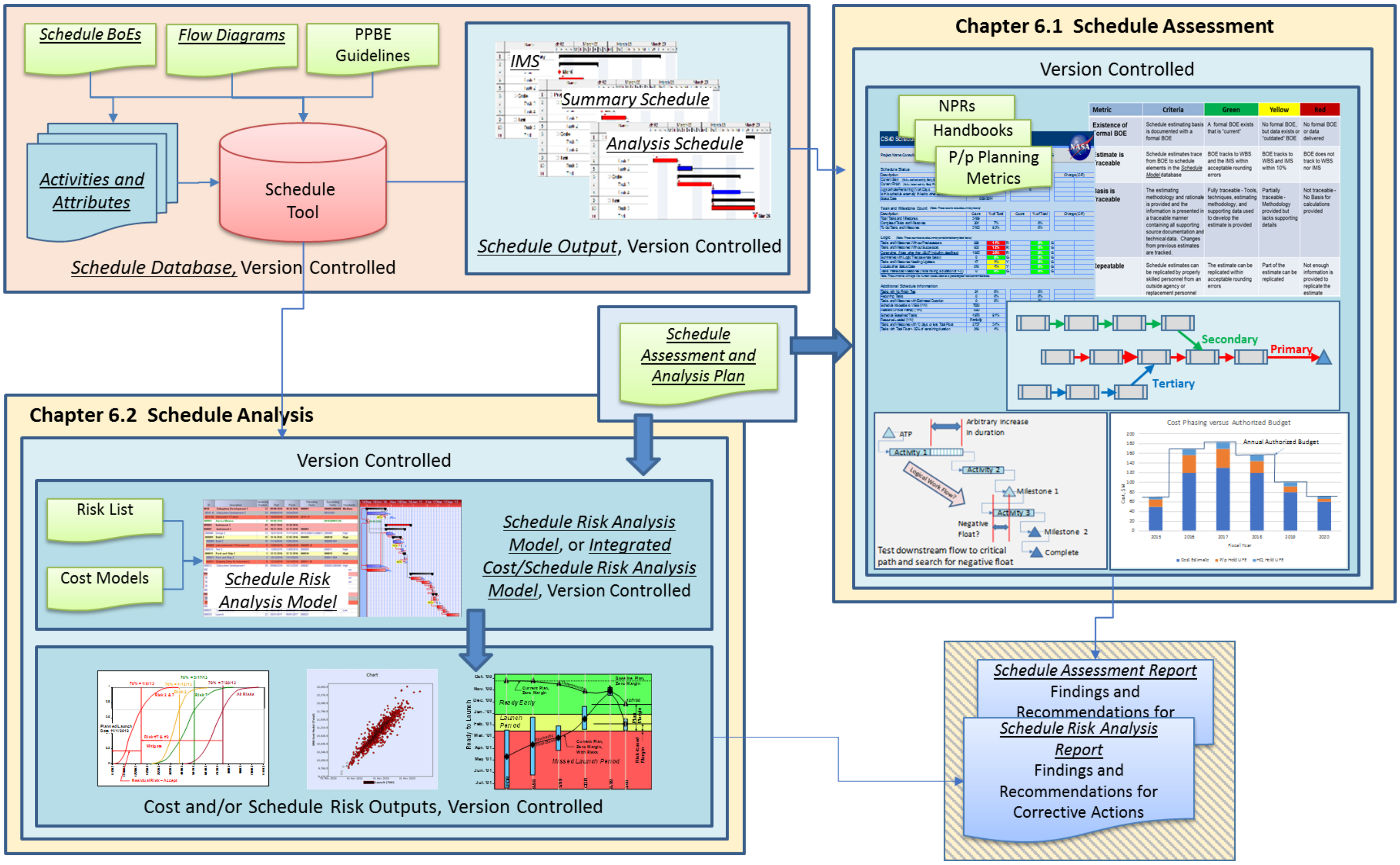


Figure 3-4. Schedule Assessment is an integrity check of data and assumptions contained in the *__Schedule Database__* *and produces a* *__Schedule Assessment Report__*. Schedule Analysis analyzes the risk of achieving cost and/or schedule objectives and produces the *__Schedule Risk Analysis Report__*.

A *__Schedule Assessment__* is a planned activity that includes performing a series of checks on the *__IMS__* (or other *__Schedule Outputs__*, as appropriate) for compliance to P/p and Agency requirements, compatibility with NASA best practices and overall schedule integrity. Critical path assessments and margin allocation along the critical paths are also performed. These schedule assessment checks can be found Section 6.2. Results of the assessment are documented in a *__Schedule Assessment Report__*. It is imperative that all assessments and results are related to specific *__Schedule Database__* outputs and the traceability is maintained via version control as specified in the Configuration Management (CM)/Document Management (DM) process.

The *__Schedule Risk Analysis Model__*, abbreviated as the *__SRA Model__*, is the model used for estimating the probable future outcome of the P/p's schedule performance. It appends risk parameters to the *__Analysis Schedule__* output from the *__Schedule Database__*. Performing a *__Schedule Risk Analysis (SRA)__* as described in Section 6.3.2 informs management of the adequacy of margin to accommodate expected risk impacts and helps management to prioritize discrete risk mitigation activities. In cases where the cost-risk is required, the cost models are incorporated, and the model is referenced as the *__Integrated Cost/Schedule Risk Analysis Model__*, abbreviated as the *__ICSRA Model__*. Results from either analysis are documented in a *__Schedule Risk Analysis Report__*. It is imperative that all analyses and results are related to specific *Schedule Database* outputs and the traceability is maintained via version control as specified in the P/p's configuration control process.

3.4 Schedule Maintenance and Control

There are two parts to the Schedule Maintenance and Control sub-function. The first part, Schedule Maintenance, routinely updates the *Schedule Database* with data from current performance reports as well as implementing approved changes. The second part, Schedule Control, includes the performance measurement against the schedule baseline and the corrective actions needed to ensure the timely execution of activities. It is imperative for Schedule Control to be performed in conjunction with Schedule Assessment and Analysis to ensure the integrity of the entire Schedule Management function. Figure 3-5 is an overview of the Schedule Maintenance and Control sub-function.

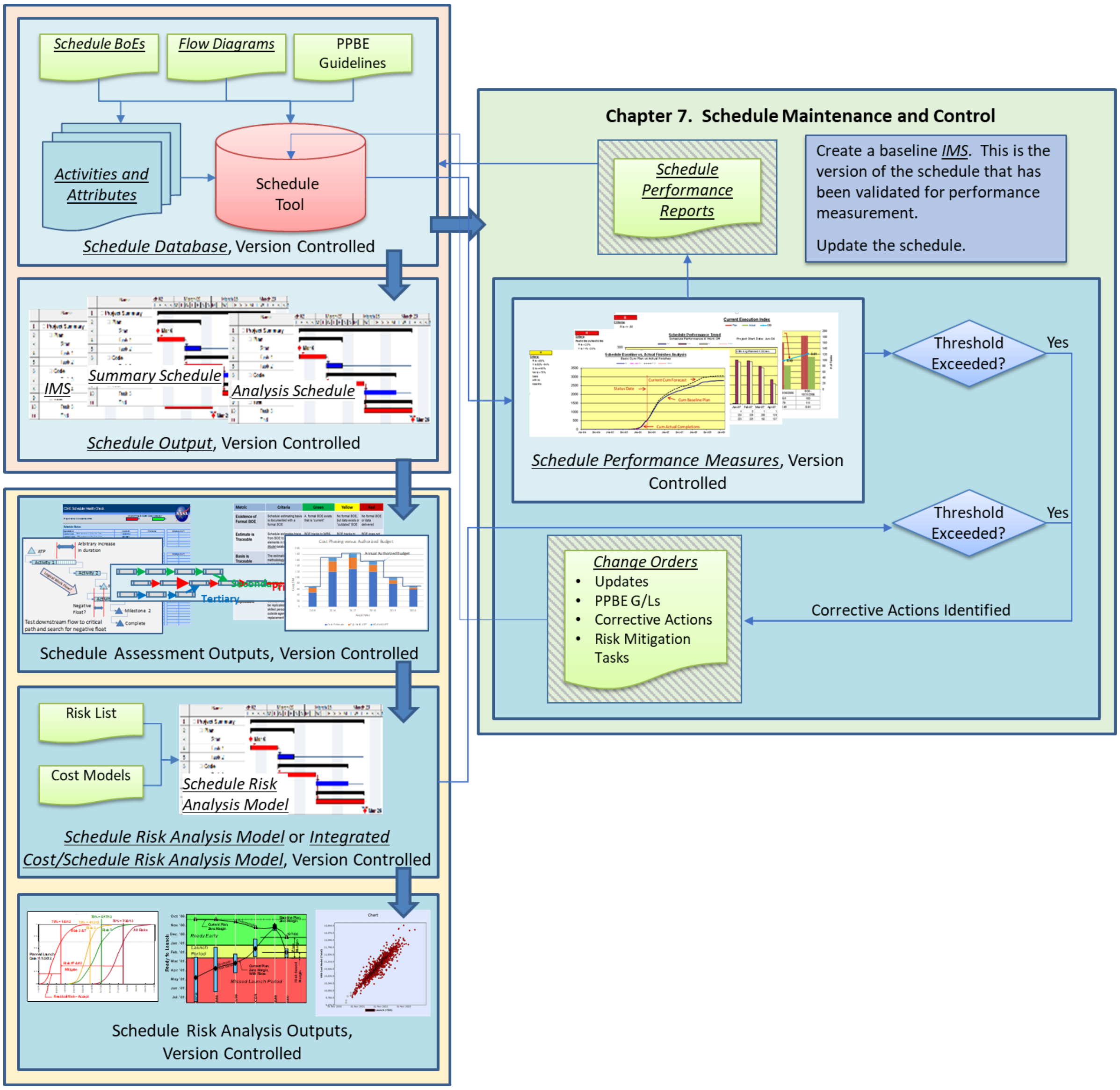


Figure 3-5. The Schedule Maintenance and Control sub-function ensures that a schedule baseline is set, routine updates are made to the Schedule Database, performance measurements are tracked, and corrective actions are taken, if necessary.

The hatched portions of the figure illustrate the two input functions to the Schedule Management data set. They include: (1) the regular monthly performance reports which contain the schedule performance data that must be input into the *Schedule Database*, and (2) the P/p management approved change orders. The change orders generally result from (1) updates to the schedule such as replanning, detailing a rolling wave, or inclusion of risk mitigation tasks, etc., (2) changes to the P/p guidelines in the annual government PPBE process, and (3) changes needed to accommodate corrective actions that result from performance measurements.

The left-hand portion of the figure is intended to show the entirety of the data set. It is critically important that the data sets be consistent and carefully controlled to ensure (1) consistent communication of data, and (2) corrective actions and other adjustments are relative to the corresponding schedule data model.

There are two methods employed to control the schedule. The first is measuring current performance to plan and when certain prescribed thresholds are crossed, corrective actions are required. Sometimes, those corrective actions may require adjustments to specific activities such as delaying them, increasing durations or changing the linkages to other tasks. In those cases, a change order is issued to change the relevant data in the *Schedule Database*. Specific data from the performance reports are used to estimate current schedule performance to plan. There exist specific pre-determined thresholds that when breached, corrective actions are required. The second method is a forward look at possible future projections of schedule performance under the influence of risk and uncertainty. There are also thresholds for this analysis and when exceeded, may also require corrective actions. The lower right portion of Figure 3-5 illustrates the performance measurement.

Schedule Maintenance and Control are iterative sub-functions that occur continuously throughout the P/p life cycle. It is imperative for Schedule Maintenance and Control to be performed in conjunction with Schedule Assessment and Analysis to ensure the integrity of the entire Schedule Management function. Chapter 7 in this document further defines the Schedule Maintenance and Control sub-functions.

3.5 Schedule Documentation and Communication

The Schedule Documentation and Communication sub-functions detail how the P/p documents and disseminates schedule information among team members, as well as other stakeholders. These sub-functions are reliant upon configuration and data management (CM/DM) and the baselining activity and facilitate subsequent management and control of content change. As shown in Figure 3-6, the Schedule Documentation and Communication sub-functions start with the *Schedule Management Plan*, which contains the requirements for the information flow from within the P/p as well as the flow upwards to Agency management and external organizations. Forms, formats, and templates are defined and usually included as appendices to the Plan.

As illustrated on the left of Figure 3-6, the Schedule Management Planning sub-function draws upon the P/p's overall CM/DM plan for the specific requirements needed. The requirements for CM/DM are shown on the left-hand side of Figure 3-6, and the right part of the figure is a general illustration of a typical suite of controlled data and documentation. All data and documentation must be consistent, and where it is important to show pending changes, those must be clearly marked and referenced to actual configuration change documentation. All documentation must consistent and clearly marked, controlled and archived per the P/p's CM/DM plan. Chapter 8 provides details.

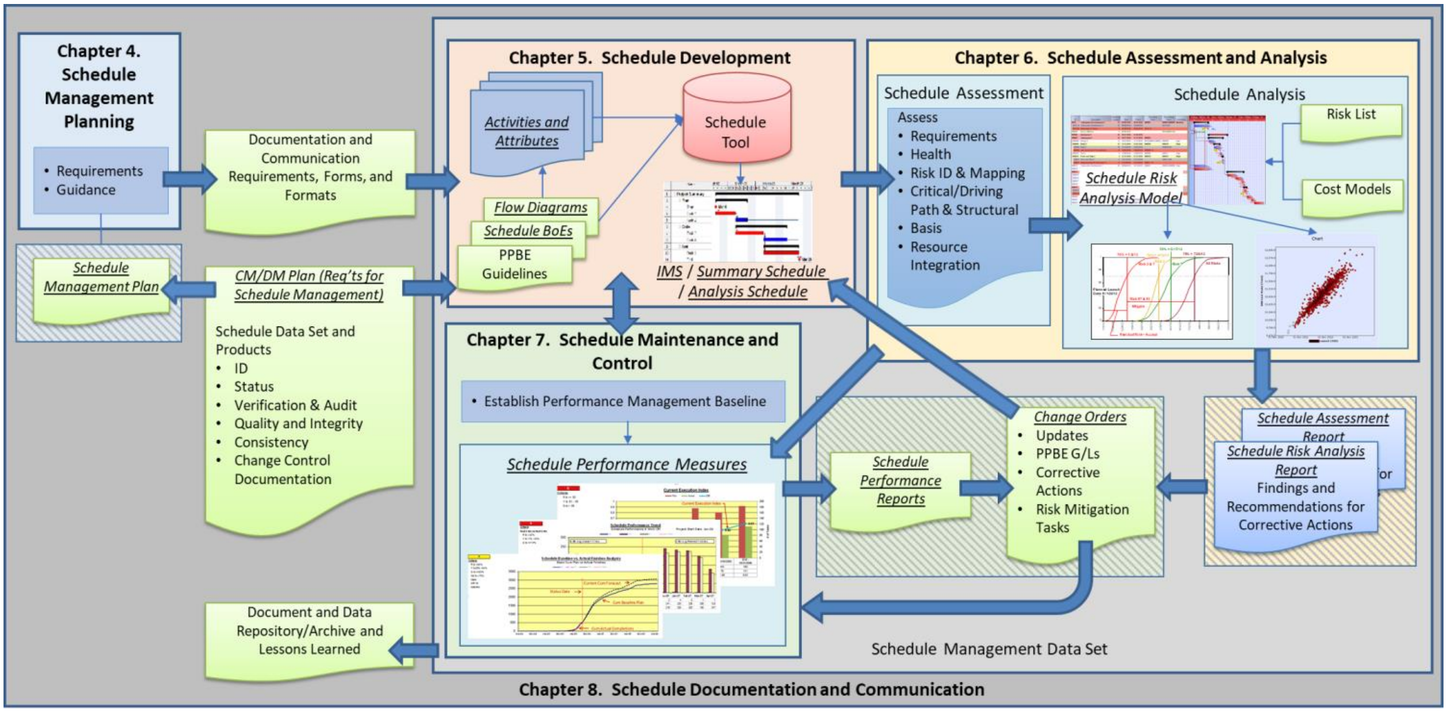


Figure 3-6. The Schedule Documentation and Communication sub-functions detail how the P/p records and disseminates schedule information among team members, as well as other stakeholders, and helps decision makers determine whether the P/p's objectives and commitments are being met. All other Schedule Management sub-functions involve the generation of schedule information and required products at varying levels of maturity that must be properly documented and communicated throughout the P/p lifecycle.

3.6 Schedule Management Roles and Responsibilities

Effective P/p oversight cannot be done without adequate staff. Thus, it is very important that the amount of schedule data, along with the complexity of processes required to maintain and analyze the data be balanced against the number and skill levels of the personnel responsible for it. While everyone on the P/p should have some level of interest in the P/p schedule, there are those that have a specific responsibility to the Schedule Management function. Those roles and responsibilities, which should be captured in the P/p's *SMP*, are discussed here:

Project Manager (PM). The PM's role in the Schedule Management function is to ensure Schedule Management principles and best practices are applied in a manner that supports the Agency and P/p life cycle requirements and objectives. The PM is responsible, with support of the P/p Planner/Scheduler, other P/p's PP&C personnel, and Technical Leads, for the schedule development guidelines, *IMS* development, baseline plan approval, schedule execution, schedule maintenance, and baseline plan control. The PM must facilitate the availability and utilization of the necessary resources, processes, tools, and techniques such that the P/p team can be successful.

Technical Lead (including WBS Element Owner, Control Account Manager (CAM), Integrated Product Team (IPT) Lead, and/or Product Development Lead). The Technical Lead has the assigned responsibility of accomplishing the work contained in each WBS element to comply with the *SMP*. Compliance with the *SMP* helps to ensure that the deliverables associated with their scope of work are provided on time. Technical Leads are accountable for the development, execution, and control of their work scope within the *IMS*, and therefore need to coordinate with the P/p Planner/Scheduler to ensure that the schedule reflects accurate information, updated in a timely manner.

Planner/Scheduler (P/S). The role of the Planner/Scheduler is to implement *SMP* processes in order to ensure the P/p's objectives are successfully achieved. The P/S must be familiar with the P/p technical scope and be able to translate that information into the network logic model that becomes the schedule baseline, or baseline *IMS*. The P/S accomplishes this, in part, by: (1) facilitating planning through coordination with the P/p team to define P/p requirements and schedule objectives; (2) developing the *IMS*; (3) assessing all schedule products to ensure integrity; (4) performing schedule control by assisting the P/p team in managing changes to the *IMS*, which includes baseline change control; and (5) providing insight to the P/p team by reporting schedule progress, performance, variances, and forecasts. The P/S is also responsible for utilizing P/p management software tools and techniques to develop, assess, maintain, and control the *IMS*. Finally, P/Ss must be able to communicate and coordinate effectively with all members of the P/p team, be proactive in their approach to problem solving, understand P/p management processes (e.g., Initiating, Planning, Executing, Reporting, Controlling, and Closing)[12], and be able to report findings to P/p management. While the terms *Planner* and *Scheduler* are often interchangeable insofar as both Planners and Schedulers perform Schedule Development (i.e., scheduling), one primary distinction is that a Planner may also oversee schedulers who perform many of the subsystem schedule development, status collection, data input, and report generation duties. The Planner is typically in a more senior-level career position, having knowledge and experience related to the integration of multiple programmatic disciplines (e.g., cost, schedule, risk), and is more involved in determining Schedule Management approaches, performing detailed schedule analysis and workaround planning to aid in decision-making, and facilitating management-level discussions related to the P/p schedule.

Schedule Analyst. The role of the Schedule Analyst is to perform analysis that will aid in identifying deviations from NASA's Schedule Management best practices and risks that may compromise the P/p's plan. The Schedule Analyst is responsible for verifying the integrity of the schedule, analyzing the critical path(s) to determine that all critical activities are being properly tracked, and conducting schedule risk analysis to understand how risks and uncertainties may alter the likelihood of potential driving paths to specific milestones and negatively impact the availability of margin. The Schedule Analyst is also responsible for analyzing the cost, schedule, and risk elements collectively for a holistic view of the P/p's programmatic health. The Schedule Analyst is responsible for building integrated models and performing sensitivity analyses that can provide management with insight into different scenarios for prioritizing resources and margin to address top P/p risks and threats.

---

[12] Project Management Institute (PMI). Project management processes. https://www.pmi.org/about/learn-about-pmi/what-is-project-management

The Schedule Analyst must be able to communicate assessment findings with P/p management as well as senior management. As it pertains to independent assessment, the Schedule Analyst is the focal point for assessing the *IMS* health and *Schedule BoE*, providing expert opinion of the schedule performance, conducting *SRAs*, *Joint Confidence Level (JCL)* analysis, and identifying schedule findings to the Standing Review Board (SRB). The Schedule Analyst works closely with the Cost Analyst throughout the entire SRB evaluation period to ensure that schedule and cost analysis results are consistent and complementary.[13]

Other P/p Team Members (e.g., PP&C personnel). The role of other P/p team members is to understand the schedule and how it relates to their specific work processes and responsibilities. For example, the Contracting Officer's Technical Representative (COTR) coordinates with the P/S to ensure the contractual deliverables are aligned (e.g., data deliverables, reviews, and hardware and software deliveries) with the activities and milestones in the schedule. The Business Manager coordinates with P/S to ensure the budget phasing integrates with the schedule timeline. The Risk Manager coordinates with the Schedule Analyst to ensure that risks are appropriately mapped to the schedule, that potential risk impacts are understood, and that approved mitigations have been incorporated into the planned schedule. In addition, the Cost Analyst coordinates with the Schedule Analyst to ensure that costs are appropriately mapped to the schedule, such that integrated cost and schedule risk analysis can be performed. Other P/p personnel who have a specific role in the P/p Schedule Management function should be identified in the P/p's *SMP*.

Schedule Community of Practice (SCoPe). SCoPe is an Agency-level community of practice for Schedule Management sponsored by the Office of the Chief Financial Officer (OCFO), given the OFCO's role of ownership of programmatic standards and policies and stewardship of programmatic competency for the Agency.[14] The primary objective of SCoPe is to operate as a conduit between the Schedule Management practitioners and Agency leadership to facilitate communication, thereby helping to strengthen NASA's programmatic policies and capabilities. The Agency's Program/project Planning and Control (PP&C) Steering Group flows direction down to SCoPe, while SCoPe serves as an advisory body to the PP&C Steering Group, providing recommendations regarding Agency Schedule Management policy, processes, and initiatives. More specifically, SCoPe's is responsible for establishing a community of practice that can strengthen the Schedule Management capabilities through Agency-wide communication (best practices, lessons learned, etc.), improvement of methodologies and tools, and training of personnel. This includes:

- Reinforcing existing and establishing new sustainable best practices for Schedule Management
- Encouraging the adoption of standards and best practices across the Agency
- Identifying areas for continuous improvements and influencing enhancements in Schedule Management policy in keeping with the identification of new/improved best practices

---

[13] OCFO-SID-0002. NASA Standard Operating Procedure Instruction (SOPI) 6.0. Release Date: May 23, 2017. https://www.nasa.gov/sites/default/files/atoms/files/sopi_6.0_final.pdf

[14] SCoPe website, https://community.max.gov/x/9rjRYg.

- Ensuring that Agency policy and guidance documents reflect consistent information regarding how to meet Schedule Management requirements
- Working with other PP&C disciplines to ensure an integrated approach to advancing the Schedule Management capabilities through data collection and research
- Working towards the advancement of schedule assessment methodologies and analysis techniques
- Providing reach-back for P/ps with respect to both in-line and independent Schedule Assessment expertise
- Providing recommendations for Agency-wide implementation of tools and techniques
- Formulating training consistent with Agency policy and the Schedule Management Handbook
- Working solutions to specific issues or areas of priority identified by the PP&C Steering Group

General SCoPe membership consists of NASA Schedule Management practitioners and subject matter experts (including both civil servant and contractor support) from each of the NASA Centers, the Jet Propulsion Laboratory, the Applied Physics Laboratory, each of the Headquarters Mission Directorates, and other Headquarters offices including the OCFO, the Office of Procurement, and the Office of the Chief Engineer (OCE). Membership is self-selecting.

3.7 Schedule Management Skillsets and Training

The success of Schedule Management depends primarily on the quality of Schedule Management skills that are dedicated to P/ps across the Agency. A consolidated list of skills and competencies needed for P/p personnel performing the Schedule Management function can be found on the SCoPe website.[15] The NASA PP&C Handbook illustrates and describes the interfaces (inputs and outputs) between the Schedule Management function and other PP&C functions.[16]

To ensure strong, consistent Schedule Management expertise is available, it is imperative that the appropriate training be taken by the P/p team members that are involved in planning, developing, assessing, analyzing, maintaining, using, controlling, documenting, or communicating P/p schedules. Selection of training should address the needs and requirements of P/p team's responsibilities. Available NASA Schedule Management training courses can currently be found through SATERN[17], APPEL[18], and CFO University[19], as well as through the NASA's SCoPe. While formal classroom and self-taught training is valuable, it is most effective when accompanied by on-the-job training (OJT) and/or

---

[15] SCoPe website, https://community.max.gov/x/9rjRYg

[16] https://nen.nasa.gov/documents/879593/1386755/PP%2BC+Handbook+1-5-17.docx/097acedf-1df7-4676-b9c1-4c0c1e83dc2e?version=1.0&download=true

[17] System for Administration, Training, and Educational Resources for NASA (SATERN). https://satern.nasa.gov/customcontent/splash_page/

[18] NASA Academy of Program/Project & Engineering Leadership (APPEL). https://appel.nasa.gov/

[19] CFO University (CFOU). https://community.max.gov/pages/viewpage.action?spaceKey=NASA&title=CFO+University

hands-on training (HOT), such as working with mentors that have direct NASA Schedule Management experience. It should be understood that the NASA Schedule Management training curriculum will cover an evolving, growing list of topics.

4 Schedule Management Planning

Schedule Management Planning provides the guidance on how the schedule will be managed according to best practices throughout the P/p life cycle, including the design, development, and implementation of all Schedule Management processes, tools, reporting forms, and formats. The requirements for each of these processes is captured in the *Schedule Management Plan (SMP)*. The *SMP* incorporates P/p products and processes that must be in place for adequate Planning, as well as the collection of requirements and data needed for Schedule Development – to create of the *Schedule Database* and its associated *Schedule Outputs*, including the *IMS*. Once this is done, the P/p has the capability to produce logically-linked sequences of activities and related reports. The *SMP* also provides guidance for the remaining Schedule Management sub-functions as follows: Schedule Assessment and Schedule Analysis – to verify quality of the schedule and likelihood of achieving the cost and schedule objectives within acceptable risk; Schedule Maintenance and Control – to provide the P/p the capability to measure performance and make adjustments to the schedule; and finally, Documentation and Communication – to facilitate the documentation and dissemination of P/p schedule information.

4.1 Best Practices

Figure 4-1 details the best practices for Schedule Management Planning.

SM.P.1 Schedule Management Plan Exists	• A Schedule Management Plan exists, which defines and explains all aspects needed for managing the P/p schedule scope, including: o Agency, P/p, Organizational, and Environmental goals, objectives, and assumptions, as well as internal/external stakeholder priorities, scope of work, roles and responsibilities; o Establishment of schedule management strategies and processes, that are clear, concise, and descriptive, including: ▪ Estimating and development scope, methods, tools, and techniques (including establishment of schedule margin and cost reserves), ▪ Assessment and analysis scope, methods, tools, and techniques, ▪ Maintenance and control scope (including partners, agreements, etc.), methods, tools, and techniques (including basis for managing scope and schedule margin, process for managing changes and/or replanning, as well as descope trigger points identified), and ▪ Documentation and communication/reporting methods (including activity codes), frequency, tools, and necessary P/p personnel interactions.
SM.P.2 Scheduling Methods/Approaches are Selected	• A scheduling methods and techniques are selected appropriate to the type and level of schedule development and management that the P/p necessitates.

SM.P.3 Schedule Management Tools are Selected	• Schedule Management tools are selected appropriate to the type and level of Schedule Management that the P/p necessitates.
SM.P.4 Milestone Registry is Defined	• The milestone registry is defined to include a list of all key dates/milestones and associated trigger points (e.g., for descopes or risk mitigations).
SM.P.5 Activity Attributes are Defined	• The activity attributes are identified appropriate to the type and level of schedule development and integrated PP&C management that the P/p necessitates.

Figure 4-1. Schedule Management Planning Best Practices.

4.2 Prerequisites

The Schedule Management Planning can be initiated when:

1. The Agency and the P/p have concurred on the P/p Commitment Agreement (PCA) and the Formulation Authorization Document (FAD)
2. The P/p has created or defined the following:
    a. P/p scope
    b. Descope plan
    c. Initial risk list
    d. WBS and WBS Dictionary
    e. Work packages, control accounts, and product owners
3. The sponsors and/or Agency have defined all external notification and control milestones
4. Interfaces with other P/ps are defined
5. The current FY PPBE guideline document exists
6. The roles and responsibilities for the development of the Schedule Management function are defined

4.3 Develop the Schedule Management Plan

The *SMP* is an implementation plan that provides the P/p with guidance and procedures needed to execute the Schedule Management function according to Agency requirements. The *SMP* guides the P/p in developing the *IMS*, including the collection of all schedule-related data that populates the *Schedule Database*, acquiring the tools and techniques to assess schedule, analyzing risks to the schedule, maintaining the schedule, measuring and controlling schedule performance, and documenting and communicating schedule information. Although not explicitly required, ***it is a best practice for a Schedule Management Plan to be developed***, ***which defines and explains all aspects needed for managing the P/p schedule scope, including:***

- ***Agency, P/p, Organizational, and Environmental requirements, goals, objectives, and assumptions, as well as internal/external stakeholder priorities, scope of work, roles and responsibilities;***
- ***Establishment of schedule management strategies and processes, that are clear, concise, and descriptive, including:***
    - ***Estimating and development scope, methods, tools, and techniques (including establishment of schedule margin and cost reserves),***
    - ***Assessment and analysis scope, methods, tools, and techniques,***
    - ***Maintenance and control scope (including partners, agreements, etc.), methods, tools, and techniques (including basis for managing scope and schedule margin, process for managing changes and/or replanning, as well as descope trigger points identified), and***
    - ***Documentation and communication/reporting methods (including activity codes), frequency, tools, and necessary P/p personnel interactions.***

Schedule Planning should be according to the space flight (and R&T) P/p life cycles as follows:

- Pre-Phase A (Pre-Authority to Proceed (ATP)): Identify and assign the P/S and/or Schedule Analyst. Develop the *Milestone Registry*. Identify the *Activity Attributes*. Produce the *Schedule Development Plan* portion of the *SMP*. Make/buy the Schedule Management tools.
- Phase A-SRR (ATP): Complete a preliminary version of the *SMP*, including the remaining sub-plans. Deploy the remaining Schedule Management sub-functions. Deploy the documentation and communication tools.
- Phase A – SDR/MDR: Fully staff and begin full-up execution of all processes. Update the *SMP*.
- Phase B – PDR (P/p Approval): Schedule Management is fully operational. Baseline the *SMP*.
- Phase C/D – CDR/SIR/ORR through Launch (PARs through Closeout): Continue to implement the *SMP* and update as necessary.

Schedule Management Planning is performed throughout the P/p life cycle, but has greatest emphasis during Phase A. In pre-Phase A (Concept Studies), there is a lack of knowledge and understanding of the technology, as well as immature mission/system requirements. Information is still being gathered and Schedule Management Planning is performed at a very high level. As shown in Figure 4-2, Schedule Management Planning takes into consideration requirements derived from several sources including, but not limited to, Agency, P/p, organizational, internal and external requirements for schedule management, performance and reporting. In addition, as tools are selected to support the execution of the Schedule Management function, ancillary requirements are derived. By Phase A (Concept & Technology Development), the mission/system concept definition is completed, most concept and trade studies are completed, preliminary requirements are established, and a preliminary P/p Plan is developed. Therefore, P/p definition becomes clear enough during Phase A to allow for a more discrete breakdown of work tasks and milestones. The *SMP* is prepared during Phase A of Project Formulation prior to Key Decision Point (KDP) I for most Programs and KDP B for Single-project Programs and projects.

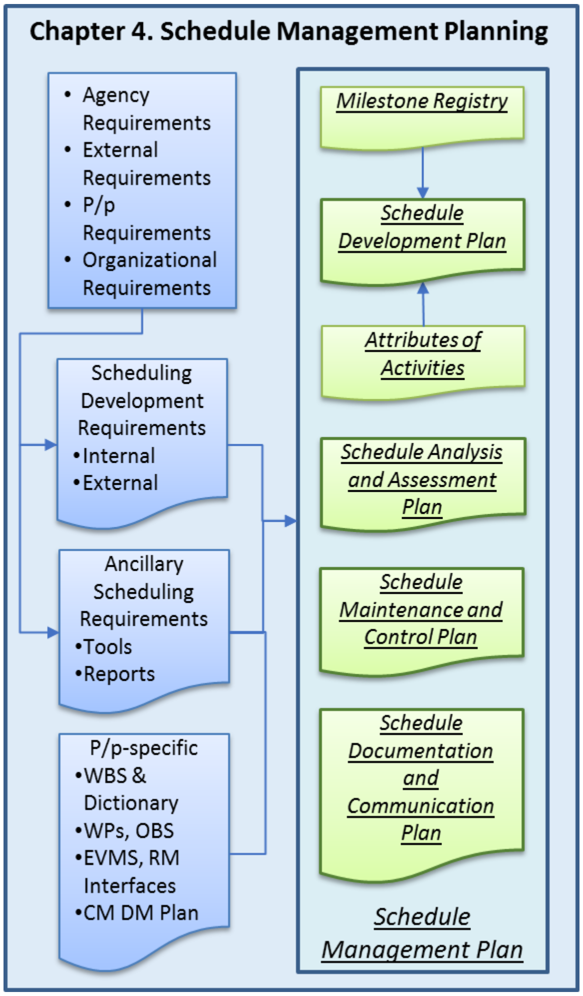
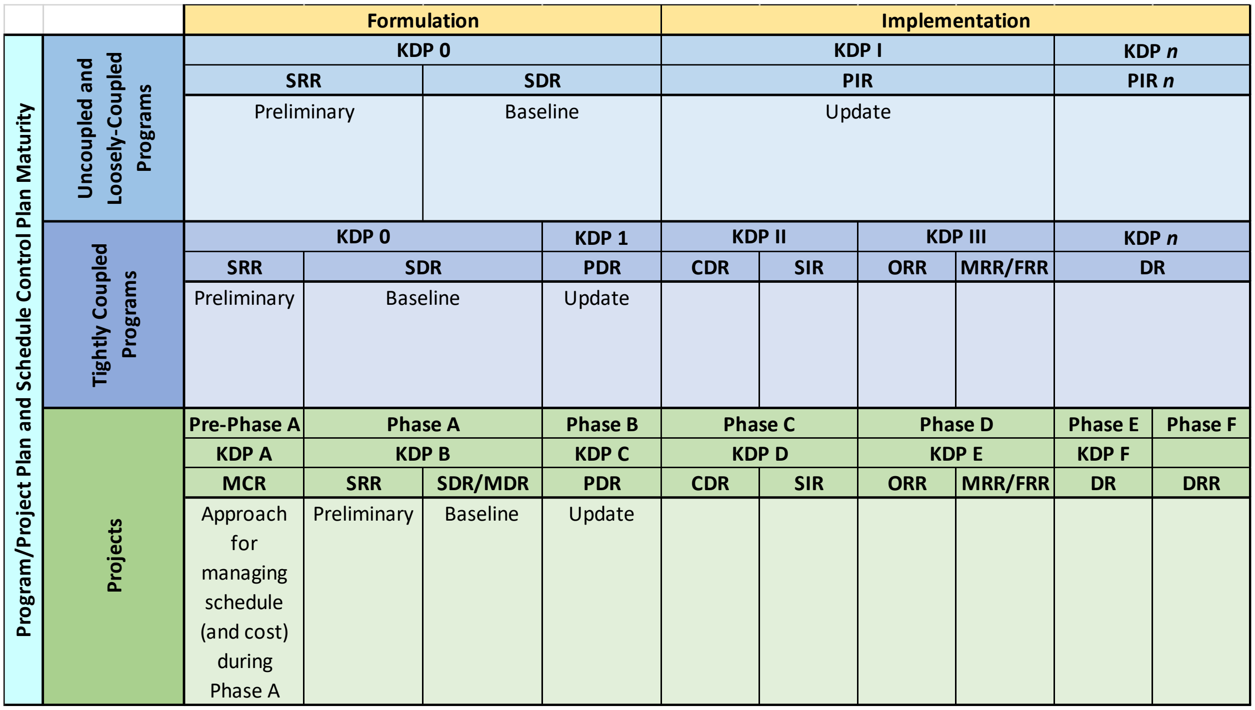


Figure 4-2. Components of the Schedule Management Plan (SMP) and sources of requirements.

The *SMP* can be a stand-alone plan or a subsidiary component of the P/p Plan. Regardless of how it is structured within a P/p's documentation, the *SMP* should be subject to document control. The *SMP* is not intended as a detailed procedure for performing "scheduling;" rather, it is a guideline for applying principles, processes, and best practices.

The *SMP* contains four sub-plans: (1) a *Schedule Development Plan* with *Milestone Registry* and *Activity Attributes* as subsections, (2) a *Schedule Analysis and Assessment Plan*, (3) a *Schedule Maintenance and Control Plan*, and (4) a *Schedule Documentation and Communication Plan*. The *SMP* defines the execution of all the sub-plans, which address development, deployment, and execution of the Schedule Management function. The Maintenance and Control Section of the *SMP* supports the development and implementation of the Technical, Cost, and Schedule Control Plan required in NPR 7120.5. A table of the required *SMP* maturity for NPR 7120.5 P/ps at given LCRs is provided in Figure 4-3.[20]



<table>
<tr><th></th><th></th><th colspan="4">Formulation</th><th colspan="6">Implementation</th></tr>
<tr><td rowspan="10">Program/Project Plan and Schedule Control Plan Maturity</td><td rowspan="3">Uncoupled and Loosely-Coupled Programs</td><td colspan="4">KDP 0</td><td colspan="4">KDP I</td><td colspan="2">KDP <i>n</i></td></tr>
<tr><td colspan="2">SRR</td><td colspan="2">SDR</td><td colspan="4">PIR</td><td colspan="2">PIR <i>n</i></td></tr>
<tr><td colspan="2">Preliminary</td><td colspan="2">Baseline</td><td colspan="4">Update</td><td colspan="2"></td></tr>
<tr><td rowspan="3">Tightly Coupled Programs</td><td colspan="3">KDP 0</td><td>KDP 1</td><td colspan="2">KDP II</td><td colspan="2">KDP III</td><td colspan="2">KDP <i>n</i></td></tr>
<tr><td>SRR</td><td colspan="2">SDR</td><td>PDR</td><td>CDR</td><td>SIR</td><td>ORR</td><td>MRR/FRR</td><td colspan="2">DR</td></tr>
<tr><td>Preliminary</td><td colspan="2">Baseline</td><td>Update</td><td></td><td></td><td></td><td></td><td colspan="2"></td></tr>
<tr><td rowspan="4">Projects</td><td>Pre-Phase A</td><td colspan="2">Phase A</td><td>Phase B</td><td colspan="2">Phase C</td><td colspan="2">Phase D</td><td>Phase E</td><td>Phase F</td></tr>
<tr><td>KDP A</td><td colspan="2">KDP B</td><td>KDP C</td><td colspan="2">KDP D</td><td colspan="2">KDP E</td><td>KDP F</td><td></td></tr>
<tr><td>MCR</td><td>SRR</td><td>SDR/MDR</td><td>PDR</td><td>CDR</td><td>SIR</td><td>ORR</td><td>MRR/FRR</td><td>DR</td><td>DRR</td></tr>
<tr><td>Approach for managing schedule (and cost) during Phase A</td><td>Preliminary</td><td>Baseline</td><td>Update</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Figure 4-3. SMP maturity requirements by P/p phase according to NPR 7120.5.

Although not explicitly identified in NPR 7120.8 as a required product for R&T P/ps, it is expected that the *SMP* would exist at a similar maturity for corresponding life cycle phases. It is also important to note that, "R&T projects that directly tie to the space flight mission's success and schedule are normally managed under NPR 7120.5." Figure 2-3 and Figure 2-4 provide an overview of the expected maturity of the *SMP* for P/ps that adhere to NPR 7120.8.

Through careful development and execution of the *SMP*, the P/p is able implement all the elements of the Schedule Management function, including: generate a cost and schedule estimate, time phase the schedule development to match the maturation of the P/p, estimate the resources needed to execute the function, and assign roles and responsibilities related to managing the P/p schedule. An *SMP* Annotated Template can be found on the SCoPe website.[21]

4.3.1 Create the Schedule Development Plan

The content of the *IMS* and therefore the overall *SMP* approach should be dependent upon how the P/p is organized. For example, there could be in-house, prime contractor, and/or external partnership activities which will influence the planning process. Additionally, Schedule Development should be

---

[20] While NPR 7120.8A does not specifically require a Basis of Estimate (BoE) product, projects that adhere to NPR 7120.8 may benefit from the documentation of BoEs to support the required programmatic products.
[21] SCoPe website, https://community.max.gov/x/9rjRYg

planned in accordance and integrated with the institutional EVM processes and methodologies on P/ps. Guidance for aligning the development of the schedule to support EVM can be found on the SCoPe website.[22]

In creating the Schedule Development Plan, all requirements needed to drive the development of the *IMS* are collected. As shown in Figure 4-4, requirements for Schedule Assessment come from NPRs, internal and external guidance documents, and the P/p planning documents. This includes the requirements for the selection of the schedule management tools and make/buy plans, the development of the *Schedule Database*, the data collection procedures necessary for populating the *Schedule Database*, and the development of the *Schedule Outputs*. The result is a fully operational capability to schedule work, capture performance, and generate outputs. All of these things are included in the Schedule Development Plan which may be a standalone plan or a part of the *SMP*. Best practices for Schedule Development are captured in Chapter 5 and should be considered for incorporation in the *Schedule Development Plan*.

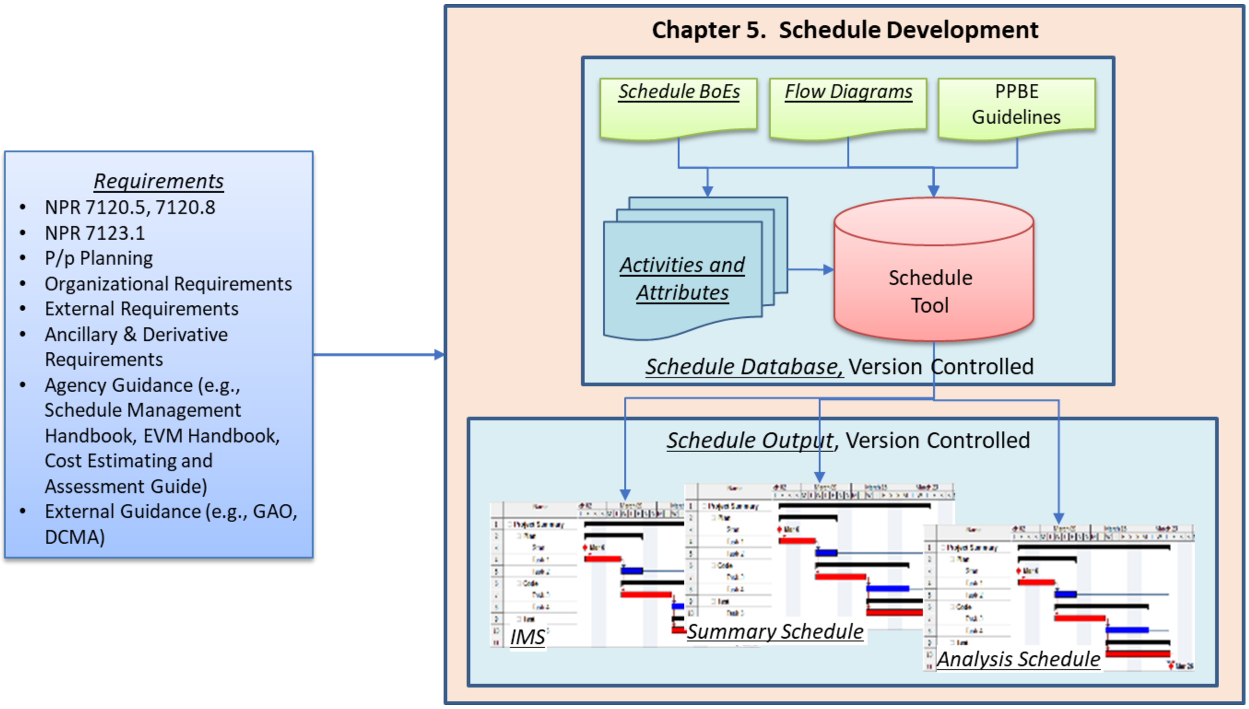


Figure 4-4. Requirements for the Schedule Development sub-function come from the NPRs, guidebooks, and P/p planning, as well as external requirements and guidance.

4.3.1.1 Collect the Top-Level Requirements for the Construction of the IMS

The *IMS* requirements are derived from several sources, the P/p-specific needs, the Agency requirements and guidelines, P/p external requirements, and the P/p's parent organization's

---

[22] SCoPe website, https://community.max.gov/x/9rjRYg

requirements. Figure 4-5 shows a more detailed look at the sources to be considered for the development of the requirements for the *IMS*, including the associated *Schedule Database*.

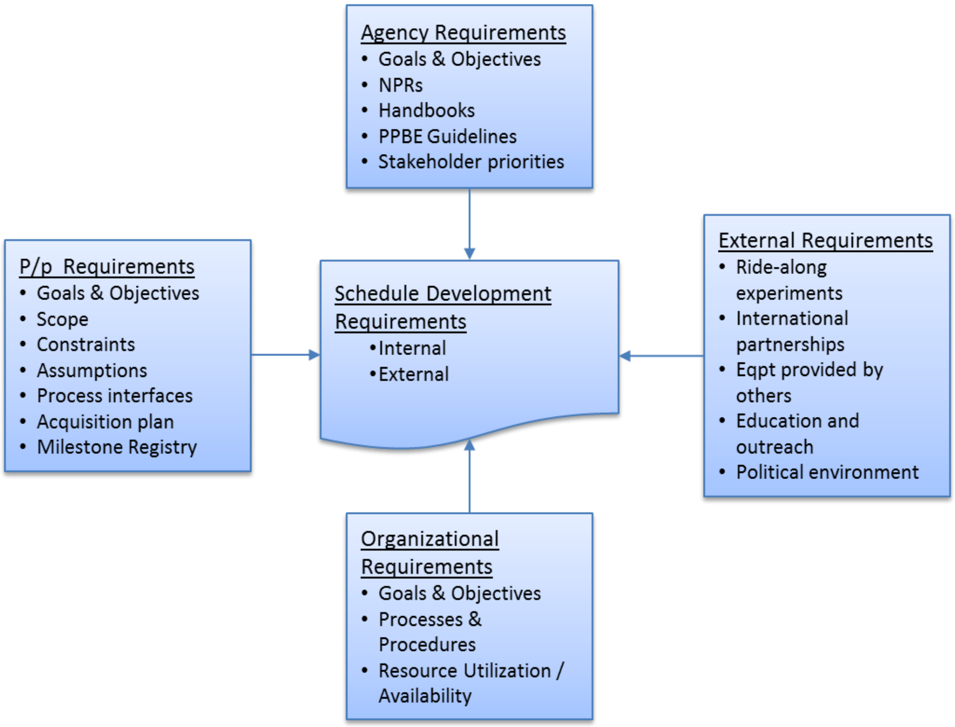


Figure 4-5. The Schedule Development Plan top-level requirements are derived from several sources: the P/p's specific needs, the Agency requirements and guidelines, P/p's external requirements, and the P/p's parent organization's requirements.

4.3.1.1.1 P/p Requirements

By far the greatest number of Schedule Management-related requirements will come from the P/p itself. The P/p will have goals and objectives that are unique as well as derivatives of the Agency goals and objectives. The P/p must establish sets of constraints, assumptions, and other guidelines in order to meet a larger set of technical, cost, safety, and resource allocation requirements. Within those sets are derivative requirements for the Schedule Management function. These data requirements come from specific P/p planning products, such as: the Work Breakdown Structure (WBS) and the WBS Dictionary detailing work packages and Performance Measurement Techniques (PMTs) needed for EVMS tracking, the Organizational Breakdown Structure (OBS) assigning activities to specific performing organizations, the Cost Breakdown Structure (CBS) (i.e., control accounts) mapping costs to activities for management and tracking purposes, and various contract schedule interface requirements. The P/p's Acquisition Plan will contain requirements for schedule information that must be managed between contracted and partnered efforts. At a lower level, the P/p must interface the Schedule Management function with other PP&C functions, such as: Resource Management, Earned Value Management (EVM), Risk Management, Configuration Management and Data Management (CM/DM). To do so levies interface and reporting requirements on the Schedule Management function. The defined approach to implement best practices in order meet each of these requirements is included in the *SMP*.

4.3.1.1.2 Agency Requirements

Agency documents, such as NPR 7120.5 and NPR 7123.1, require specific documents to establish P/p commitments, plans for schedule management, and products needed by phases of development. These include:

- ***P/p Formulation Authorization Document (FAD)*** – The FAD is authorized by NASA Headquarters as the formal initiation of formulation. It identifies the resources, scope of work, period of performance, goals, and objectives for the formulation process.
- ***P/p Commitment Agreement (PCA)*** – The PCA is the agreement between NASA Headquarters and the PMs that documents the Agency's commitment to implement the P/p requirements within established constraints. It identifies key P/p milestones for the implementation process.
- ***P/p Formulation Agreement (PFA)*** – The PFA is the single-project Program’s or project’s response to the FAD. It serves as a tool for communicating and negotiating the P/p’s formulation plans and resource allocations with the Program and Mission Directorate.
- ***P/p Plan*** – The P/p Plan is an agreement between NASA Headquarters, the Center Director, and the PMs that further defines the PCA requirements and establishes the plan for P/p implementation. It identifies additional key P/p milestones and lower level schedules and establishes the P/p strategy for schedule development, maintenance, and control.
- ***P/p Budget*** – P/ps need to ensure that the budget plan and the schedule plan adequately correlate. This requires a joint effort and good communication between the Resource Management function and the P/S early in the P/p life cycle. It is a recommended practice that budget and schedule planning be done at a level of detail that will provide sufficient management insight, control, and the ability to accurately measure and track progress. Budget and schedule planning and development should be carried out by both the Resource Manager and the P/S in a manner that accurately correlates the time phasing of both products. This collaborative approach aids in ensuring that the necessary consistency exists between the two plans. Because this is typically a manual effort, a disciplined process should be established and documented.
- ***P/p Technical, Schedule, Cost (TSC) Control Plan*** – The TSC Control plan documents how the P/p plans to control requirements, technical design, schedule, and cost to achieve the program requirements on the P/p. The plan describes how the P/p monitors and controls the requirements, technical design, schedule, and cost to ensure that the high-level requirements levied on the P/p are met. It describes the P/p’s technical, cost, and *Schedule Performance Measures* in objective, quantifiable, and measurable terms and documents how the measures are traced from the program requirements on the P/p. In addition, it documents the minimum mission success criteria associated with the program requirements on the P/p that, if not met, trigger consideration of a Termination Review. The minimum success criteria are generally defined by the P/p’s threshold science requirements. The P/p also develops and maintains the status of a set of programmatic and technical leading indicators. While certain technical indicators are required, the Agency also highly recommends the use of a common set of

programmatic indicators to support trend analysis throughout the life cycle.[23] The schedule control portion of this plan should reflect what is captured in the *SMP*.

More abstract, but likely more important are the stakeholder priorities, which may have schedule implications as well as schedule reporting requirements. From these sources, typical requirements are usually control milestones which are loaded into the *Milestone Registry*, and specific reporting forms and formats such as those needed to show performance to schedule, which are further defined in Chapters 7 and 8. After the PDR, there are specific milestones in the Management Agreement (MA) document and the Agency Baseline Commitment (ABC) document that must be in the *Schedule Database* and regular reports of performance to those milestones are required. On an annual basis, the PPBE process will issue a guideline document to the P/p, which contains scheduling requirements that need to be met in concert with an annual funding profile.

4.3.1.1.3 External Requirements

External requirements are those that directly impact the P/p's routine operation, but are not an intrinsic part of the P/p. These types of requirements can come from partnerships with other Agencies, universities or other research institutions, international partnerships, or other business arrangements not involving contracts or procurements. Examples include the relationship to other P/ps or experiments, which may provide "ride-along" equipment, the launch vehicle, or systems or services such as command and data handling. Any of these cases will generate requirements for additional tasks for the management and control of the relationships. Environmental and national and local political issues should be considered as well.

Examples of External Requirements:

- *Orion's partnership with ESA for the Service Module*
- *Science Mission Directorate requires every Mars mission to carry an orbital communication relay satellite (Electra)*
- *Experiments provided by universities funded by external grants*
- *National and international policies regarding the use of nuclear materials.*
- *Environmental issues related to the use of hazardous materials*

4.3.1.1.4 Organizational Requirements

The P/p's host organization, usually a NASA Center, is also a source of requirements for the Schedule Management function. These requirements, typically in the form of resources, may include the availability of personnel with the appropriate skills or the availability of a facility, either of which will impact the scheduling process to match the availability. There may be process control standards imposed by the host organization such as the GSFC "Gold Rules" or JPL Design Principles, for example. Typical requirements are generally process related such as guidelines for the inclusion of margin, or forums and formats for organizational reporting. The organization may also standardize scheduling tools. Multi-Center P/ps may have a mix of requirements specific to each Center that need to be considered in Schedule Management Planning, such as different scheduling tools or reporting processes that need to be carefully integrated.

---

[23] NASA/SP-2014-3705, NASA Space Flight Program and Project Management Handbook. Pages 157-158. https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20150000400.pdf

4.3.1.2 Collect the Ancillary and Derivative Requirements for Schedule Development

Within the Schedule Development sub-function, there are ancillary requirements and derivative requirements. While the sections above describe the sources of imposed requirements on the Schedule Management function, this section of the *SMP* identifies the requirements derived internal to the Schedule Management function. The sources of these requirements are shown in Figure 4-6.

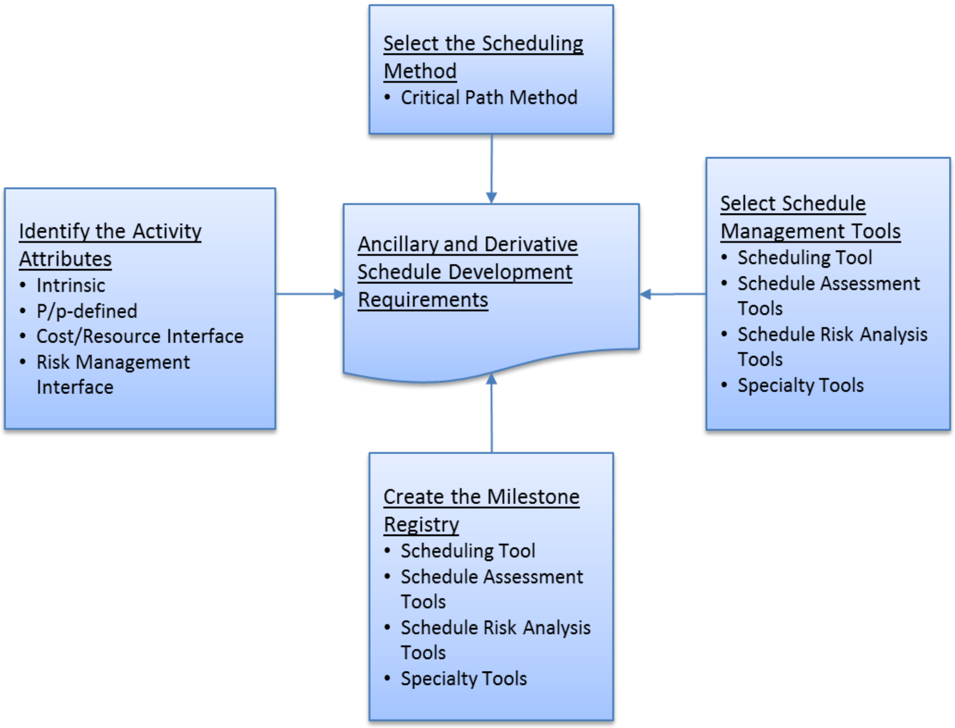


Figure 4-6. There are ancillary and derivative requirements that are not specifically levied on the Schedule Management function but must be determined from other sources in order to completely fulfill the needs of the Schedule Management function.

4.3.1.2.1 Select the Scheduling Method s and Techniques

It is a best practice for scheduling methods and techniques to be selected that are appropriate to the type and level of schedule development and management that the P/p necessitates. A scheduling method must be selected that will meet higher-level, as well as functional P/p management requirements. This decision needs to be made early because it drives the requirements for the formation of the schedule management processes. For example, the scheduling method may impact tool selection, in addition to reporting forms and formats. In general, the commonly-used scheduling method that has been demonstrated effective for NASA P/ps is identified below:

- **Critical Path Method (CPM).** CPM is a network diagram scheduling technique that determines the shortest time to complete the P/p by calculating the longest path through a network of tasks to the P/p end date.

CPM scheduling should be used, when practical. In conjunction with CPM, a P/p may choose to employ Rolling Wave Planning, which uses progressive elaboration, is a method that allows for scheduling to occur in waves, adding a greater level of detail as the P/p evolves. The P/S should also consider different

IMS development techniques that acknowledge the differences among NASA's P/p types, acquisition strategies, external partnering agreements, and other factors with respect to the integration of schedule data. These methods and techniques are described in Section 5.5.3 and Section 5.6.1.

4.3.1.2.2 Select Schedule Management Tools

It is a best practice for Schedule Management tools to be selected appropriate to the type and level of schedule management that the P/p necessitates. Schedule Management tools are used to develop, maintain, analyze, assess, and control P/p schedules (and document and communicate). Agency-wide adherence to Schedule Management tool recommendations can improve data sharing capability, increase interoperability with other agency standard tools, and potentially enable speedy accessibility through common Agency-wide procurement vehicles. Prior to selecting any Schedule Management tool, P/p functionality requirements and desires should be defined. This approach will help ensure that tools are selected that best satisfy those needs. It is also a recommended practice that common toolsets be used across a P/p, which will allow for easier integration and understanding of P/p information. Types of tools used to support the Schedule Management function may include:

> **Scheduling Tool.** The scheduling tool is the primary element of the *Schedule Database* as shown in Figure 3-2, as it is the place where all schedule-related data is integrated to build the *IMS*. Examples of typical scheduling tools are Oracle Primavera P6 and Microsoft (MS) Project. It is important to note that the P/p may make a schedule tool selection that is different from that which the contractor may be using. In those cases, the interface requirements must be specified in order for the P/p to create the integrated schedule.
>
> **Schedule Assessment Tools.** Schedule health check tools are needed. Some are automated and work well as add-ons. An example is the NASA STAT tool, an MS Project add-on. Other tools are standalone and require the *IMS* to be uploaded to the tool, such as Deltek's Acumen Fuse. Still other assessment tools may be check lists developed from best practices such as those included in the GAO Schedule Assessment Guide.[24] The assessment tools need to be specified and a make or buy plan developed.
>
> **Schedule Risk Analysis Tools.** *Schedule Risk Analysis* (*SRA*) tools are sometimes integral with the scheduling software and sometimes add-on macros. Examples of add-ons are JACS, Polaris, Primavera Risk Analysis, @Risk, and Full Monte. If using an add-on approach, the selection must be made in parallel with the selection of a scheduling tool to ensure compatibility.
>
> **Specialty Tools.** All scheduling software can output useful reports, but they don't always output the specific report format needed. It is best to work with the P/p management team, pose typical decision-making reports, and select those that best suit their needs. Once that is done, the creative process on how to generate those reports begins. There may be a need for specific data exports from the scheduling tool or the *SRA* tool. Those export formats need to be defined. There may be a need to make or buy performance measurement plotting tools. Examples of plots needed for performance measurement are Baseline Execution Index (BEI), Schedule Performance Index (SPI),

---

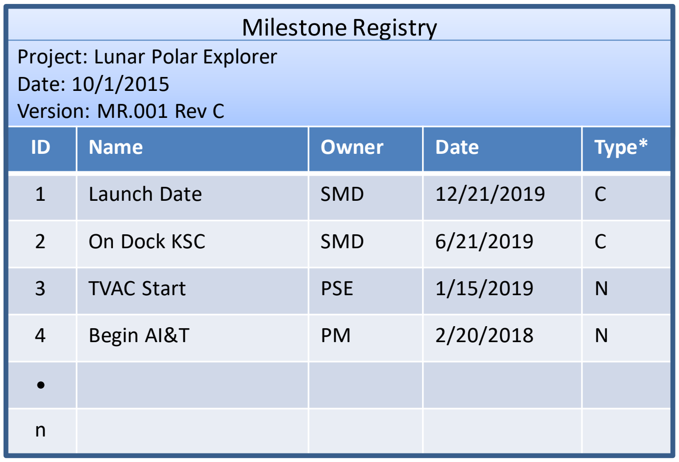
[24] GAO-16-89G. GAO Schedule Assessment Guide. December 2015. http://www.gao.gov/assets/680/674404.pdf

and Current Execution Index, (CEI), and performance trends for those indices over time. Examples of plots needed for *SRA* are Confidence Level curves *JCL* curves, scatterplots, as well as various risk sensitivity and trending reports. Often MS Excel is used as the plotting software to produce custom reporting formats that may not be standard in the *SRA* tool.

Tools are addressed in the chapters corresponding to Schedule Management functions that they support. A list of tools commonly used throughout the Schedule Management life cycle can be found on the SCoPe website.[25]

4.3.1.2.3 Create the Milestone Registry

It is a best practice for a milestone registry to be defined to include a list of all key dates/milestones and associated trigger points (e.g., for descopes or risk mitigations). A list of key P/p milestones are collected. At a minimum, the notification and control milestones should be captured. Control milestones are typically milestones owned by the sponsors or the stakeholders and cannot be changed by the P/p. Notification milestones are those controlled by the P/p; however, the P/p must notify the sponsor or the stakeholders of any changes. These milestones are compiled into a *Milestone Registry* as a Table to be included as an appendix to the *SMP*, as shown in Figure 4-7. At the KDP B, the MA and the ABC dates are added.



Milestone Registry
Project: Lunar Polar Explorer
Date: 10/1/2015
Version: MR.001 Rev C

ID	Name	Owner	Date	Type*
1	Launch Date	SMD	12/21/2019	C
2	On Dock KSC	SMD	6/21/2019	C
3	TVAC Start	PSE	1/15/2019	N
4	Begin AI&T	PM	2/20/2018	N
•				
n				

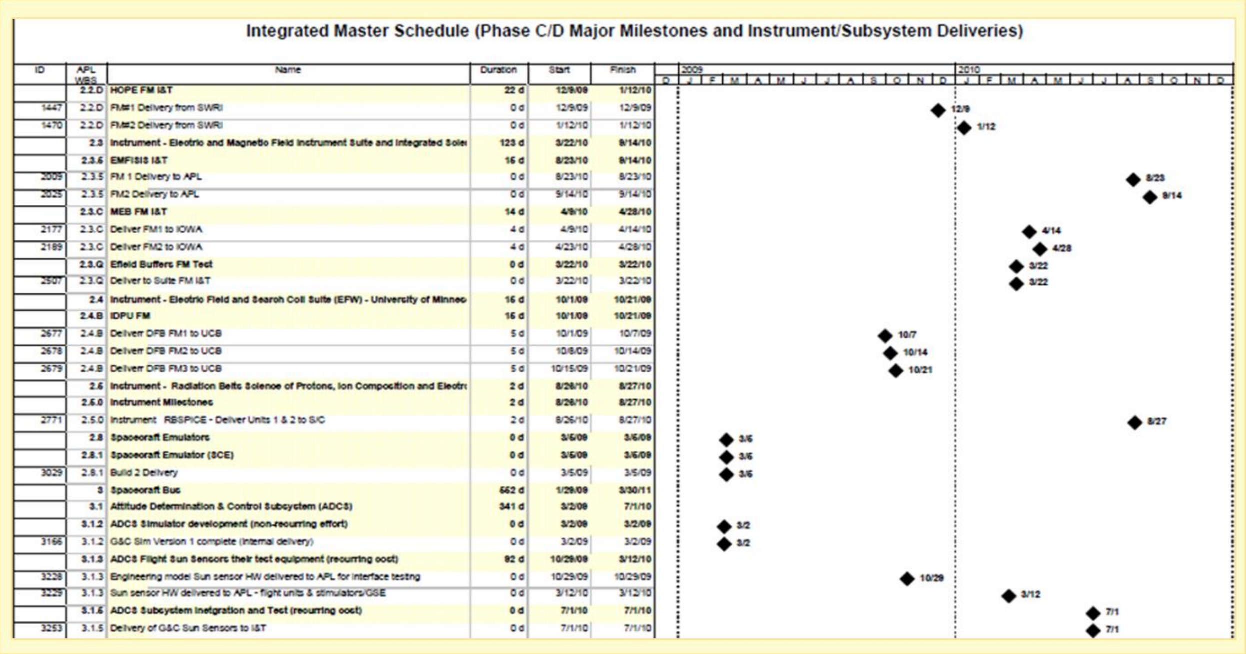
*Type: C, Control, N, Notification

Figure 4-7. The figure shows an example of a generic Milestone Registry.

The *Milestone Registry* may also be used to identify major P/p events (e.g., LCRs, KDPs), contractual or acquisition events (e.g., procurements, hardware deliveries), or other interfaces or programmatic milestones. As such, the *Milestone Registry* is helpful in communication with other PP&C functions. For instance, initial acquisition milestones are provided to the Acquisition and Contract Management function for use in developing solicitations. The *Milestone Registry* may ultimately be maintained in the *IMS*, as shown in Figure 4-8.

---

[25] Schedule Management tools are referenced in the Agency Schedule Management Tool Matrix located at the SCoPe website, https://community.max.gov/x/9rjRYg.



Integrated Master Schedule (Phase C/D Major Milestones and Instrument/Subsystem Deliveries)

ID	APL WBS	Name	Duration	Start	Finish
	2.2.D	**HOPE FM I&T**	**22 d**	**12/9/09**	**1/12/10**
1447	2.2.D	FM#1 Delivery from SWRI	0 d	12/9/09	12/9/09
1470	2.2.D	FM#2 Delivery from SWRI	0 d	1/12/10	1/12/10
	2.3	**Instrument - Electric and Magnetic Field Instrument Suite and Integrated Sole**	**123 d**	**3/22/10**	**9/14/10**
	2.3.6	**EMFISIS I&T**	**16 d**	**8/23/10**	**9/14/10**
2009	2.3.5	FM 1 Delivery to APL	0 d	8/23/10	8/23/10
2025	2.3.5	FM2 Delivery to APL	0 d	9/14/10	9/14/10
	2.3.C	**MEB FM I&T**	**14 d**	**4/9/10**	**4/28/10**
2177	2.3.C	Deliver FM1 to IOWA	4 d	4/9/10	4/14/10
2189	2.3.C	Deliver FM2 to IOWA	4 d	4/23/10	4/28/10
	2.3.Q	**Efield Buffers FM Test**	**0 d**	**3/22/10**	**3/22/10**
2507	2.3.Q	Deliver to Suite FM I&T	0 d	3/22/10	3/22/10
	2.4	**Instrument - Electric Field and Search Coil Suite (EFW) - University of Minnes**	**16 d**	**10/1/09**	**10/21/09**
	2.4.B	**IDPU FM**	**16 d**	**10/1/09**	**10/21/09**
2677	2.4.B	Deliverr DFB FM1 to UCB	5 d	10/1/09	10/7/09
2678	2.4.B	Deliverr DFB FM2 to UCB	5 d	10/8/09	10/14/09
2679	2.4.B	Deliverr DFB FM3 to UCB	5 d	10/15/09	10/21/09
	2.5	**Instrument - Radiation Belts Science of Protons, Ion Composition and Electr**	**2 d**	**8/26/10**	**8/27/10**
	2.5.0	**Instrument Milestones**	**2 d**	**8/26/10**	**8/27/10**
2771	2.5.0	Instrument RBSPICE - Deliver Units 1 & 2 to S/C	2 d	8/26/10	8/27/10
	2.8	**Spacecraft Emulators**	**0 d**	**3/5/09**	**3/5/09**
	2.8.1	**Spacecraft Emulator (SCE)**	**0 d**	**3/5/09**	**3/5/09**
3029	2.8.1	Build 2 Delivery	0 d	3/5/09	3/5/09
	3	**Spacecraft Bus**	**562 d**	**1/29/09**	**3/30/11**
	3.1	**Attitude Determination & Control Subsystem (ADCS)**	**341 d**	**3/2/09**	**7/1/10**
	3.1.2	**ADCS Simulator development (non-recurring effort)**	**0 d**	**3/2/09**	**3/2/09**
3166	3.1.2	G&C Sim Version 1 complete (internal delivery)	0 d	3/2/09	3/2/09
	3.1.3	**ADCS Flight Sun Sensors their test equipment (recurring cost)**	**92 d**	**10/29/09**	**3/12/10**
3228	3.1.3	Engineering model Sun sensor HW delivered to APL for interface testing	0 d	10/29/09	10/29/09
3229	3.1.3	Sun sensor HW delivered to APL - flight units & stimulators/GSE	0 d	3/12/10	3/12/10
	3.1.5	**ADCS Subsystem Inetgration and Test (recurring cost)**	**0 d**	**7/1/10**	**7/1/10**
3253	3.1.5	Delivery of G&C Sun Sensors to I&T	0 d	7/1/10	7/1/10

Figure 4-8. The figure shows an example of a generic Milestone Registry maintained within the IMS and filtered using field codes.

4.3.1.2.4 Identify the Activity Attributes

It is a best practice for activity attributes to be identified appropriate to the type and level of schedule development and integrated PP&C management that the P/p necessitates. Once all requirements as described in the above sections are collected, the necessary *Activity Attributes* can be identified. These attributes are setup as data fields in the scheduling software to facilitate the coding of activities in the *IMS*. The field codes are can then be used to develop *Schedule Database* and check the inputs to verify that they produce the appropriate *Schedule Outputs*. They also provide the interface needed between the *IMS* and other P/p management processes. For example, the *IMS* forms the backbone of EVM, so it is critical that the schedule is setup and maintained in a way that supports EVM processes and tools. Certain fields within the scheduling tool must match the data fields contained in the EVM tool(s) in order for the data to transfer properly. It is very difficult and inefficient to make data field assignments after the fact. A typical example is trying to find empty fields for *SRA* inputs (e.g., software add-ons for MS Project) after the schedule tool is already populated and in service. Figure 4-9 illustrates the sources for requirements for identification of activity attributes.

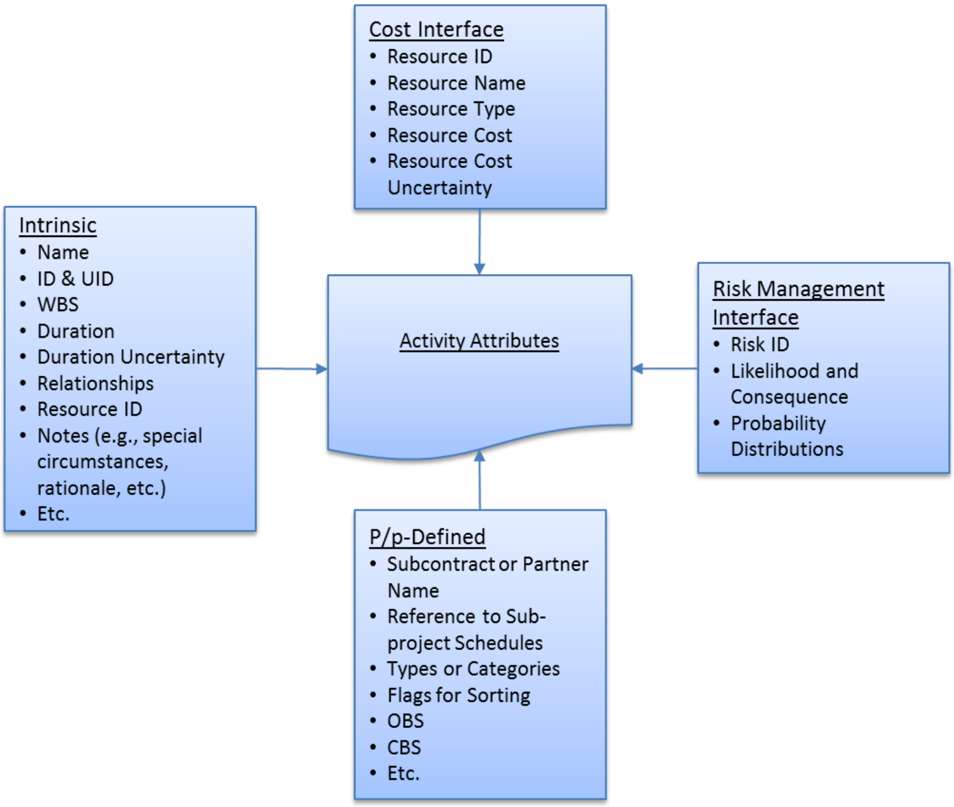


Figure 4-9. All necessary Activity Attributes must be identified in order to allocate activity data to fields in the IMS.

Cost interface attributes are those that relate the activity to the cost estimates (e.g., Resource Name, Resource Type, Resource Uncertainty Distribution and parameters, etc.). Risk Management Interface attributes are those that relate to the Risk Management Process (e.g., risk likelihood and impact probability distribution). P/p-defined attributes are special attributes that the P/p may assign such as the name of a contract, a reference field to a sub-project schedule, a type field for different categories of P/p elements or flags for sorting. Intrinsic attributes are those specific to the activity itself (e.g., WBS, OBS, CBS/CAM, uncertainty distribution, etc.). Most scheduling software has default fields for many of the intrinsic attributes.

Establishing all of the *Activity Attributes* during Schedule Management Planning facilitates the construction of the *Schedule BoE* by defining the data required for the activities. For example, activity uncertainty parameters need to be captured in the *Schedule BoE* and should therefore be defined as part of the *Activity Attributes*.

4.3.1.3 For Inclusion in the SMP

The *Schedule Development Plan* portion of the *SMP* may be developed as a separate sub-plan allowing early implementation to support Phase A execution. When the collection of all requirements for Schedule Development is completed, compile the requirements for inclusion in the *Schedule Development Plan*. Construct the *Milestone Registry* for inclusion as an appendix. The *Milestone Registry* contains all the notification and control milestones as derived from P/p, Agency, and organizational needs as well as those that are interfaces with contracted efforts and partnerships. The construction of the _IMS_ must be compliant with the _Milestone Registry,_ and routine reporting as well as risk assessment reporting should address the milestones.

After collection of the requirements for the attributes for the activities, construct the table of _Activity Attributes_ for inclusion in the _Schedule Development Plan_ as an appendix. The table of _Activity Attributes_ is used to develop the _IMS_ by defining the required fields for the _Schedule Database_.

At this point in the planning process, most specifications are available for building the _IMS_. A schedule tool has been selected for logically linking the activities and exporting and displaying the schedule information. A make/buy plan is available, and a schedule of development and deployment activities is available. An estimate of the resources and skill level needed for development of the _IMS_ should be included in this section of the _SMP_. Resources for maintenance should not be included in the development section of the _SMP_, as they are included in the section on Schedule Maintenance.

4.3.2 Create the Assessment and Analysis Plan

Schedule Assessment is focused on the quality of the _IMS_. It consists of a suite of techniques used to determine the compliance to requirements and sets of best practices. Schedule Analysis is the process used to understand the projected future performance of the planned schedule given the uncertainty and risk associated with the P/p. The analyses are routinely performed to ensure that cost and schedule commitments can be met with acceptable risk and are required by NPR 7120.5 at specific review milestones and that sufficient schedule margin is available for accommodating risks and uncertainties.

In creating the _Schedule Assessment and Analysis Plan_, all requirements needed to define the processes for Assessment and Analysis are collected. The requirements collected, and _Activity Attributes_ previously identified in the _Schedule Development Plan_ will also aid in the implementation of the Schedule Assessment and Analysis sub-functions. Best practices for Schedule Assessment and Schedule Analysis are captured in Chapter 6 and should be considered for incorporation in the _Schedule Assessment and Analysis Plan_.

4.3.2.1 Collect the Requirements for Schedule Assessment

The purpose of the Schedule Assessment sub-function is to test the information contained in the _Schedule Database_ and its outputs for validity and integrity. As shown in Figure 4-10, requirements for Schedule Assessment come from NPRs, internal and external guidance documents, and the P/p planning documents.

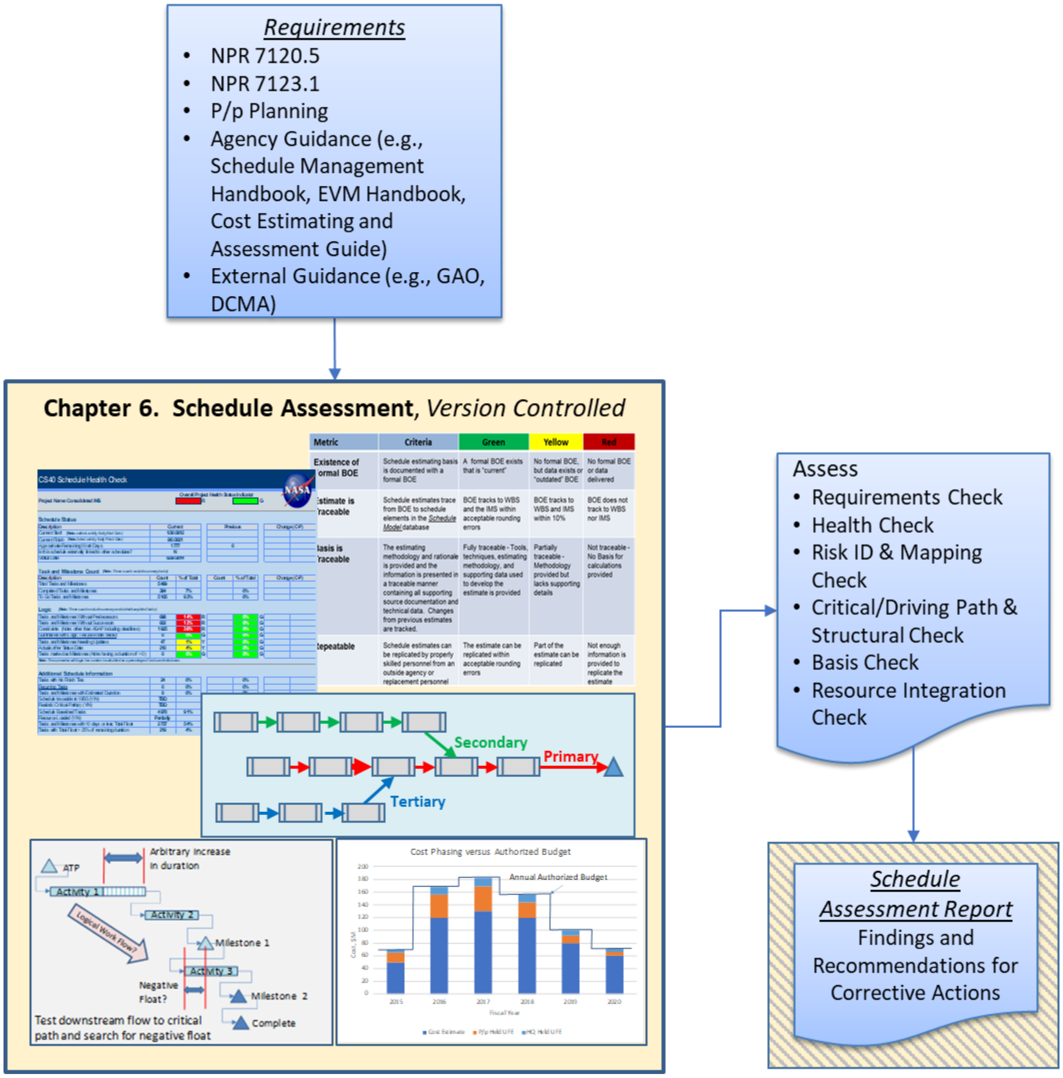


Figure 4-10. Requirements for the Schedule Assessment sub-function come from the NPRs, guidebooks, and P/p planning.

Typical procedures for this sub-function include:

- **Requirements Check.** Assesses the schedule's compliance with Agency and P/p requirements.
- **Health Check.** Assesses the schedule's overall integrity by gauging its health aligning with various general best practice categories.
- **Risk ID & Mapping Check.** Assess the existence and comprehensiveness of P/p schedule risks and their placement within the schedule's structure.
- **Critical/Driving Path and Structural Check.** Assesses the structural quality & fidelity of all possible critical paths and driving paths and compliance with horizontal tractability standards. Depends upon a satisfactory Health Check.
- **Basis Check.** Assesses the justification of each discrete schedule element, including risks. Depends, in part, upon a satisfactory Risk ID & Mapping Check.

- **Resource Integration Check.** Affirms that P/p's budget, workforce, and cost estimates at any point in the P/p life cycle map to the corresponding IMS.

When planning the tools and techniques for the quality assessment of the schedule, they must be able to support the Schedule Assessment sub-function per P/p requirements. These may include forms, formats, check lists, and a make/buy plan for software tools.

4.3.2.2 Collect the Requirements for Schedule Analysis

The purpose of the Schedule Analysis sub-function is to evaluate the magnitude, impact, and significance of P/p uncertainties and risks. As shown in Figure 4-11, requirements for Schedule Analysis come from two primary sources, NPRs and the P/p planning documents.

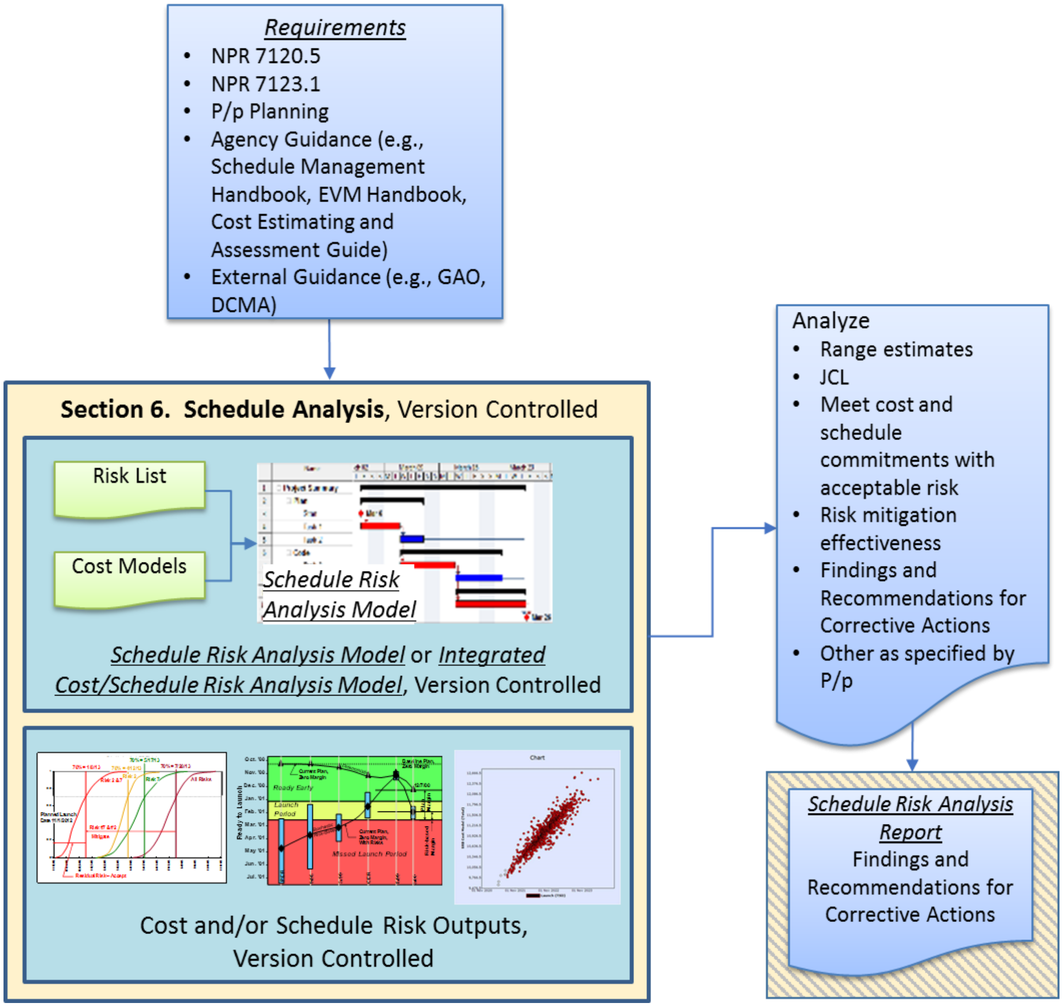


Figure 4-11. Requirements for the Schedule Analysis sub-function come from the NPRs, guidebooks, and P/p planning.

NPR 7120.5 requires risk-informed schedule completion range estimates at P/p milestones as early as MCR. This requirement can be met through use of an *SRA* to establish the expected range of completion dates according to P/p-identified confidence levels. NPR 7120.5 also requires a *JCL* estimate at KDP C. The *JCL* requirement necessitates the use of a cost-loaded schedule with both cost and schedule risks and uncertainties loaded into an *Integrated Cost and Schedule Risk Analysis Model* (*ICSRA Model)*. NPR 7123.1 specifies a success criterion of ensuring that cost and schedule commitments can be met with acceptable risk at subsequent milestones.

In addition, the P/p may levy requirements to have an *SRA* or an *ICSRA* performed for the following reasons:

- As support to the establishment of the baseline
- At specified milestones in preparation for LCRs
- At regular intervals for tracking risk-based estimates-at-completion
- As specified to support risk mitigation planning
- As support to development of the schedule to ensure sufficient schedule margin

The above requirements will specify the type of analyses and the trigger(s) and frequency of those analyses. Other requirements are needed to specify the analysis tool and the expected outputs. Some scheduling software include a schedule risk analysis package or can accommodate schedule risk analysis add-ons. Examples of schedule risk analysis tools are JACS, Polaris, Primavera Risk Analysis, @Risk, and Full Monte.

Whether the complete *IMS* or an *Analysis Schedule* is used as the basis for the *SRA* or the *ICSRA*, it will need to interface with the risk management data and the cost data.[26] Techniques for integration of schedule, cost, and risk must be specified as a part of the planning process. This needs to be done to determine whether there are additional requirements to make/buy application software to link the databases within the tools. This collection of requirements is used to develop the analysis capability and facilitate the allocation of resources to execute the analyses.

The expected outputs of the *SRA* or the *ICSRA* need to be defined, and tools to process the data and create the reports will need to be specified. Then a make/buy plan needs to be created and included as a part of the *SMP*. Examples of outputs that need to be considered are:

- Confidence level curves and data tables
- Probability density functions (PDFs) and data tables
- Scatterplots and data tables
- Risk and task sensitivity indicators such as tornado charts
- Risk trends over time

---

[26] The NASA Project Planning and Control (PP&C) Handbook discusses the interfaces between the Schedule Management Function and other PP&C functions. See SP-2016-3424. September 16, 2016.

Upon completion of this task, all information is available for development of the analysis capability and the reporting formats, scheduling the analyses (e.g., frequency), and allocating resources for the analysis.

4.3.2.3 For Inclusion in the SMP

Compile the requirements for types of assessments and analyses and include them in the *SMP*. Include a table to illustrate when specific assessments and analyses are performed in support of P/p review milestones or P/p internal activities. In addition, include an estimate of the resources and skills needed to support assessment and analysis efforts throughout the P/p life cycle.

4.3.3 Create the Schedule Maintenance and Control Plan

Schedule Maintenance and Control helps to ensure that the schedule is at the appropriate maturity throughout the P/p lifecycle and that it can be used to actively manage the P/p. The *Schedule Maintenance and Control Plan* captures the requirements for updating and controlling the schedule throughout the lifecycle. This includes the performance metrics to be collected periodically and the associated thresholds for action. The information is solicited from the activity owners or from CAMs that may own several activities or groups of activities. If the P/p has an active EVM system, then the EVM data can be used. Even if the P/p is not subject to the requirement to have a formal EVM process in place, the scheduling tool can output the same cost and schedule performance parameters.

NPR 7120.5 requires a Technical, Schedule and Cost Control (TSC) Plan. The Schedule portion of the TSC Plan captures the requirements that support the development and implementation of the schedule control and may be a stand-alone document, part of the P/p Plan, or captured in the Schedule Maintenance and Control section of the *SMP*. Best Practices for Schedule Maintenance and Control are captured in Chapter 7 and should be considered for incorporation in the *Schedule Maintenance and Control Plan*.

4.3.3.1 Collect the Requirements for the Schedule Maintenance Sub-Function

The Schedule Maintenance sub-function consists of loading the current performance information into the *IMS* and making changes as directed through the CM/DM change order process. The performance information is usually a monthly update process to support the P/p monthly and quarterly management review cycle. Change orders, however, are on-demand rather than routine and may originate for the following reasons:

- General updates to activities, e.g. detail for a rolling wave
- Changes imposed through requirements contained in the PPBE guidance
- Corrective actions originating from the performance control processes
- Inclusion of risk mitigation activities as approved by the P/p

Figure 4-12 illustrates the process for Schedule Maintenance.

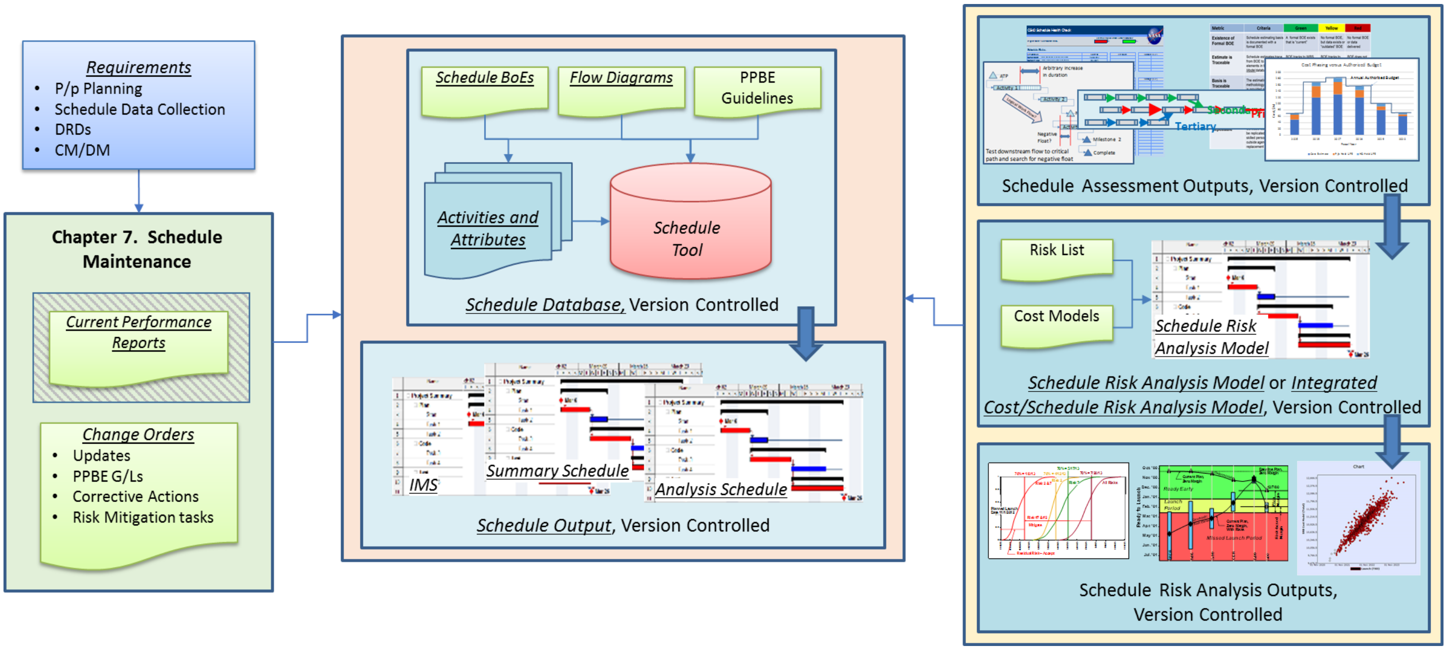


Figure 4-12. The P/p must define the requirements for Schedule Maintenance to update the schedule. A typical process is shown here.

4.3.3.2 Collect the Requirements for the Schedule Control Sub-Function

Collecting the requirements for the Schedule Control sub-function includes defining the metrics and measures for schedule performance measurement. Some are backwards looking, meaning they are measures of performance to date. Others are forward looking using the SRA capability to make future estimates of performance. Backwards-looking examples are:

- Baseline Execution Index, or Current Execution Index
- Schedule Performance Index
- Erosion of float or margin
- Number of milestones due versus milestones completed

Examples of forward-looking measures using the SRA are:

- Probability of on-time delivery of selected deliverables
- Probability of on-time completion
- Sufficiency of margin

Figure 4-13 illustrates the process for Schedule Control.

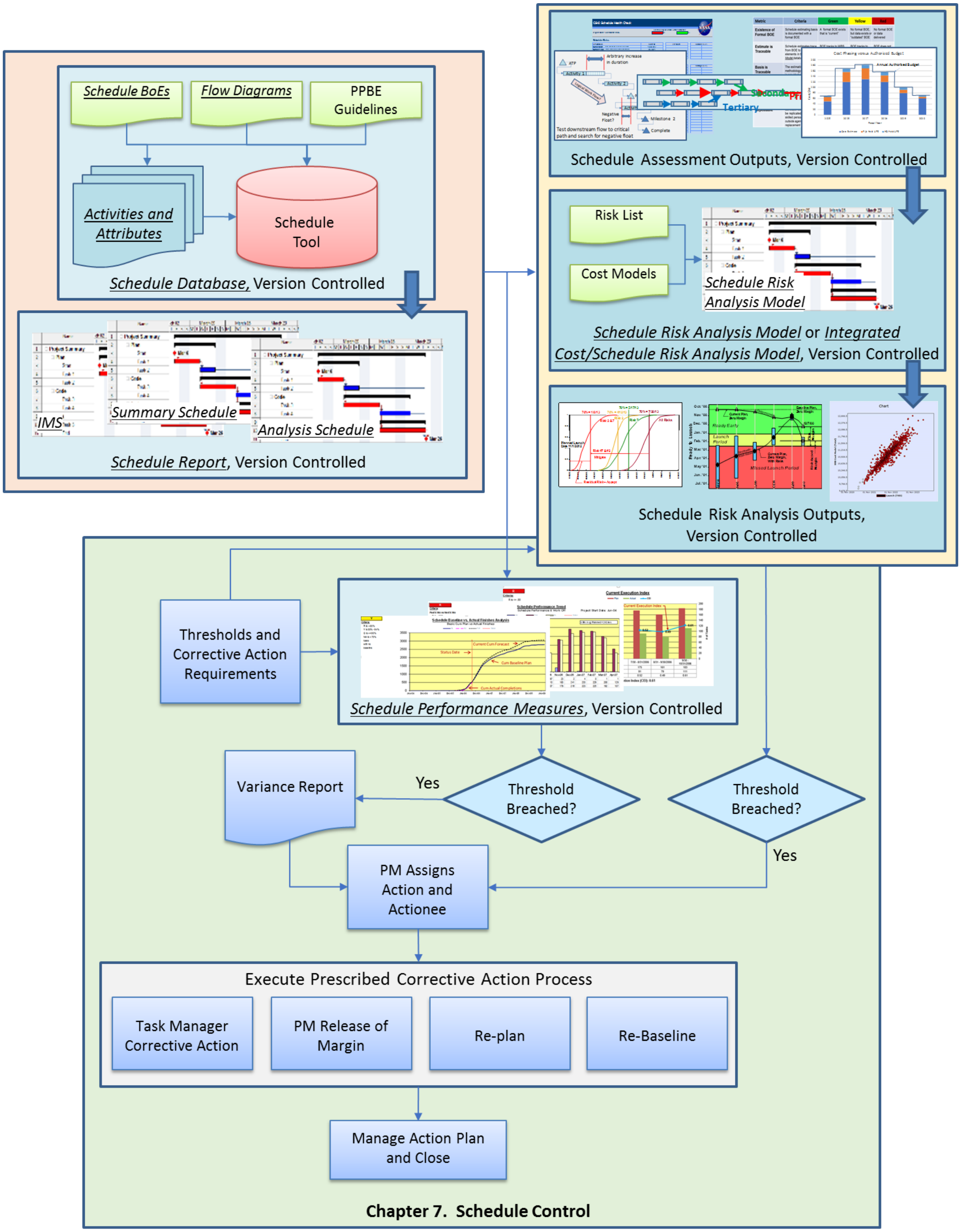


Figure 4-13. The P/p must define the requirements for Schedule Control. A typical process is shown here.

It is important to note that any integrated, technical/schedule/cost control aspects are required to be included in a Technical, Schedule, and Cost (TSC) Control Plan per NPR 7120.5. The Schedule Control section of the *SMP* should support and be consistent with the content in the TSC Control Plan. The NPR should be referenced for the complete set of requirements for the TSC Control Plan, which includes documenting how the P/p plans to control requirements, technical design, schedule, and cost to achieve its high-level requirements. The TSC Control Plan will:

- Describe the plan to monitor and control the requirements, technical design, schedule, and cost of the P/p.
- Describe the P/p's *Schedule Performance Measures* in objective, quantifiable, and measurable terms and document how the measures are traced from the program high-level requirements.
- Establish baseline and threshold values for the performance metrics to be achieved at each Key Decision Point (KDP), as appropriate. In addition, document the mission success criteria associated with the P/p-level requirements that, if not met, trigger consideration of a Termination Review.
- Develop and maintain the status of a set of programmatic and technical leading indicators to ensure proper progress and management of the P/p. These include:
    - Requirement Trends (percent growth, to-be-determined/to-be-resolved (TBD/TBR) closures, number of requirement changes)
    - Interface Trends (percent Interface Control Document (ICD) approval, TBD/TBR burndown, number of interface requirement changes)
    - Verification Trends (closure burndown, number of deviations/waivers approved/open)
    - Review Trends (Review Item Discrepancy (RID)/Request for Action (RFA)/Action Item burndown per review)
    - Software Unique Trends (number of requirements per build/release versus plan)
    - Problem Report/Discrepancy Report Trends (number open, number closed)
    - Cost Trends (Plan, actual, UFE, EVM, NOA)
    - Schedule Trends (critical path slack/float, critical milestone dates)
    - Staffing Trends (Full-time equivalent (FTE)/work year equivalent (WYE)
    - Technical Performance Measures (Mass margin, power margin)
    - Additional P/p-specific indicators, as needed
- Describe the approach to monitor and control the P/p's ABC. Describe how the P/p will periodically report performance. Describe mitigation approach if the P/p is exceeding the development cost documented in the ABC to enable corrective action prior to triggering the 30 percent breach threshold. Describe how the P/p will support a baseline review in the event the Decision Authority (DA) directs one.

- For loosely coupled or uncoupled programs, describe the EVM requirements flowed down to the projects. For tightly coupled programs, single-project programs, and projects, describe the EVMS. Include references to the EVM Implementation Plan, a control plan that may be stand-alone or included as part of the P/p Plan, which details the P/p's processes for establishing, monitoring, and controlling the *IMS* and utilizing the technical and schedule margins and UFE to meet the management and commitment baselines, as well as the methods the P/p will use to communicate changes for the schedule.
- Describe any additional specific tools the P/p will use to implement the control processes (e.g., the requirements management system, the information management systems, Integrated P/p Management Reports (IPMR), etc.).
- Describe how the P/p will monitor and control the *IMS*, including any replanning techniques available.
- Describe how the P/p will utilize its technical and schedule margins and Unallocated Future Expense (UFE) to control the Management Agreement and external commitment baselines.
- Describe how the P/p plans to report technical, schedule, and cost status to the MDAA, including frequency and the level of detail.
- Describe how the P/p will address technical waivers and deviations and how dissenting opinions will be handled.

4.3.3.3 For Inclusion in the SMP

Compile the requirements for the Schedule Maintenance and Control sub-functions, including a description of the maintenance and control processes, integrated with the routine P/p review processes and the schedule management CM/DM process. Select the desired *Schedule Performance Measures* and build the processes and tools needed to import data from the *Schedule Database*. Identify the required plots. Define the thresholds that trigger corrective action and prescribe the corrective action for the different cases of breach. In addition, include an estimate of the resources and skill level needed for building the capability and executing the processes throughout the P/p life cycle.

4.3.4 Create the Schedule Documentation and Communication Plan

The P/p must establish the needs for schedule reporting and schedule performance metrics such that the requirements for the schedule outputs can be established. The *Schedule Documentation and Communication Plan* captures the requirements for when and how the P/p records and disseminates schedule information. Schedule Documentation and Communication are reliant upon Configuration and Data Management (CM/DM) and facilitate subsequent management and control of content change, as well as reporting. Best practices for Schedule Documentation and Communication are captured in Chapter 8 and should be considered for incorporation in the *Schedule Documentation and Communication Plan*.

4.3.4.1 Collect the Requirements for the Schedule Documentation and Communication Plan

The requirements for the CM/DM of the schedule management plans, processes, and products are derived from the P/p overall CM/DM plan. The data and products to be managed are identified in Figure 4-14 below.

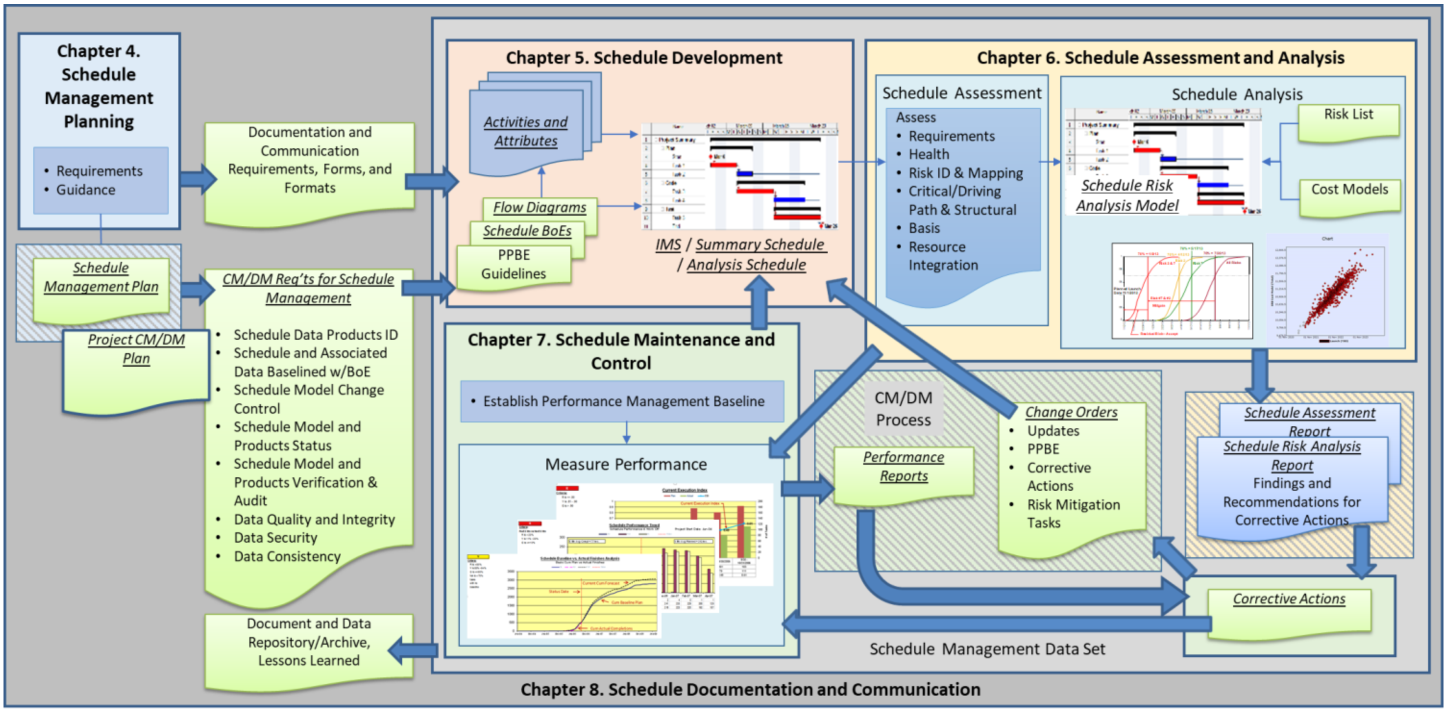


Figure 4-14. The documentation and data to be managed by the CM/DM process is identified here.

The documentation and data to be managed and controlled consist of at least, but not limited to, informal backups and formal archives of the following:

- *SMP*
- *Schedule Database*, including its data inputs and the *Schedule BoE*
- *Schedule Outputs*, including but not limited to, the *IMS*, *Summary Schedule*, and *Analysis Schedule*
- *Schedule Assessment Outputs/Report* and *Schedule Risk Analysis Outputs/Report*
- *Schedule Performance Reports* and *Corrective Actions/Baseline Change Requests*
- Lessons Learned

All data products must be clearly coded for consistency. For example, a performance report must be clearly tagged to a specific output from the *Schedule Database*, which is in-turn tagged to the current performance report that was used for the update. Another example is the different levels of Gantt charts; detail for internal management and high-level for external review. They must all be consistent and coded such that the relationship is clear.

All interested parties will specify the report types needed. Those requirements need to be collected and used to specify the processes and tools needed to generate the required data for those reports. This will further lead to the definition of forms and formats usually defined in Data Requirements Documents (DRDs).[27] Examples of report types can be found in Section 8.3.2.4.

Communication of schedule information varies with the audience. The audience must be identified and the appropriate information products, message type, delivery, and schedule for distribution defined to support internal P/p reviews, LCRs, and KDPs.

4.3.4.2 For Inclusion in the SMP

Compile the requirements for CM/DM and include a plan to develop and document the process specific to schedule data and information. Capture the requirements for the communication of schedule information, which include the defined communication flow and the frequency. Specify the data and report formats using DRDs and attach the DRDs as appendices to the *SMP*.[28] In addition, include an estimate of the resources needed to develop and maintain the processes throughout the P/p life cycle.

4.4 Skills and Competencies Required for Schedule Management Planning

The skills and competencies required for Schedule Management Planning can be found on the Scope website.[29]

5 Schedule Development

It is a best practice for the schedule to be developed in accordance with the Schedule Management Plan. Per Section 4.3, the Schedule Management Planning sub-function produces the *Schedule Management Plan*, which provides instructions for Schedule Development - to guide the development of the *IMS* and associated schedule products. Specifically, the *Schedule Development Plan*, the first of four sub-plans in the *SMP*, includes the definition of the tools and techniques appropriate to the type/level of scheduling the P/p necessitates. The objective of the Schedule Development process is to define, develop and deploy a scheduling capability, including the capability to display the P/p's time-phased activities in an *IMS* and to export specific outputs as required for the other Schedule Management sub-functions as described in Chapters 6, 7, and 8. When complete, the P/p will have a *Schedule Database* contained within a scheduling tool that has the capability to generate *Schedule Outputs*, including an *IMS* with all the required *Schedule Performance Measures* and associated *Schedule Performance Reports*, a *Summary Schedule* for management reporting, and an *Analysis Schedule* to be

---

[27] NASA has standard procedures in place to support the early development and documentation of operational concepts during system development. This includes Data Requirements Document (DRDs), which describe the format and content of the information to be provided, as well as the Data Requirements List (DRL), which set forth the data requirements in each DRD. https://www.nasa.gov/sites/default/files/files/NNK14MA74C-Attachment-J-02-Data-Requirement-Deliverables(1).pdf

[28] The Integrated Program Management Report (IPMR) Data Requirements Document (DRD) Implementation Guide discusses different options for tailoring the Data Item Description (DID), which describes overarching requirements. The IPMR is a consolidation of the Contract Performance Report (CPR) and the IMS and is required on all new contracts when an EVMS is a requirement. The IMS is Format 6 of the IPMR. See the NASA IPMR DRD Implementation Guide for preparation of the IPMR DRD, https://evm.nasa.gov/reports.html. Appendix D of the NASA Earned Value Management (EVM) Implementation Handbook provides guidance for the CPR DRD, https://evm.nasa.gov/handbooks.html. CPR Format 5 for IMS analysis can be found at https://evm.nasa.gov/reports.html.

[29] SCoPe website, https://community.max.gov/x/9rjRYg

used for the *SRA/ICSRA*. The Schedule Development sub-function will culminate with the creation of the *IMS*, which supports the requirement to baseline the *IMS*.

5.1 Best Practices

Figure 5-1 details the best practices for Schedule Management Development.

SM.D.1 Schedule Development Follows the SMP	• The schedule is developed in accordance with the Schedule Management Plan.
SM.D.2 Schedule BoE Provides Rationale for all Elements of the Schedule	• The Schedule Basis of Estimate (BoE) is created and maintained throughout the P/p's life cycle that documents basis rationale for all elements of the planned schedule, assessment and analysis findings, reporting artifacts, and primary source data, documents and other pertinent information.
SM.D.3 Schedule is Developed Using Appropriate Tools	• The schedule is developed using tools appropriate to the type and level of schedule management that the P/p requires.
SM.D.4 Schedule Activities are Coded to Facilitate P/p Management Support Processes/Functions	• The schedule is coded such that it facilitates P/p management support processes and other programmatic functions.
SM.D.5 Schedule is Developed Using Appropriate Scheduling Methods	• The schedule is developed using Critical Path Method Scheduling.
SM.D.6 Schedule is Tiered According to WBS	• Schedule activities are collected as organized in the WBS and tiered according to the lower-level, related WBS items.
SM.D.7 Schedule Naming Convention is Established	• A schedule activity naming convention is established that allows for clear, concise, and differentiable activities.
SM.D.8 Schedule Activities Capture All Work Scope Down to the Work Package Level	• Schedule activities capture all approved work scope, such that all work can be allocated to complete the WBS elements in an integrated manner.
SM.D.9 Schedule is Developed to Lowest Appropriate Level of Detail	• Schedule is developed to the lowest level of detail appropriate, typically the work package level, as early in the P/p life cycle as possible.
SM.D.10 Schedule Activities Demonstrate Horizontal Traceability	• Schedule activities demonstrate horizontal traceability, such that they are logically sequenced using proper relationship types that account for the interdependence of all activities and milestones.
SM.D.12 Schedule Activities Use Minimal Lead and Lag Relationships	• Schedule activities only use lead and lag relationships when the values represent real situations of needed acceleration or delay time between activities.
SM.D.13 Schedule Activities Limit the Use of Constraints	• Schedule logic limits the use of constraints other than "As Soon As Possible" to situations that represent actual work flow.

SM.D.14 Schedule Activities are Scheduled According to the Same Time Units	• All activity durations are scheduled according to the same time units.
SM.D.15 Schedule Activities are Represented According to Appropriate Calendars	• Activities are scheduled according to representative calendars that appropriately distinguish between working and non-working days.
SM.D.16 Schedule Activity Durations are Estimated Using Appropriate Sources / Processes	• Schedule activity durations, including associated duration uncertainties, are derived based on sources and/or processes that are appropriate and provide the best justification for their estimation.
SM.D.17 Adequate Schedule Margin is Identified as Part of the Schedule Baseline	• Adequate margin is established and allocated as part of the schedule baseline and is clearly identifiable.
SM.D.18 Cost and/or Resources are Assigned to Schedule Activities	• The schedule includes costs and/or resources assigned to all applicable activities at the most appropriate WBS level.
SM.D.19 Schedule is Time Phased	• The schedule is time-phased to align with the availability of funding to provide the earliest possible finish date.
SM.D.20 Discrete Risks are Mapped to the Schedule	• Discrete risks are quantified and mapped to appropriate activities within schedule.
SM.D.21 All Schedule Products Tie to the IMS	• The integrated master schedule (IMS) is the foundation for all schedule information.
SM.D.22 Schedule Demonstrates Vertical Traceability to the IMS at all Levels	• The schedule reflects vertical traceability in that any and all supporting schedules contain consistent information and can be traced to the IMS.

Figure 5-1. Schedule Development Best Practices.

5.2 Prerequisites

The Schedule Development can be initiated when:

- P/p Plans, including domain-related plans
- *SMP*, including schedule guidance and ground rules & assumptions (GR&As)
- Other P/p GR&A documents
- The *SMP* sub-plan, *Schedule Development Plan,* which specifies the requirements, implementation approach, and timeline for developing the *IMS*, is available
- The *Milestone Registry* is available
- The table of *Activity Attributes* is available
- A scheduling tool has been selected to facilitate the maintenance, documentation and control of the *IMS*

The *Schedule BoE* is typically documented in conjunction with the development of the *IMS*, with preliminary and baseline versions established when required and subsequent updates throughout the P/p life cycle, as necessary. The following sections guide the P/S through the Schedule Development process.

5.3 Understand the P/p Scope

An understanding of the complete P/p work content must exist in order for a valid schedule to be developed. Thus, the first steps in developing a new P/p *IMS* include understanding the P/p work scope, including the Work Breakdown Structure (WBS), the Organizational Breakdown Structure (OBS), the P/p funding dynamics and Cost Breakdown Structure (CBS), and reviewing pertinent P/p agreements and authorization documents. As more information becomes available as part of the P/p management processes, more detailed information can be utilized to aid in the development of the planned schedule.

5.3.1 Work Breakdown Structure (WBS)

The WBS is the "what" of P/p scope. It is a product-oriented, hierarchical division of the hardware, software, services, facilities, and other work activities that make up the total P/p scope of work. It organizes, displays, and defines the products to be developed and/or produced and relates the elements of the work to be accomplished to each other and the end products. The WBS also decomposes the scope of work into manageable segments to facilitate planning and control of cost, schedule, and technical content. The WBS is typically accompanied by a WBS Dictionary, which is a narrative definition of each element appearing on the WBS. The WBS Dictionary describes the work content of each WBS element in product-oriented terms and relates each element to the respective, progressively higher levels of the structure.

A clear understanding of the work content is necessary before a valid schedule can be developed. The P/p work scope may be captured in the P/p Plan or in a collection of other P/p documents (e.g., Acquisition Plan, Verification Plan, Request for Proposal, Statement of Work (SOW)/contracts, other external agreements, including international partnership agreement, including MOUs, MOAs, etc.). P/p scope may include information gleaned from mission concepts, trade studies, system requirements, test and verification requirements, safety requirements, hardware and software specifications, system design, interface design, tooling requirements/design, manufacturing standards, unique P/p ground rules and assumptions (GR&As), known risks, etc. These inputs should be clearly articulated by the technical team and incorporated into the WBS and WBS Dictionary. The WBS will cover all work elements identified in the approved P/p scope of work, including both in-house and contracted efforts. A trace between P/p Plans, agreements, and other P/p documentation helps to ensure that all work is captured in the WBS.

Since a WBS plays such a critical role in organizing and managing a P/p, it is important to know what attributes are involved in a sound WBS document. Listed below are several key characteristics generally found in a complete and meaningful P/p WBS document:

- Predominantly product-oriented
- Uses correct standard level two WBS template (from NPR 7120.5 and NPR 7120.8)
- Sub-divided elements are logical, hierarchical, and easy to understand

- Consistent with NASA Structure Management (NSM) coding
- Includes total P/p scope of work (including contractor effort)
- Allows for work summarization at each level
- Subdivision of work (hierarchy) is aligned with system architecture (e.g., system, subsystem, component)
- Reflects element integration and relationships

A good WBS defines the effort in measurable elements that provide the means for integrating and assessing technical, schedule, and cost performance. Care should be taken to validate that the total P/p scope of work is included in the WBS prior to establishing the schedule baseline. If work is not included in the WBS/WBS Dictionary that has been approved by P/p management, then it should not be included within the *IMS*. The structure and format of the schedule should closely correlate to the approved WBS to ensure traceability and consistency in reporting. This is accomplished by including within the *IMS* the correct WBS code that is associated with each schedule task for all applicable elements, such as hardware, software, test facilities, logistical subsystems, subcontracts, international contributions, and support systems. Task definition begins with the product-oriented WBS, extending and detailing the WBS down to discrete and measurable tasks.

In addition to providing a framework for planning, the WBS becomes very important to the P/S by allowing various reporting data to be selected, sorted, and summarized to meet the analysis and forecasting needs of P/p management and to aid in Schedule (and cost) Control. For P/ps with contractor support, the contractors are typically required to extend approved Contractor WBS (CWBS) elements to the necessary level of detail. It should be noted that while the Agency Core Financial System is currently limited to seven WBS levels for capturing actual P/p costs, a P/p's technical WBS and schedule can further extend to lower levels to ensure that work definition and progress insight is sufficient for proper management. NPR 7120.5 and NPR 7120.8 outline WBS structures for space flight programs and research and technology programs, respectively, and should be used as guidance on creating WBSs for these types of P/ps. The NASA WBS Handbook provides additional examples that can be tailored for most P/ps.[30] Starting with the approved WBS will not only help ensure that the total scope of work is included in the schedule, but also will ensure consistency in the integration of cost and schedule data.

Figure 5-2 provides an example of a product-oriented WBS with recommended development guidance highlighted.

---

[30] NASA/SP-2010-3404/REV1. NASA Work Breakdown Structure Handbook. October 2016. https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20160014629.pdf

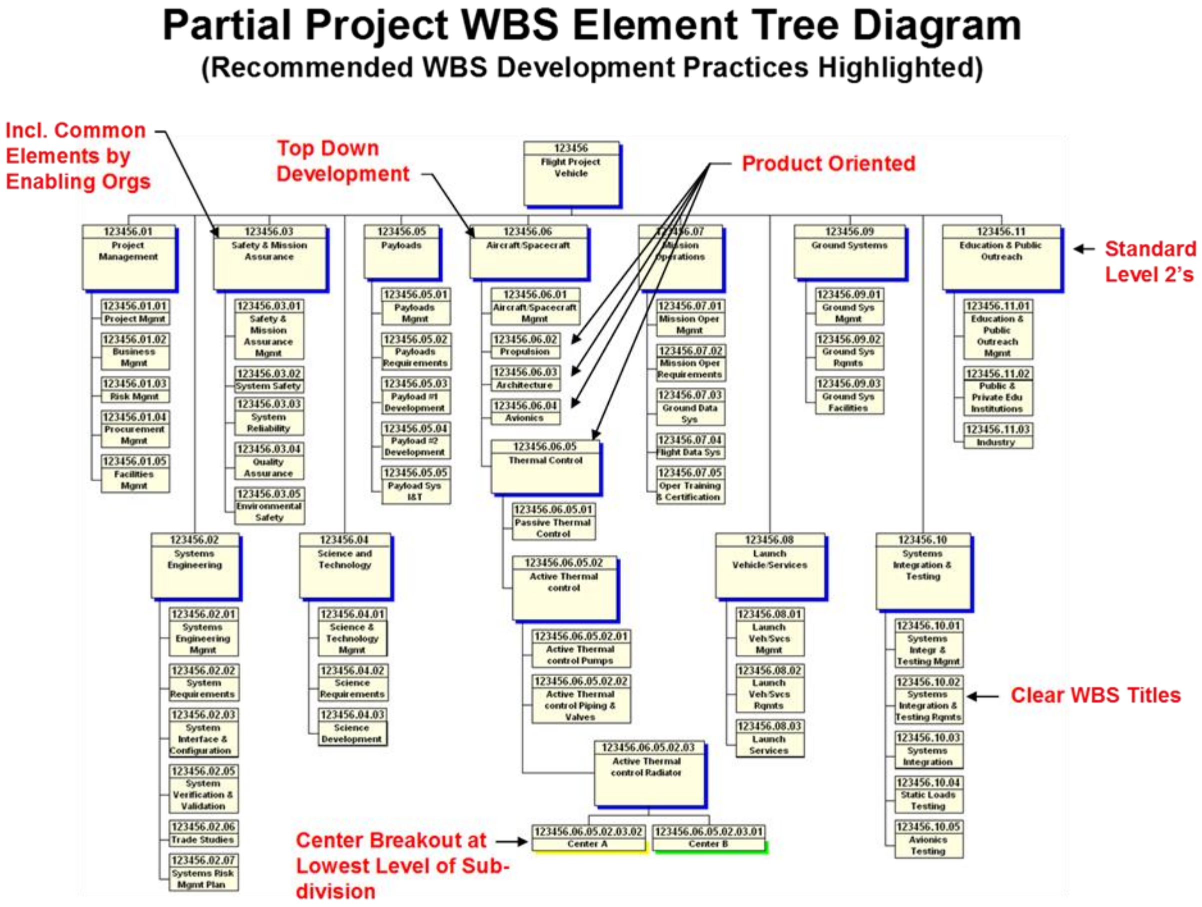


Figure 5-2. Product-oriented Work Breakdown Structure (WBS) example.

5.3.2 Integrated Master Plan (IMP)

Although not typically a NASA-developed product, in some instances, a contractor may use an Integrated Master Plan (IMP) in conjunction with the WBS to aid in the development of its *IMS*. The IMP is an event-based, top-level plan consisting of a hierarchy of P/p events, as shown in Figure 5-3. Each key P/p event is decomposed into specific accomplishments, and each specific accomplishment is decomposed into specific criteria.[31]

---

[31] http://acqnotes.com/acqnote/careerfields/integrated-master-plan

IMP Level	Activity #	Task Name	WBS Reference
Event	A	Event A - Integrated Baseline Review/PDR (IBR/PDR)	-
Accomplishment	A01	Management Planning Reviewed	-
Criteria	A01a	Program Organization Established	1.2.1
Criteria	A01b	Initial Configuration Management Planning Completed	1.2.2
Criteria	A01c	Initial Integrated Master Schedule Reviewed	1.2.1
Criteria	A01d	Risk Management Plan Reviewed	1.2.1
Accomplishment	A02	Baseline Design Reviewed	-
Criteria	A02a	Requirements Baseline Completed	1.3.1
Criteria	A02b	Review of Existing Baseline Engineering Drawings Completed	1.1.1
Accomplishment	A03	IBR Conducted	-
Criteria	A03a	IBR Meeting Conducted	1.2.1
Criteria	A03b	IBR Minutes and Action Items Generated	1.2.1
Accomplishment	A04	PDR Conducted	-
Criteria	A03c	PDR Meeting Conducted	1.3.2
Criteria	A03d	PDR Minutes and Action Items Generated	1.3.2
Event	B	Event B - Critical Design Review (CDR)	-
Accomplishment	B01	Design Definition Completed	-
Criteria	B01a	Design Deltas to Baseline Identified	1.1.1, 1.3.1
Criteria	B01b	Drawings Completed (Baseline & Delta)	1.3.1
Accomplishment	B02	System Performance Assessment	-
Criteria	B02a	Updated Drawings and Specifications Reviewed	1.3.1
Criteria	B02b	Analysis Results Reviewed	1.3.2
Criteria	B02c	Test Results Reviewed	1.3.2
Accomplishment	B03	Mission Performance Predictions Reviewed	-
Criteria	B03a	Analysis Results Reviewed	1.3.2
Criteria	B03b	Test Results Reviewed	1.3.2
Accomplishment	B04	Payload Integration Plan Reviewed	-
Criteria	B04a	Payload Design Reviewed at the System Level	1.3.3
Criteria	B04b	Payload Testing (Component, Functional, Static) Reviewed	1.3.5
Criteria	B04c	Safety and Failure Analysis Reviewed	1.3.2
Accomplishment	B05	Initial Test Plan Reviewed	-
Criteria	B05a	Initial Test Schedule Reviewed	1.2.1
Criteria	B05b	Initial Test Requirements Reviewed	1.2.2
Accomplishment	B06	Critical Design Review (CDR) Conducted	-
Criteria	B06a	IBR/PDR Minutes and Action Item Closure Plan Finalized	1.2.2
Criteria	B06b	CDR Meeting Conducted	1.3.2
Criteria	B06c	CDR Minutes and Actions Genearated	1.3.2

Figure 5-3. Integrated Master Plan (IMP) example.

The IMP provides a PM with a systematic approach to planning, scheduling and execution.[32] Both the IMP and the *IMS* form the foundations for the implementation of the EVMS. The IMP should provide sufficient definition to allow for tracking the completion of required accomplishments for each event and to demonstrate satisfaction of the completion criteria for each accomplishment. In addition, the IMP demonstrates the maturation of the development of the product as it progresses through a

---

[32] The Integrated Program Management Report (IPMR) Data Requirements Document (DRD) Implementation Guide states, "IPMR DRD shall be integrated with the Contract Work Breakdown Structure (CWBS), the Integrated Master Plan (IMP) if applicable, Integrated Master Schedule (IMS), Risk Management Processes, Plans and Reports (where required), Probabilistic Risk Assessment Processes and Reports (where required), the Cost Analysis Data Requirement (CADRe) and the Monthly/Quarterly Contractor Financial Management Reports (533M/Q)." See the NASA IPMR DRD Implementation Guide for preparation of the IPMR DRD, https://evm.nasa.gov/reports.html.

disciplined systems engineering process. The IMP events are not tied to calendar dates; each event is completed when its supporting accomplishments are completed and when this is evidenced by the satisfaction of the criteria supporting each of those accomplishments. The IMP is generally contractually binding and becomes the baseline execution plan for the P/p. Although fairly detailed, the IMP is a relatively top-level document in comparison with the *IMS*. The *IMS* relates to the IMP in that it shows all the detailed tasks required to accomplish the work effort contained in the IMP in a time-based network of activities. Thus, the IMP outline code should be traceable to both the WBS and the *IMS* with all tasks containing an appropriate IMP assignment, if/when applicable.

The IMP and *IMS* are valuable tools a PM can use in preparing for a Request for Proposal (RFP) and Source Selection because they serve as the basis of an offeror's proposal and evaluation criteria. The IMP and *IMS* should clearly demonstrate that the P/p is structured and executable within schedule and cost constraints and with an acceptable level of risk. Thus, both the IMP and *IMS* are key ingredients in P/p planning, proposal evaluation, source selection, and program execution.[33] However, the IMP is not a NASA-required product.

5.3.3 Organizational Breakdown Structure (OBS)

The OBS is the "who" of P/p scope. It is the hierarchical division of the organization structure that defines who performs the work. Many P/ps require resources from more than one organization or department. The use of a P/p OBS helps to identify the responsibilities, hierarchy, and interfaces between these organizations. An OBS may be established regardless of whether the organization is structured by function, Integrated Product Teams (IPT), or by matrix assignment. An OBS, if used, should reflect the organizational responsibilities as they pertain to the P/p. This may or may not differ from the functional organizational hierarchy. One example of an OBS is shown in Figure 5-4.

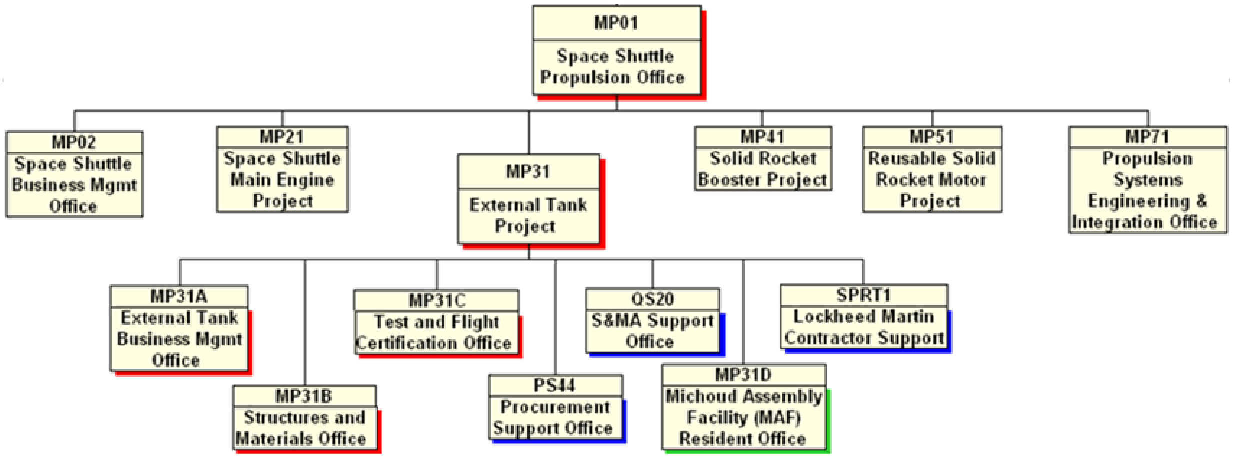


Figure 5-4. Organizational Breakdown Structure (OBS) example.

---

[33] Department of Defense. Integrated Master Plan and Integrated Master Schedule Preparation and User Guide. Version 0.9. October 21, 2005. http://acqnotes.com/acqnote/careerfields/integrated-master-plan.

The OBS also identifies the resources available to assign to work activities and to resource load the schedule. When combined with the WBS, the OBS is used to develop a responsibilities assignment matrix (RAM), which clearly identifies which organization is responsible for each task in the schedule as shown in Figure 5-5. RAMs are typically used to identify control accounts, which are described in the following section, in support of the EVMS.

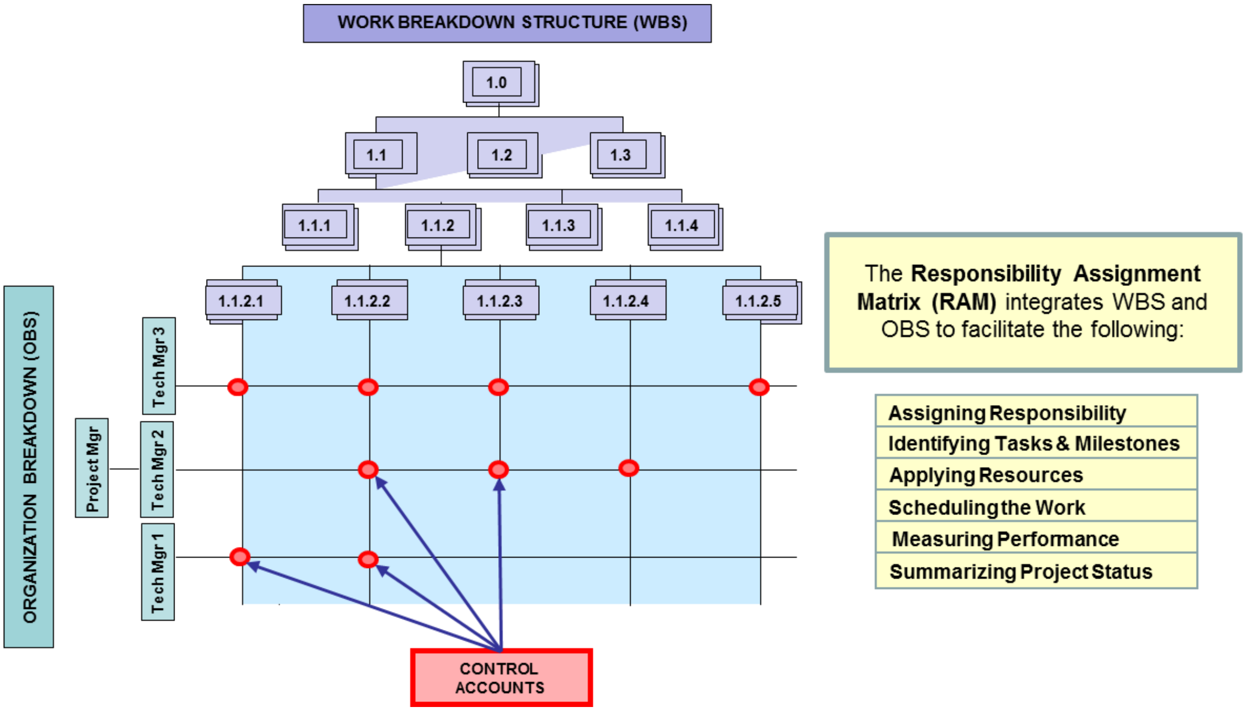


Figure 5-5. Responsibility Assignment Matrix (RAM) example.

5.3.4 Cost Breakdown Structure (CBS)

The Cost Breakdown Structure (CBS), also sometimes referred to as the Resource Breakdown Structure (RBS), is the “how much” of P/p scope. It is the hierarchical structure that classifies resources into control accounts. At the highest level, these are labor, travel, materials, equipment, and other direct and indirect costs. As shown in Figure 5-5, the intersection of the OBS and the WBS defines the control account. A control account is a natural management point for planning and control since it represents the work assigned to one responsible organizational element (or integrated product team) for a single WBS element. A control account is also the point at which budgets (resource plans) and actual costs are accumulated and compared to earned value for management control purposes. The person accountable for planning and managing the resources authorized to accomplish the work effort in the control account is the Control Account Manager (CAM). The CAM is usually responsible for the creation, status, and maintenance of the schedule activities within the control account. Establishing the control accounts helps to ensure that no duplication of responsibility occurs, and it lies the foundation for fully integrating all aspects of P/p planning, including scope, schedule, budget, work authorization, and cost accumulation processes in support of the EVMS.

Typically for NASA P/ps, the WBS is the primary source for development of the CBS, with each control account being consistent with a work package or detailed task.[34] If composed with cost information, a WBS may serve directly as a CBS. Otherwise, it may be loaded with cost information attributed to its respective elements to create the CBS. A resource- or cost-loaded schedule can be used as a tool that yields insight and assistance to the P/p management team in their management of weekly and monthly "resource" allocations. It assists the P/p with the on-going evolution of P/p budget estimates that satisfy various Agency, program, and P/p budget development needs. For example, cost loading ensures the P/p has a complete and consistent performance baseline (or formal PMB, if applicable) that includes integrated cost and schedule for all elements of the Work Breakdown Structure (WBS). Because it is not uncommon for the cost-estimating tool and the *IMS* to differ in WBS at lower-levels, it may be necessary to roll-up, or otherwise adjust, the cost estimate in order to align the WBS levels in both tools. When cost and schedule are developed jointly, cost loading verifies alignment at the lowest level of the cost WBS (schedule WBS is likely at a much lower level). The integration of programmatic (cost, schedule, risk) and technical elements provides a better understanding of how programmatics are interrelated. For example, the dependencies between cost increases associated with schedule slips (due to potential risks, poor performance, uncertainty, or any other constraint) or possibly even cost decreases with schedule duration reductions (opportunity, risk mitigation, additional funding, etc.) represent how an overall plan may be affected by changes in any element. Additional information on Resource and Cost Loading can be found in Section 5.5.12. Additional information the CBS can be found in the NASA Cost Estimating Handbook, Appendix B.

In some cases, the schedule may or may not directly include elements of the CBS (i.e., resource or cost loading the schedule). Depending on the specific cost models or estimating approaches the cost analyst has chosen, the P/p WBS may not have sufficient granularity, or misalignment may exist between the WBS and the estimating methods. Any adjustments that are made to the P/p WBS must be coordinated with the P/p to ensure that the changes will not cause issues with understanding or communicating the estimate.[35]

The CBS should be traceable to the P/p budget. Budget planning information (i.e., all estimated P/p costs and obligations including FTEs, WYEs, ODCs, procurements, travel, facilities, and other costs for each fiscal year during all phases of a P/p) is used during Schedule Management Planning and Schedule Development, leading to an approved baseline *IMS*. Having a clear understanding of the budget, and specifically, the funding that will be available is critical to establishing a credible *Schedule BoE*, as the *IMS* should be traceable at some level to the P/p CBS. This information aids in determining *IMS* task durations, interdependencies, constraints, and calendars.

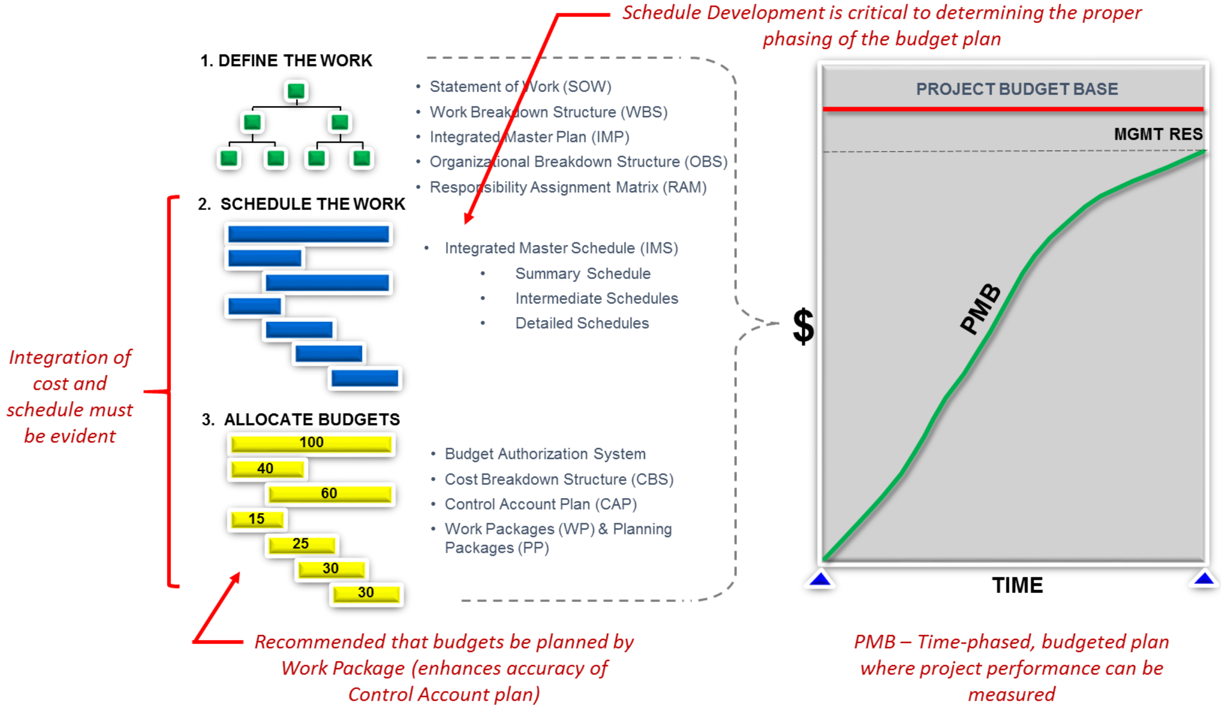
It is imperative that the baseline *IMS* correlates to and is in agreement with all segments of the integrated cost and schedule baseline, in order to establish a good baseline to which performance can be measured. For instance, the PMB is the time-phased cost plan for accomplishing all authorized work scope in a P/p's life cycle, which includes both NASA internal costs and supplier costs. The P/p's

---

[34] NASA Cost Estimating Handbook, V4.0. February 2015. Appendix B. Page B-2. https://www.nasa.gov/sites/default/files/files/01_CEH_Main_Body_02_27_15.pdf

[35] NASA Cost Estimating Handbook, V4.0. February 2015. Appendix B. Page B-2. https://www.nasa.gov/sites/default/files/files/01_CEH_Main_Body_02_27_15.pdf

performance against the PMB is measured using EVM, if required, or other performance measurement techniques if EVM is not required. Figure 5-6 illustrates the how cost and schedule are linked together to inform the PMB.



Schedule Development is critical to determining the proper phasing of the budget plan

Integration of cost and schedule must be evident

Recommended that budgets be planned by Work Package (enhances accuracy of Control Account plan)

PMB – Time-phased, budgeted plan where project performance can be measured

Figure 5-6. Cost and schedule estimates must be integrated to establish a credible PMB.

Having a clear understanding of the budget, and specifically, the funding that will be available to a P/p and when is critical in establishing a credible *IMS*. Funding levels and phasing may restrict the amount of work that can be done in a specific time period forcing the P/p to replan or, if severely constrained, may lead the P/p to descope (i.e., minimize or delete some requirements). Thus, it is important to understand whether the P/p scope can be accomplished per the available funding given the costs associated with the planned work. Incorporating costs into a P/p *IMS* provides a time-phased spending estimate (i.e., cost-loaded schedule) that can be compared to funding availability over time. If there are misalignments, the P/p has the data needed to re-phase the planned work or to descope the requirements to match available budget.

Caution. During the planning process, it is important to ensure the P/p commitments never exceed the authorized P/p funding for a specific fiscal year and do not exceed the planned annual budget for complete LCC. Remember that P/p funding and the P/p budget are different entities, but they are related. NASA funding is incremental, almost always by FY, and refers to the dollars authorized for P/p expenditure during that FY. On the other hand, a P/p budget plan refers to the value assigned to the time-phased resources necessary to accomplish the scheduled effort. There should always be integration between funding, planned budget, and the associated work content to be scheduled. In Figure 5-7, an authorized budget plan is shown as a function of FY.

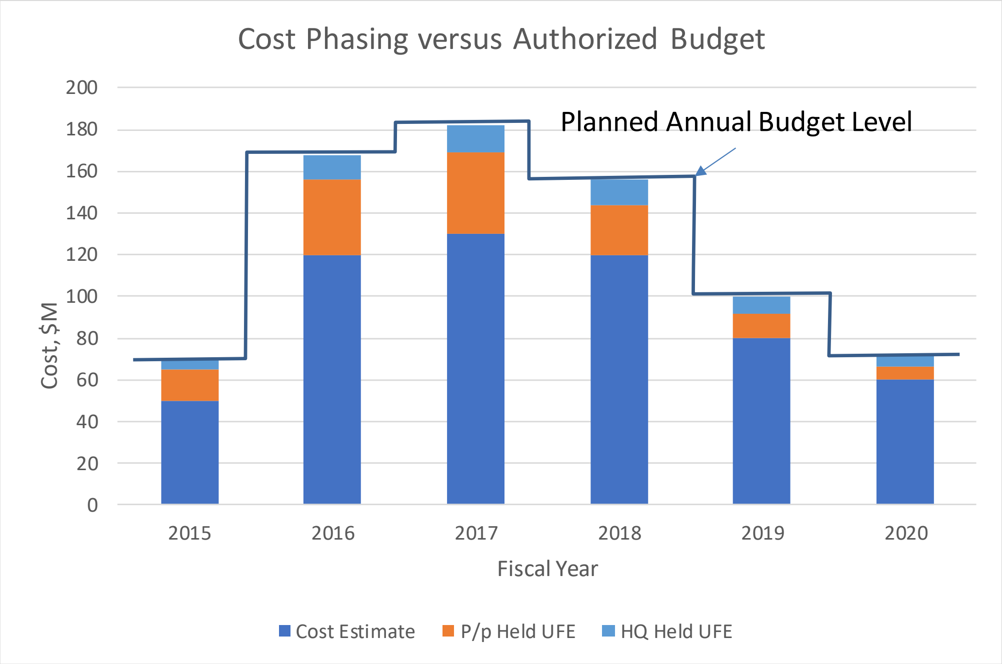


Figure 5-7. Relationship between P/p phasing and P/p budget.

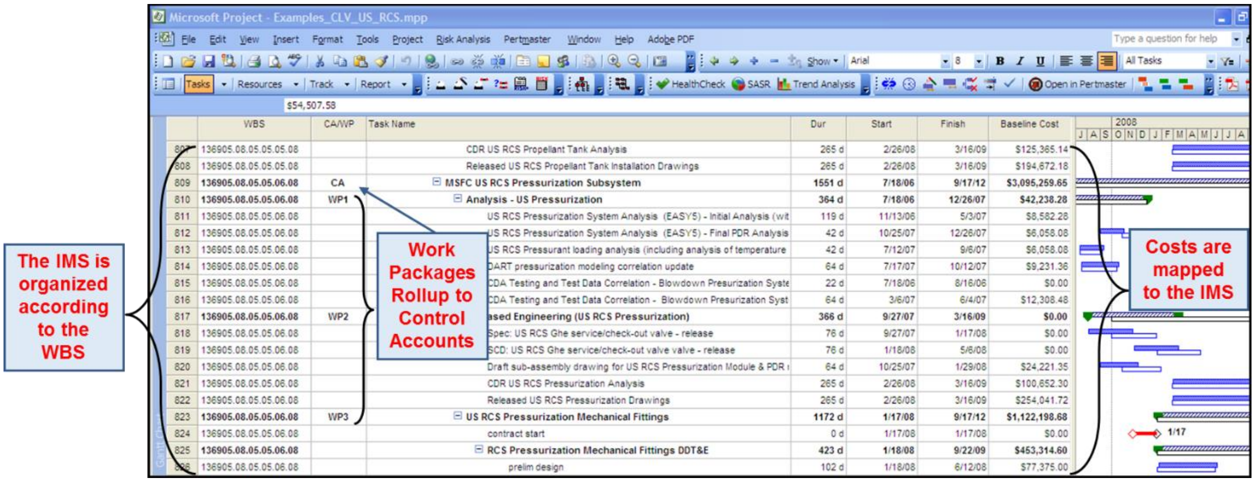
The P/S must work with the P/p to schedule the work such that the P/p estimated cost with Management Reserve (MR) does not exceed the authorized budget plan for any FY. It is important to understand the difference between MR and UFE.

- **Management Reserve (MR).** MR is an amount of the total P/p "budget" withheld for management control rather than designated for accomplishment of a specific task or set of tasks. MR is typically set aside for unforeseen and unplanned events. MR is not included in the performance baseline (or official PMB, if applicable.) In other words, no scope is assigned to MR. MR is typically held at the total P/p or contract level. MR should not be used to cover past performance variances. Expected uses of MR include:
    - Budgeting work that is within the P/p or contract scope (not for external changes);
    - Replanning future work based on improved knowledge, such as work method/sequence, make/buy decision changes, changes to planning assumptions, etc.
    - Budgeting for the realization of known/unknown risks, or as buffer to offset risk
- **Unallocated Future Expense (UFE).** Although not included in the performance baseline (or official PMB, if applicable), UFEs are the costs expected to be incurred but cannot yet be allocated to a specific WBS sub-element of the P/p's plan because the estimate includes risks and specific needs that are not yet known. In other words, UFE is the "funding" that is provided to accommodate the realization of risk and uncertainty associated with a cost or schedule estimate. UFE may also be used for overruns and for changes within the scope of the P/p. Management control of some or all of the UFE may be retained above the level of the P/p (i.e., Agency, Mission Directorate, or Program). These funds may ultimately be distributed to mitigate the risk, to make the product work, or to accommodate cost or schedule growth, but

because not all risks or uncertainties will be realized, initial allocation of funds to particular WBS elements would be premature. During a P/p's KDPs, the Decision Authority typically determines whether UFE is necessary, and documents the decision in a Decision Memorandum. For P/p's with a *JCL* requirement, UFE is typically established by exercising probabilistic techniques, and is the portion of estimated cost required to meet a specified *JCL*. The *JCL* is further described in Section 6.3.2.4, as well as in the NASA Cost Estimating Handbook, Appendix J.

5.3.5 Integrated Master Schedule (IMS)

The *Integrated Master Schedule* (*IMS*) is the "when" of P/p scope. It supports all internal NASA P/p and all external contractor activities, when applicable. The purpose of an *IMS* is to provide a time-phased plan for performing the P/p's approved total scope of work and achieving the P/p's goals and objectives within a determined timeframe. Whether developed for a Program or project, the *IMS* contains tasks, milestones, and interdependencies logically sequenced in a manner that accurately models the implementation plan for all approved scope from P/p start through completion based on all P/p work as defined/broken down by the established WBS. The *IMS* also provides management a vehicle which enables integration of the approved P/p work scope reflected in the work breakdown structure (WBS), cost estimate, and programmatic risks to ensure alignment with the P/p's integrated performance baseline (or PMB). This includes both government and contractor work. The detail is sufficient to identify the longest path of activities through the entire P/p. Prior to establishing the baseline, the schedule is referred to as the preliminary schedule or preliminary *IMS*; once baselined, it is the schedule baseline or baseline *IMS*. Figure 5-8 shows an example of a schedule that integrates the "who", "what", and "how much" of the P/p scope.



$54,507.58

	WBS	CA/WP	Task Name	Dur	Start	Finish	Baseline Cost
807	136905.08.05.05.05.08		CDR US RCS Propellant Tank Analysis	265 d	2/26/08	3/16/09	$125,365.14
808	136905.08.05.05.05.08		Released US RCS Propellant Tank Installation Drawings	265 d	2/26/08	3/16/09	$194,672.18
809	**136905.08.05.05.06.08**	**CA**	**⊟ MSFC US RCS Pressurization Subsystem**	**1551 d**	**7/18/06**	**9/17/12**	**$3,095,259.65**
810	**136905.08.05.05.06.08**	**WP1**	**⊟ Analysis - US Pressurization**	**364 d**	**7/18/06**	**12/26/07**	**$42,238.28**
811	136905.08.05.05.06.08		US RCS Pressurization System Analysis (EASY5) - Initial Analysis (wit	119 d	11/13/06	5/3/07	$8,582.28
812	136905.08.05.05.06.08		US RCS Pressurization System Analysis (EASY5) - Final PDR Analysis	42 d	10/25/07	12/26/07	$6,058.08
813	136905.08.05.05.06.08		US RCS Pressurant loading analysis (including analysis of temperature	42 d	7/12/07	9/6/07	$6,058.08
814	136905.08.05.05.06.08		DART pressurization modeling correlation update	64 d	7/17/07	10/12/07	$9,231.36
815	136905.08.05.05.06.08		CDA Testing and Test Data Correlation - Blowdown Presurization Syste	22 d	7/18/06	8/16/06	$0.00
816	136905.08.05.05.06.08		CDA Testing and Test Data Correlation - Blowdown Presurization Syst	64 d	3/6/07	6/4/07	$12,308.48
817	**136905.08.05.05.06.08**	**WP2**	**ased Engineering (US RCS Pressurization)**	**366 d**	**9/27/07**	**3/16/09**	**$0.00**
818	136905.08.05.05.06.08		Spec: US RCS Ghe service/check-out valve - release	76 d	9/27/07	1/17/08	$0.00
819	136905.08.05.05.06.08		SCD: US RCS Ghe service/check-out valve valve - release	76 d	1/18/08	5/6/08	$0.00
820	136905.08.05.05.06.08		Draft sub-assembly drawing for US RCS Pressurization Module & PDR	64 d	10/25/07	1/29/08	$24,221.35
821	136905.08.05.05.06.08		CDR US RCS Pressurization Analysis	265 d	2/26/08	3/16/09	$100,652.30
822	136905.08.05.05.06.08		Released US RCS Pressurization Drawings	265 d	2/26/08	3/16/09	$254,041.72
823	**136905.08.05.05.06.08**	**WP3**	**⊟ US RCS Pressurization Mechanical Fittings**	**1172 d**	**1/17/08**	**9/17/12**	**$1,122,198.68**
824	136905.08.05.05.06.08		contract start	0 d	1/17/08	1/17/08	$0.00
825	**136905.08.05.05.06.08**		**⊟ RCS Pressurization Mechanical Fittings DDT&E**	**423 d**	**1/18/08**	**9/22/09**	**$453,314.60**
826	136905.08.05.05.06.08		prelim design	102 d	1/18/08	6/12/08	$77,375.00

Figure 5-8. Integrated Master Schedule (IMS) example that ties together all aspects of the P/p scope.

The remainder of this Chapter discusses: (1) the *Schedule BoE*, which documents the ground rules and assumptions (GR&A), constraints, and any other rationale that dictates how the *IMS* is developed, and (2) the development of the *IMS*. The *IMS* is further discussed in Section 5.6.1.

5.4 Develop the Basis of Estimate

It is a best practice for a Schedule Basis of Estimate (BoE) to be created and maintained throughout the P/p's life cycle that documents basis rationale for all elements of the planned schedule,

assessment and analysis findings, reporting artifacts, and primary source data, documents and other pertinent information. As defined by NPR 7120.5, "a *Basis of Estimate* (*BoE*) is the documentation of the ground rules, assumptions, and drivers used in developing the cost and schedule estimate, including applicable model inputs, rationale or justification for analogies, and details supporting cost and schedule estimates."[36] The *Schedule BoE* dossier acts as a comprehensive, structured collection of technical and programmatic information necessary to fully develop, understand, assess, analyze, and theoretically reproduce the *IMS*, while also playing a supplementary role in schedule maintenance and control. A *BoE* ideally serves in the following critical capacities:

- Enables the development of the *IMS* by capturing basis rationale alongside primary data sources and reinforcing methodological consistency.
- Provides a medium for assessing schedule *reliability,* the ultimate measure of schedule quality.
- Guides schedule evolution through expert dialogue and discovery of evidence for specific schedule improvements
- Captures the end-to-end narrative of the P/p through the lens of schedule for the benefit of in-line practitioners and agency community of practice
- Enables dialogue and streamlined information exchange between the P/p and Independent Assessment teams

Populating the *Schedule Database* necessitates the development and maintenance of a robust *BoE* in order to ultimately produce an *IMS* that can be considered reliable. The *BoE* should include places for basis rationale associated with all data that feeds into the *Schedule Database*. The *BoE* should complete the trace from all basis rationale to primary sources of data used to develop the schedule by including all referenced material in some form. This handbook therefore provides no specific *BoE* template or format, though it is necessary that the P/p's *BoE* always house both the current and past versions of the *IMS* alongside counterpart incarnations that can be easily annotated and tracked by P/Ss, according to the Schedule Documentation processes described in Section 8.3.3.

Note: Hereafter in this document, the schedule *BoE* dossier will be referred to simply as the "*BoE*". It is noted where the *Schedule BoE* should be differentiated from other types of "basis of estimate" documents (like those pertaining to cost).

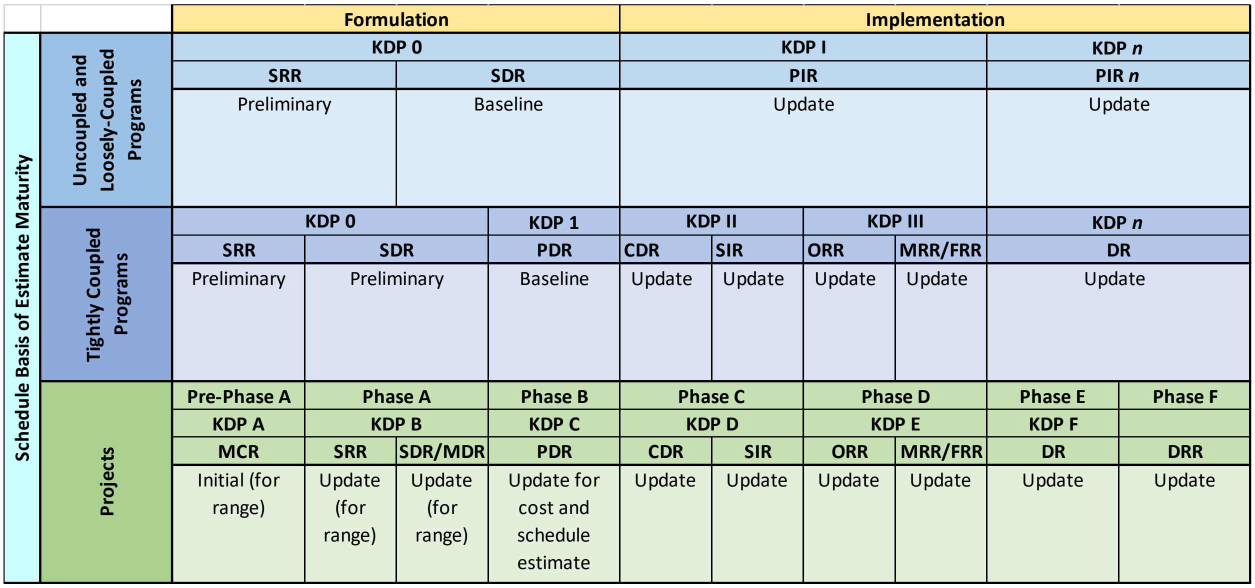
5.4.1 BoE Maturity by P/p Phase

It is a requirement for P/ps that are governed by NPR 7120.5, which states, "all programs and projects develop cost estimates and planned schedules for the work to be performed in the current and following life cycle phases (see Appendix I tables). As part of developing these estimates, the program

---

[36] NPR 7120.5E. NASA Space Flight Program and Project Management Requirements. Effective Date: August 14, 2012. Expiration Date: August 14, 2020. Appendix A. https://nodis3.gsfc.nasa.gov/npg_img/N_PR_7120_005E_/N_PR_7120_005E_.pdf

or project shall document the *BoE* in retrievable program or project records."[37] A table of the required *BoE* maturity at given LCRs is provided in Figure 5-9.[38]



<table>
<tr><td></td><td></td><td colspan="4">Formulation</td><td colspan="6">Implementation</td></tr>
<tr><td rowspan="9">Schedule Basis of Estimate Maturity</td><td rowspan="3">Uncoupled and Loosely-Coupled Programs</td><td colspan="4">KDP 0</td><td colspan="4">KDP I</td><td colspan="2">KDP <i>n</i></td></tr>
<tr><td colspan="2">SRR</td><td colspan="2">SDR</td><td colspan="4">PIR</td><td colspan="2">PIR <i>n</i></td></tr>
<tr><td colspan="2">Preliminary</td><td colspan="2">Baseline</td><td colspan="4">Update</td><td colspan="2">Update</td></tr>
<tr><td rowspan="3">Tightly Coupled Programs</td><td colspan="3">KDP 0</td><td>KDP 1</td><td colspan="2">KDP II</td><td colspan="2">KDP III</td><td colspan="2">KDP <i>n</i></td></tr>
<tr><td>SRR</td><td colspan="2">SDR</td><td>PDR</td><td>CDR</td><td>SIR</td><td>ORR</td><td>MRR/FRR</td><td colspan="2">DR</td></tr>
<tr><td>Preliminary</td><td colspan="2">Preliminary</td><td>Baseline</td><td>Update</td><td>Update</td><td>Update</td><td>Update</td><td colspan="2">Update</td></tr>
<tr><td rowspan="4">Projects</td><td>Pre-Phase A</td><td colspan="2">Phase A</td><td>Phase B</td><td colspan="2">Phase C</td><td colspan="2">Phase D</td><td>Phase E</td><td>Phase F</td></tr>
<tr><td>KDP A</td><td colspan="2">KDP B</td><td>KDP C</td><td colspan="2">KDP D</td><td colspan="2">KDP E</td><td>KDP F</td><td></td></tr>
<tr><td>MCR</td><td>SRR</td><td>SDR/MDR</td><td>PDR</td><td>CDR</td><td>SIR</td><td>ORR</td><td>MRR/FRR</td><td>DR</td><td>DRR</td></tr>
<tr><td>Initial (for range)</td><td>Update (for range)</td><td>Update (for range)</td><td>Update for cost and schedule estimate</td><td>Update</td><td>Update</td><td>Update</td><td>Update</td><td>Update</td><td>Update</td></tr>
</table>

Figure 5-9. Schedule BoE maturity requirements by P/p phase according to NPR 7120.5.

Although not explicitly identified in NPR 7120.8 as a required product for R&T P/ps, it is expected that a *BoE* would exist at a maturity corresponding to the maturity of the *IMS*. It is also important to note that, "R&T projects that directly tie to the space flight mission's success and schedule are normally managed under NPR 7120.5." Figure 2-3 and Figure 2-4 provide an overview of the expected maturity of the *BoE* for P/ps that adhere to NPR 7120.8.

BoE endures across the life cycle; its structure and maturity is phase-dependent. For Uncoupled and Loosely-Coupled Programs, a preliminary BoEs is required at SRR, with a baseline at SDR, and updates at subsequent LCRs. For Tightly-Coupled Programs, preliminary BoEs are required at SRR and SDR, with a baseline at PDR, and updates at subsequent LCRs. For projects, preliminary BoEs are required at MCR, SRR, and SRR/MDR, with a baseline at PDR, and updates required in conjunction with the maturity of the schedule at each life cycle review. It is important to note that the *BoE* will evolve as the P/p matures. For example, a project's *BoE* for Phases E and F is not required until SIR.

Early in Formulation, the P/p may need to rely on historical data from past P/ps to estimate the overall schedule duration. Pre-Phase A and Phase A typically use analogies provided by tools or databases that

---

[37] NPR 7120.5E. NASA Space Flight Program and Project Management Requirements. Effective Date: August 14, 2012. Expiration Date: August 14, 2020. Page 37.
[38] While NPR 7120.8A does not specifically require a Basis of Estimate (BoE) product, projects that adhere to NPR 7120.8 may benefit from the documentation of BoEs to support the required programmatic products.

store historical information, such as SMART, the Schedule Repository, CADRe, and NICM.[39] A summary of these tools and databases can be found in Section 5.5.9.3.2.

While it is likely that some historic data will be available for most P/ps, in the cases of new technologies, there may be instances where analogous data does not specifically exist (e.g., new technology developments, etc.). In these cases, the P/S and/or Schedule Analyst should increase the amount of uncertainty, and perhaps the point estimate itself, to account for the lack of relevance to the analogy. Any assumptions made concerning the derivation of uncertainty and durations should be documented in the *BoE* and the *IMS*, as well as ensuring the *IMS* has the appropriate amount of float and/or margin.

In subsequent phases, documentation will have been generated specific to the P/p with more detailed information, and the schedule will be more detailed by means of the rolling wave or similar approach. By PDR, when the schedule is more detailed, defining all work required to accomplish the complete P/p effort, the basis rationale for the selected durations, the duration uncertainties, and any other specific attributes for the activities should be captured in the *BoE*. Attributes of the activities to include in the *BoE* may include, but are not limited to:

- Activity owners
- Workflow logic
- WBS, OBS, and CBS identifiers (WBS Dictionary should provide appropriate description of the work effort that is represented by schedule activities)
- Work package identifiers
- Shifts required
- Duration and duration uncertainty with associated rationale
- Other assumptions and/or constraints

Thoroughly documenting the BoE also aids the P/S in carrying out the Schedule Assessment procedures, such as the *Requirements* Check, described in Section 6.2.2.1.1, and the *Basis Check*, described in Section 6.2.2.2.2.

5.4.2 Source Information to Inform the BoE

All P/p documentation available should be reviewed and used to support Schedule Development, including the documentation of the *BoE*, as these documents may contain many of the ground rules, assumptions, and drivers for the P/p. The following is a list of typical P/p products that P/S should have access to and be very familiar with when starting the Schedule Development sub-function:

---

[39] The Cost Analysis Data Requirement (CADRe), the Schedule Management and Relationship Tool (SMART), the Project Cost Estimating Capability (PCEC), and the NASA Instrument Cost Model (NICM) can be found on the One NASA Cost Engineering Database (ONCE), www.oncedata.msfc.nasa.gov. REsource Data STorage And Retrieval System (REDSTAR) access can be requested through the NASA Access Management System (NAMS), https://www.hq.nasa.gov/office/itcd/nams.html.

- P/p Plans (see Appendix I in NPR 7120.5 for the types of P/p Plans required and their associated maturity by phase)
- Agreements and Authorization Documents (e.g. Formulation Agreement Document, Decision Memorandums, etc.)
- Scope Definition
    - Work Breakdown Structure (WBS) and WBS Dictionary
    - Integrated Master Plan (IMP), if available
    - Organizational Breakdown Structure (OBS)
    - Cost Breakdown Structure (CBS)
- Cost Estimate/BoEs
    - Program Planning Budget Execution (PPBE) data
    - Request for Proposal (RFP) or Contract
        - Task Agreements (TA)
        - Data Requirements Document (DRD)
        - Bill of Materials (BOM)
    - Core Financial Business Warehouse Reports
- P/p Risk Information (Risk Management Plan) and Database
    - Risk Statements and Context
    - Risk Matrix, including Likelihood (probability) and Consequence (duration distributions)
    - Risk Impact descriptions (cost, schedule, technical)
    - Risk Mitigation descriptions (incl. cost and schedule requirements, technical aspects)

These sources provide critical insights regarding overall P/p scope and duration needed for developing a schedule with a valid basis, such as: correct task sequencing, responsibilities, task duration, and resource information.

It is important to realize that P/p personnel may not have the same interpretation or understanding of the approved SOW. Resolving these differences is necessary for the development of an accurate and useable schedule for P/p management. The P/S can play a significant role in helping to resolve these differences by asking the right questions (e.g., *In what WBS element does specific effort belong? What type of deliverable is required? What type of testing is required?*), and by bringing to light the areas of conflict so that responsible managers can come to an agreement on the work scope. For example, the P/S should always help the P/p team understand the necessary inputs (e.g., responsibility, in-house or contracted effort, quantities, and facility requirements) to task and schedule definition, as well as the inherent interfaces involved. In addition, and equally important to capturing the complete scope of the P/p in Schedule Development is documenting any exclusions and risks to the P/p, as these are P/p attributes that may affect the Schedule Management approach. Per NPR 7120.8, a Research and

Technology (R&T) P/p tends to define a cost/schedule structure rather than an LCC and associated end date. Thus, it is important to understand the complete scope that will take the R&T P/p to its end date.

If relevant data or documentation has not been developed, the P/S should lead or otherwise galvanize development of these documents. More information on how the P/S might interface with other PP&C functions are included described in the PP&C Handbook.[40] By initially gathering and understanding as much of this data as possible, the effort will lead to a more accurate and meaningful schedule for use in guiding P/p management.

5.4.3 Documenting the BoE in Conjunction with Developing the IMS

Documenting the basis rationale for *Activity Attributes* initializes the *BoE*, along with capturing primary data sources. This activity should be done in conjunction with developing the *IMS* as defined in Section 5.5, as well as any capturing any related assumptions or rationale from the assessment of the *IMS* as described in Chapter 6.

As the P/p continues through its life cycle and changes are made to the *IMS*, the rationale for changes and supporting data should be captured within the *BoE* and tracked through the P/p's change control process, as described in Chapter 7.

5.5 Develop the Schedule

Schedule Development is a function initiated early in the Formulation of a P/p and is accomplished by following the requirements and the *Schedule Development Plan* in the *SMP*. Schedule Development activities should be performed according to the P/p life cycles as follows:

- Pre-Phase A (Pre-ATP): Initialize documentation within the preliminary *BoE*. Implement the scheduling methodology and tools. Establish data fields that correspond with the planned *Activity Attributes*. Begin developing preliminary *IMS*.
- Phase A-SRR (ATP): Initiate loading the *Schedule Database* to capture the entire scope of work for the P/p that support the milestones identified in the planned *Milestone Registry*. Define relationships and constraints of the activities. Assign resources. Continue developing and testing the preliminary *IMS* and its associated *Schedule Database*. Continue documenting the *Schedule BoE*.
- Phase A – SDR/MDR: Update the preliminary *IMS*. Continue Schedule Assessment and commensurate *BoE* development.
- Phase B – PDR (Program Approval): Baseline the *IMS* and its *BoE*. Develop an *Analysis Schedule*, if necessary.
- Phase C/D – CDR/SIR/ORR through Launch (PARs through Closeout): Continue developing the *IMS* per the rolling wave approach, if applicable. Continue developing the *Analysis Schedule*, if necessary.

---

[40] https://nen.nasa.gov/documents/879593/1386755/PP%2BC+Handbook+1-5-17.docx/097acedf-1df7-4676-b9c1-4c0c1e83dc2e?version=1.0&download=true

Figure 5-10 illustrates how the implementation of the SMP results in a time-phased set of activities that aligns the development and deployment of the IMS and associated products with the continuous Schedule Management processes according to the P/p life cycle. The continuous Schedule Management processes that are executed throughout the P/p life cycle according to three of the sub-plans in the SMP include:

- Schedule Assessment and Analysis, Chapter 6
- Schedule Maintenance and Control, Chapter 7
- Schedule Documentation and Communication, Chapter 8

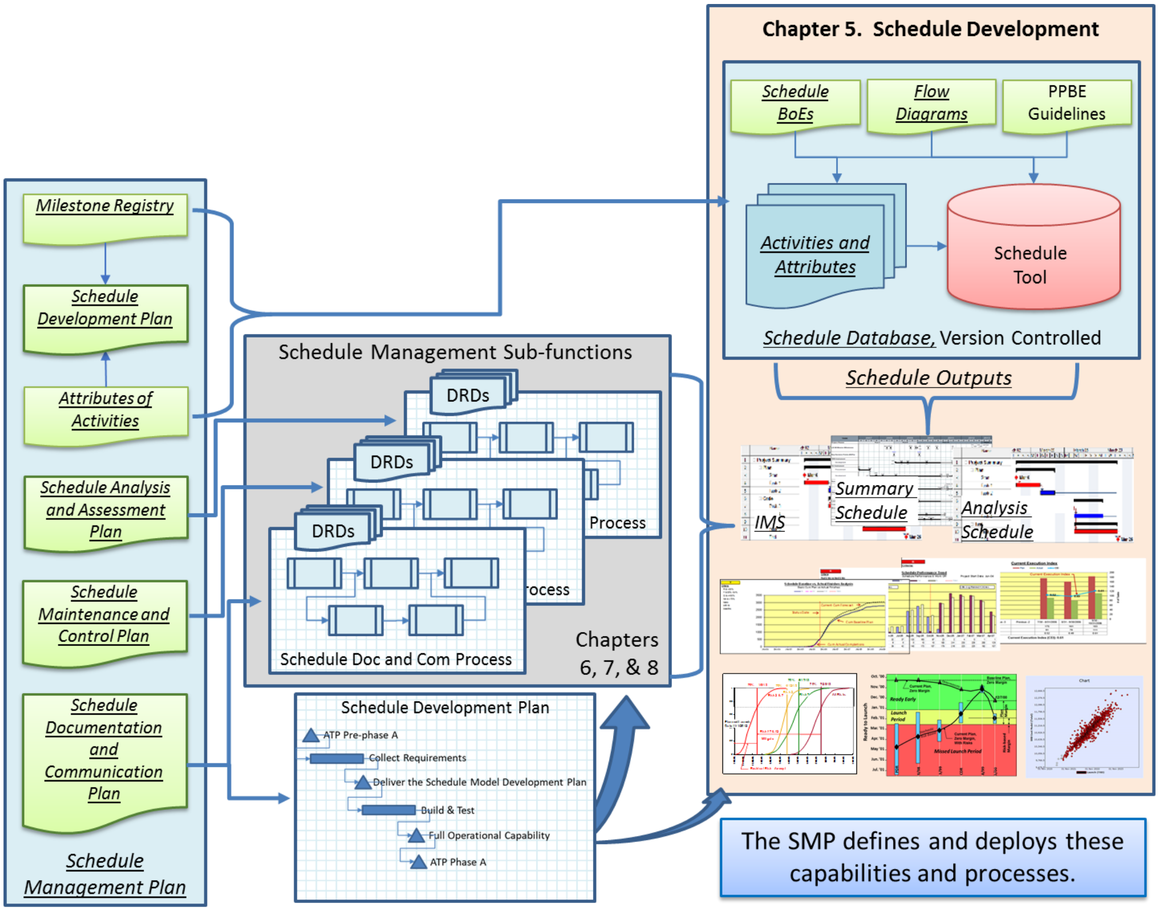


Figure 5-10. Schedule Development and its relationship to the other Schedule Management processes.

The primary output of Schedule Development is the *IMS*, although other *Schedule Outputs*, such as a *Summary Schedule* or an *Analysis Schedule* may be produced, in addition to *Schedule Performance Measures*. *Schedule Outputs* and *Schedule Performance Measures* are further defined in Section 5.5.13.

5.5.1 Ensure Scheduling Tool Capabilities

It is a best practice for the schedule to be developed using tools appropriate to the type and level of schedule management that the P/p requires. Choosing the right schedule management tools is critical to success, not only for the P/p team, but also for any contractors involved. It should be clearly understood during up-front P/p planning and process development that there are numerous management tool sets available that do not allow for easy and/or accurate transfer and integration of schedule and performance data. It is crucial for achieving successful P/p management that tools, which provide efficient and accurate transfer and integration of data, be chosen, and where possible, mandated for all P/p participants. At a minimum, scheduling tools should satisfy the following capabilities:

Functional

- Provide for entering and editing of baseline plan, current/forecast plan, and accomplished (actual) schedule data
- Specify relational dependencies between tasks and milestones (including lag and lead values as needed, but kept to a minimum)
- Define P/p calendars that reflect the business schedule (e.g., workdays, non-workdays, holidays, and work-hours)
- Display and print P/p schedules in Gantt and network diagram form
- Calculate total slack (float) and free slack for all P/p tasks and milestones
- Provide user-defined code fields for filtering, grouping, summarizing, and organizing data, and mirroring *BoE*-related information where appropriate
- Create, view, and print basic reports such as task, cost, and resource listings
- Provide capability for cost loading, and resource loading and leveling

Technical

- Supports email capability of schedule data in native file formats
- Uses Open Database Connectivity (ODBC) or Dynamic Data Exchange (DDE) standards to read/write to other databases
- Provides capability of saving data files such as MPX, DBF, XML, HTML, and X-12
- Provides online “help” capability
- Provides capability for creating PDF files or graphic files such as: jpeg, bmp, gif, or tif

Interface

- Supports data interface to chosen in-house EVM applications (e.g., Internally developed EVM spreadsheets or commercial EVM applications)
- Supports data interface to EVM data analysis applications
- Supports data interface to schedule risk analysis applications, such as range estimates and *JCL* analyses

MS Project and Oracle Primavera P6 are common scheduling tools that are used throughout the Agency and can handle differing levels of schedules and integration with other PP&C tools and data. Both on-site and cloud versions (such as MS Project Server) generally meet the capabilities listed above.

Document the BoE for the Scheduling Tool

Scheduling tool selection should be documented in the *Schedule Development Plan*. Documentation of the specific tool selection and the corresponding rationale is considered part of the *BoE*. The P/S document that the tool selected is compliant with the P/p requirements and the requirements. The P/S should also ensure that any additional tools used to create, house, and maintain the entire *Schedule BoE* are compliant with the requirements and execution techniques pertaining to the *BoE* as outlined in this chapter and Section 6.2.

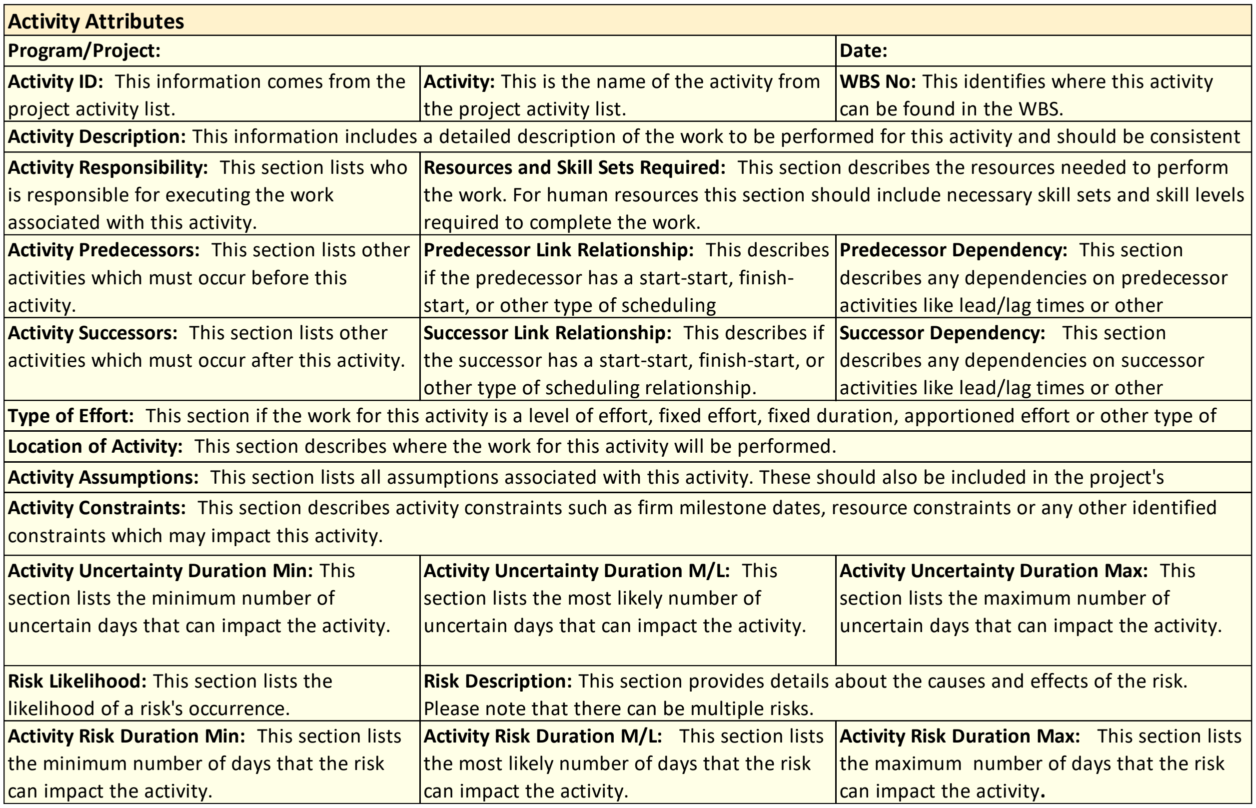
5.5.2 Establish Schedule Field Codes

Information in the schedule should be consistent with key documents and other information through activity codes.[41] ***It is a best practice for the schedule to be coded such that it facilitates P/p management support processes and other programmatic functions.*** Coding of activities can aid in organizing, displaying and reporting schedule information in useful formats. Appropriate coding can also facilitate consistent vertical schedule traceability, as well as help to filter and summarize schedule data to provide reports at the summary, intermediate, and detail schedule levels, as needed. The coding structure can be as basic or as comprehensive as necessary for the P/p's needs.

Developing the table of *Activity Attributes* is available as a prerequisite to Schedule Development. The table specifies the fields needed in the *IMS* to interface with other P/p management process as well as provides additional information that the P/p needs. The fields need to be allocated during the Schedule Development process. The minimum set of *Activity Attributes* that require coded fields in the schedule are shown in Figure 5-11.

---

[41] GAO-16-89G. GAO Schedule Assessment Guide. Page 24. December 2015. http://www.gao.gov/assets/680/674404.pdf



Activity Attributes		
Program/Project:		**Date:**
Activity ID: This information comes from the project activity list.	**Activity:** This is the name of the activity from the project activity list.	**WBS No:** This identifies where this activity can be found in the WBS.
Activity Description: This information includes a detailed description of the work to be performed for this activity and should be consistent		
Activity Responsibility: This section lists who is responsible for executing the work associated with this activity.	**Resources and Skill Sets Required:** This section describes the resources needed to perform the work. For human resources this section should include necessary skill sets and skill levels required to complete the work.	
Activity Predecessors: This section lists other activities which must occur before this activity.	**Predecessor Link Relationship:** This describes if the predecessor has a start-start, finish-start, or other type of scheduling	**Predecessor Dependency:** This section describes any dependencies on predecessor activities like lead/lag times or other
Activity Successors: This section lists other activities which must occur after this activity.	**Successor Link Relationship:** This describes if the successor has a start-start, finish-start, or other type of scheduling relationship.	**Successor Dependency:** This section describes any dependencies on successor activities like lead/lag times or other
Type of Effort: This section if the work for this activity is a level of effort, fixed effort, fixed duration, apportioned effort or other type of		
Location of Activity: This section describes where the work for this activity will be performed.		
Activity Assumptions: This section lists all assumptions associated with this activity. These should also be included in the project's		
Activity Constraints: This section describes activity constraints such as firm milestone dates, resource constraints or any other identified constraints which may impact this activity.		
Activity Uncertainty Duration Min: This section lists the minimum number of uncertain days that can impact the activity.	**Activity Uncertainty Duration M/L:** This section lists the most likely number of uncertain days that can impact the activity.	**Activity Uncertainty Duration Max:** This section lists the maximum number of uncertain days that can impact the activity.
Risk Likelihood: This section lists the likelihood of a risk's occurrence.	**Risk Description:** This section provides details about the causes and effects of the risk. Please note that there can be multiple risks.	
Activity Risk Duration Min: This section lists the minimum number of days that the risk can impact the activity.	**Activity Risk Duration M/L:** This section lists the most likely number of days that the risk can impact the activity.	**Activity Risk Duration Max:** This section lists the maximum number of days that the risk can impact the activity**.**

Figure 5-11. Example of a typical Activity Attributes table.

There are an infinite number of field and field codes that either exist or can be created. The tools used along with the P/p characteristics determine the limitations on this parameter. The number of field codes needed for a P/p will vary widely, depending on many factors such as P/p size, maturity, industry or technology, complexity, entities involved, phase, and so on. The appropriate number of field codes to use is the number required to effectively and efficiently manage the P/p. The same can be said for the types of field codes to use. Field codes can be set using different code types, such as Flag, Number, Text, and Date codes. Commonly-used field codes include:

- **WBS.** The WBS defines hierarchical organization of the work to be executed by the P/p team. The WBS is an important coding structure that when incorporated into the *IMS*, aids in extracting and formatting desired schedule data.
- **Control Account Code (and/or CWBS).** Although it may be different the control account code, or CWBS, helps to map work scope to the control account from which the work is funded. Each control account may be mapped to more than one work package, but each work package can only be mapped to one control account. Coding schedule activities by control account is a management tool to integrate scope, budget, cost, and schedule and can help facilitate earned value performance measurements.
- **Responsibility Code.** The responsibility code can be used in a number of ways, such as a reference to a responsible person, team, or group (e.g., Technical Lead, CAM, IPT, etc.). This is not the same as the OBS, but rather a more specific identifier. The field code can be useful for

sorting and grouping of data into distinct work groups. The result may then be used to collect status, plan resources, or to communicate a group's work plans.

- **Phase Code.** The phase code may be defined in different ways, but usually as a logical grouping of work that flows along the P/p timeline, more or less sequentially. For example, one such definition may result in phases such as Engineering, Procurement, Fabrication, and Testing. It is often used to organize data to facilitate interface-planning efforts and produce summary-level reports.
- **Activity Type Code.** The activity type code helps to distinguish between schedule activities that have different functions within the *IMS*, such as milestones, regular activities, LOE activities, summary activities, "margin activities", or other "placeholder activities." Activity type coding can facilitate Schedule Assessment, Analysis, and Control by making it easier to filter through activities of interest. It is a recommended practice that any "activity" other than a regular activity be coded appropriately.
- **EVM Codes.** The EVM code helps to filter on tasks that are used as inputs to EV metrics. the selected *IMS* tasks' Unique Identifiers (UID) are associated with a coding structure, which ties into the EVM software used. The coding structure identifies the start and end of tasks that support a milestone within the EVMS. The coding structures can be as basic or as comprehensive as necessary for the P/p's needs.
- **Other Commonly-Used Codes.** P/p activities may also be coded for consistency with such information as the related contractor, location, phase, contract line item number (CLIN), work package number, CAM, and SOW paragraph as applicable.[42] Other commonly-used or customized codes may include Activity ID, Area, System, Department, Step, Priority, Resource Names, Resource Costs, Uncertainties, Risks, etc.

P/p management may occasionally be faced with an opportunity to become creative with regard to coding of data. For example, schedules may need to be constructed that are adaptable to special requirements specific to a particular report or action tracking product. In some cases, a request for isolating a particular requirement, design, fabrication, or test phase may be requested. Most scheduling software tools are flexible in allowing field customization for filtering, sorting, and grouping to enable displaying specific criteria. Coding may become more informal in these cases but should still be documented. It is a recommended practice to maintain a coding dictionary, or some equivalent documentation, to capture field code information. In larger P/ps this document should be incorporated by reference or inclusion in other applicable P/p documentation with changes controlled appropriately.

Once particular field codes are defined for use in a P/p, it is a recommended practice that the field code value be used consistently for all related P/p data. Consistency is the key to a successful data structure and coding scheme. For example, if the resource abbreviation "E" for "Engineers" has been established, this resource abbreviation should be used in all places where a resource abbreviation for "Engineers" is required. There may be occasions where this practice may not be practical, or even possible, due to

---

[42] GAO-16-89G. GAO Schedule Assessment Guide. Page 24. December 2015. http://www.gao.gov/assets/680/674404.pdf

system limitations or incompatibilities. In these scenarios, a cross reference table can be created to relate pertinent codes. Continuing the example above, if the P/p's payroll tool uses the abbreviation "Eng" for "Engineers," but the tool has a limit of only one character for the "Engineers" resource, it may be necessary to use "E" for Engineers in the scheduling tool. The cross-reference table in Figure 5-12 would then contain the following entry:

Data Type	Data Item	Payroll Tool	Scheduling Tool
Resources	Engineers	Eng	E

Figure 5-12. Example of schedule coding crosswalk to resource coding.

It is important to maintain the integrity of the data structure while enabling various users with varying needs to query the data effectively and efficiently. Coding enables various forms of filtering, such as the grouping or sorting of data without altering the structure. Grouping refers to the gathering of data that share some common characteristic. Sorting refers to ordering data in an arrangement that differs from the natural order as stored in the database. Users may find it useful, for example, to order activities by the planned start date. Sorting by planned start in ascending order would generate a list of activities in order they are scheduled to be worked. In some situations, it may be a desirable to group together schedule activities that use the same resource for certain reports, for example. Grouping by values in a resource code field would enable this function. Or, it may be desirable to group schedule tasks together that use the same Center code for a report that would show certain data summarized by Center. This will aid P/p personnel that need to reference or read schedules without having a detailed understanding of the scheduling tool being used.

The use of field codes can aid in the integration of P/p management (e.g., PP&C functions). If EVM is required, it is a recommended practice that schedule data be coded with the set of NASA-identified EVM fields, at a minimum, since the complete set of EVM milestones comprises the PMB from a schedule perspective. The EVM-required field codes are provided on the SCoPe website.[43] Figure 5-13 shows an example of a schedule coded with an interface to the Risk Management System, two interfaces with the Earned Value Management System (EVMS), and an identification field listing the CAM for each activity.

---

[43] SCoPe website, https://community.max.gov/x/9rjRYg

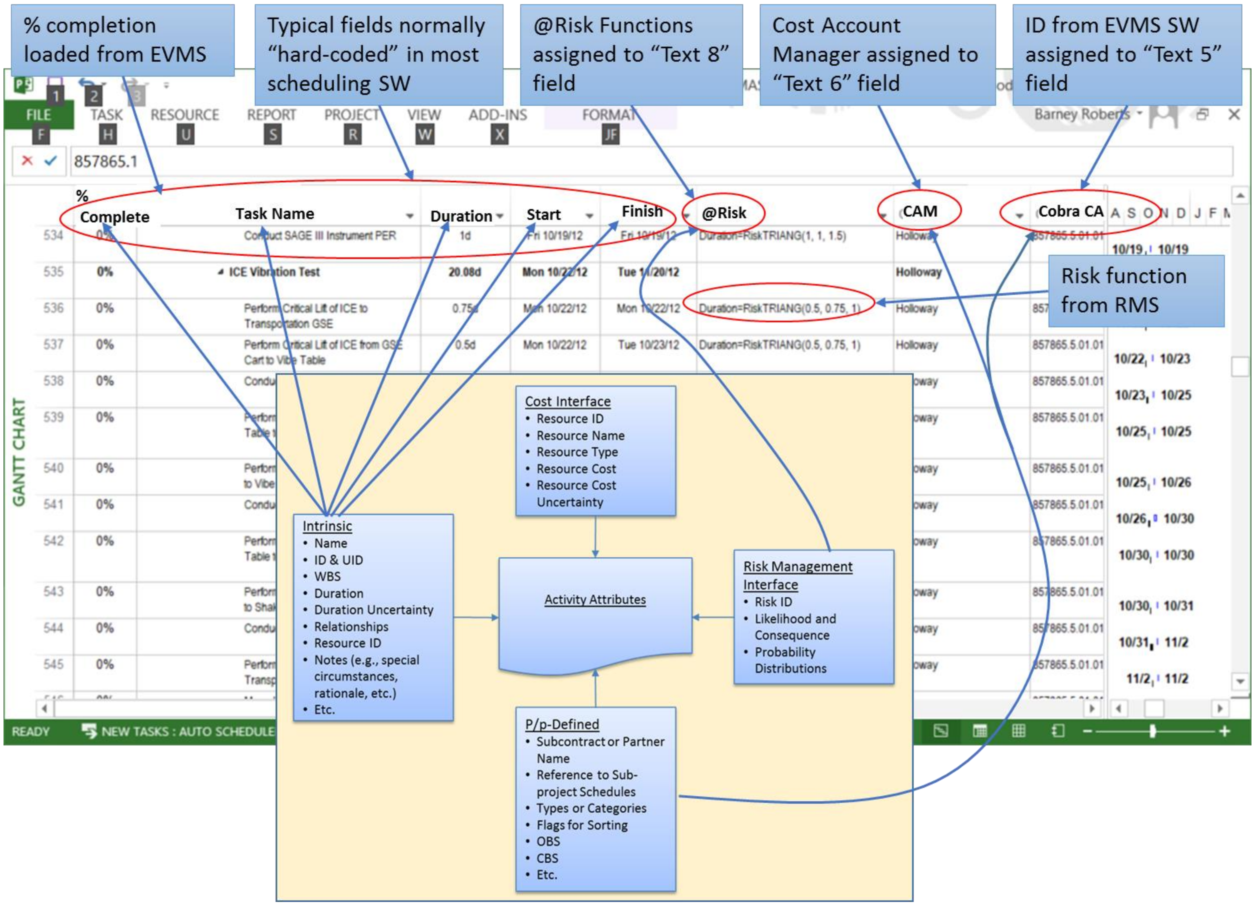


Figure 5-13. Example showing a few typical Activity Attributes coded into fields in the MS Project scheduling tool.

The project shown had approximately 20 field codes defined for information and interface with other processes. The intrinsic fields are those that are "hard-coded" in most scheduling software. Other important attributes often used, but not shown in the example are:

- From the Organizational Breakdown Structure (OBS), a code that identifies the organization that is responsible for execution of the activity. Example: Power and Propulsion Division, code PPD.
- For contracted activity, a code that identifies the contract and/or a code that identifies the contractor.
- For contracted activity, a Contract Line Item Number (CLIN).
- Flags are commonly used to identify specific classes of activities to enable quick search, e.g., notification milestones, control milestones, target milestones, interface milestones, critical activities, etc.
- Sometimes integration working groups are assigned to a collection of activities that are closely related such as APW, Avionics, Power and Wiring.

In a similar fashion, but not shown here, the cost database for the *IMS* has fields that need to be established for the cost interface including resource name, resource costs, uncertainties, and risk functions from the Risk Management System.

Document the BoE for the Schedule Field Codes

The table of *Activity Attributes* and associated field codes to be used in the *IMS* are considered part of the *BoE*. Rationale for field code types can be captured in the table of *Activity Attributes* (e.g., fields necessary to implement EVM, if required) and should include ties to the schedule content that will be assessed, analyzed, and controlled.

5.5.3 Implement Scheduling Method

It is a best practice for the schedule to be developed using Critical Path Method (CPM) scheduling. CPM is a logic network diagram scheduling technique used to estimate the minimum P/p duration by calculating critical path, which is the longest path through the schedule network. Most scheduling software supports CPM scheduling. Five approaches for characterizing the P/p *IMS* in support of CPM are described in Section 5.6.1.

The essential technique for employing CPM is to construct a model of the P/p that includes the following:

- A list of all activities required to complete the P/p (typically categorized within a work breakdown structure)
- The time (duration) that each activity will take to complete
- The dependencies between the activities
- Logical end points such as milestones or deliverable items

Although CPM scheduling offers a visual, time-phased representation of P/p activities, the P/S should be aware that it does have limitations when used in its most basic form:

- Based on only deterministic task duration; does not consider duration uncertainty
- Less focus on non-critical tasks that can cause risk
- Does not consider resource dependencies; assumes resources are free when needed
- Misuse of float/slack (work expands to fill the time)
- Early finishes (time gains) not effectively being used by subsequent activities (typically due to early start dates not accounting for resource availability or lack of resource-informed schedule)

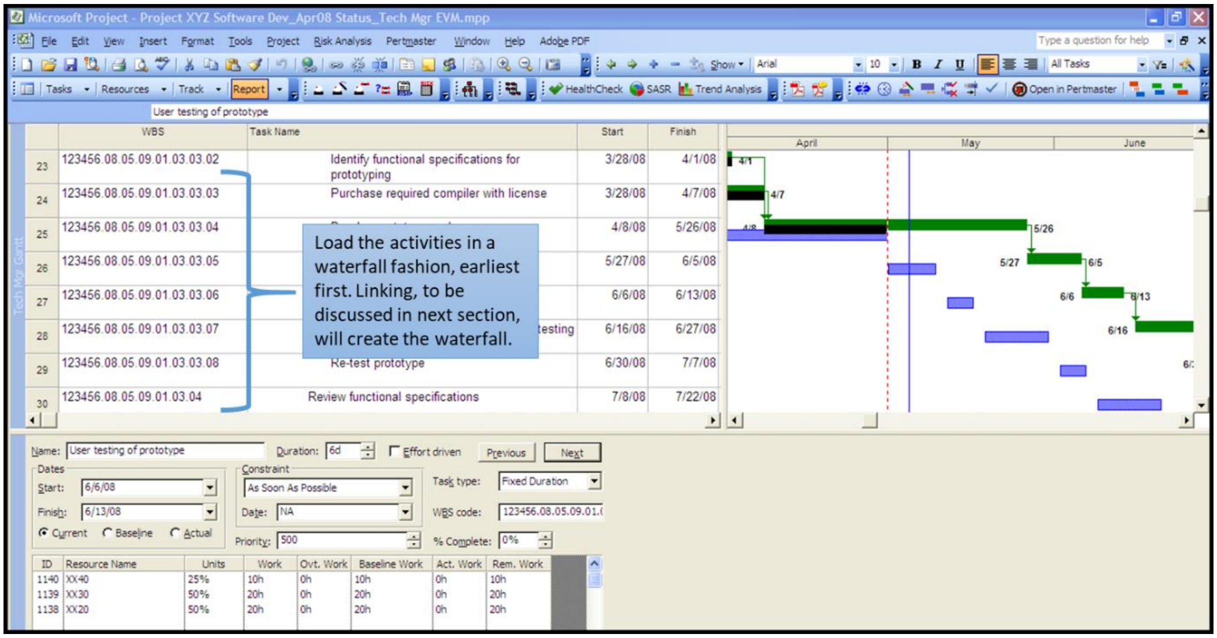
Thus, it is a recommended practice for NASA P/ps to use CPM scheduling in an expanded form to include the integration of other programmatic aspects (e.g., cost, risk, etc.), which provides a more integrated and holistic representation of the P/p. For instance, CPM scheduling is more effective and informative when risks and resources and/or costs are integrated into the schedule. If management focuses solely on critical activities without taking into account critical resources, it risks ignoring or overworking a P/p's most valuable assets and potentially jeopardizing the P/p's timely completion.[44] If management does not consider the potential discrete risk impacts to a schedule, it may not be managing to the path most likely to delay the P/p.

Document the BoE for the Scheduling Method

Because CPM scheduling is a best practice, it is necessary to document the rationale for any portions of the schedule that use alternate scheduling methods (e.g., agile) in the *BoE*. It is important to understand how schedules or portions of the schedule that do not employ CPM scheduling may affect assessment metrics and analysis results.

5.5.4 Determine Schedule Hierarchy

It is a best practice for the schedule activities to be collected as organized in the WBS and tiered according to the lower-level, related WBS items. The *IMS* structuring is particularly important to facilitate supporting P/p management processes and functions. For example, in most cases, the WBS is the primary structure of the EVMS. Whether or not EVM is required, activities should be organized in a sequential, waterfall approach. In general, a sequence of events should be broken down such that when one activity finishes, another starts. While this approach may not always be possible, if the schedule is developed using this approach, the effort of logically connecting the activities will be much easier. It is important to avoid up/down flows because such an arrangement greatly complicates the checking, verification and performance tracking, as well as the schedule assessment process. This process is facilitated by the field codes setup in Section 5.5.2. Figure 5-14 shows an example, where activities are loaded in a waterfall method starting with the P/p start date.



User testing of prototype

	WBS	Task Name	Start	Finish
23	123456.08.05.09.01.03.03.02	Identify functional specifications for prototyping	3/28/08	4/1/08
24	123456.08.05.09.01.03.03.03	Purchase required compiler with license	3/28/08	4/7/08
25	123456.08.05.09.01.03.03.04		4/8/08	5/26/08
26	123456.08.05.09.01.03.03.05		5/27/08	6/5/08
27	123456.08.05.09.01.03.03.06		6/6/08	6/13/08
28	123456.08.05.09.01.03.03.07	testing	6/16/08	6/27/08
29	123456.08.05.09.01.03.03.08	Re-test prototype	6/30/08	7/7/08
30	123456.08.05.09.01.03.04	Review functional specifications	7/8/08	7/22/08

Load the activities in a waterfall fashion, earliest first. Linking, to be discussed in next section, will create the waterfall.

Name: User testing of prototype
Duration: 6d
☐ Effort driven
Previous
Next
Dates
Start: 6/6/08
Finish: 6/13/08
● Current ○ Baseline ○ Actual
Constraint
As Soon As Possible
Date: NA
Priority: 500
Task type: Fixed Duration
WBS code: 123456.08.05.09.01.
% Complete: 0%

ID	Resource Name	Units	Work	Ovt. Work	Baseline Work	Act. Work	Rem. Work
1140	XX40	25%	10h	0h	10h	0h	10h
1139	XX30	50%	20h	0h	20h	0h	20h
1138	XX20	50%	20h	0h	20h	0h	20h

Figure 5-14. Load the activities in a waterfall fashion, earliest first.

---

[44] GAO-16-89G. GAO Schedule Assessment Guide. Page 87. December 2015. http://www.gao.gov/assets/680/674404.pdf

Document the BoE for the Scheduling Hierarchy

Because the *IMS* requires traceability to the WBS, it is important to include in the *BoE* rationale for any activity flows that are not organized according to the WBS hierarchy. Providing justification for the hierarchy used in the schedule will aid in resource allocation and understanding the critical path, as well as tracing accountability to the appropriate Technical Leads.

The *Requirements Check*, Procedure 1, should be performed at this juncture to ensure *IMS* traceability to the P/p's requirements set, which includes the WBS, as described in Section 6.2.2.1.1.

5.5.5 Determine Activity Naming Convention

It is a best practice for a schedule activity naming convention to be established that allows for clear, concise, and differentiable activities. Each activity represents a discrete, measurable element of work that is part of the overall P/p scope. In order to describe the work to be accomplished without ambiguity, activity and milestone descriptions need to be unique. The P/S should work with the Technical Lead that is responsible for the activity to develop a clear and specific description. An activity description should also be concise yet complete – complete enough to stand on its own, but concise enough to facilitate ease of use, such that personnel other than the P/S will be able to understand the work scheduled. This applies to all activities, not just summary-level activities. Acronyms and abbreviations are acceptable as long as they are standardized and used consistently throughout all P/p documentation.

Activity nomenclature convention or methodology should be established at the beginning of the P/p and adhered to throughout the P/p life cycle. It is a recommended practice that summary activity names be aligned with the WBS naming structure for easier traceability. A P/p may elect to use a "noun, adjective, modifier" or "modifier, adjective, noun" convention of for all summary activity descriptions and a "verb, adverb, modifier" or "modifier, adverb, verb" convention for all discrete measurable activities. For example, detailed (non-summary) activity descriptions should contain a "verb" so it is completely clear what the accomplishment of work being scheduled is (e.g., "Fabricate CM Front Bay Access Panel BR549"), whereas summary-level activities descriptions should not contain a verb and be more "noun" oriented (e.g., "CM Fabrication of all Access Panels"). This type of standardized approach, if used consistently, will make efforts such as reporting or searching the *Schedule Database* and *IMS* much easier.

Document the BoE for the Activity Naming Convention

The P/p's preferred approach for the activity naming approach in the *IMS* should be defined in the *SMP* as part of the *BoE*. Consistency in the naming approach supports the alignment of the *IMS* with the WBS. It also aids in traceability of activities for Assessment and Analysis, and the tracking of activities for Maintenance and Control, and alignment of the *IMS* with the WBS.

5.5.6 Capture All Scope

It is a best practice for the schedule activities to capture all approved work scope, such that all work can be allocated to complete the WBS elements in an integrated manner. It is critical that the *IMS* contain tasks, milestones, and interdependencies logically sequenced in a manner that accurately models the implementation plan for all approved scope from P/p start through completion based on all P/p work as defined/broken down by the established WBS. Utilizing the WBS, as well as other P/p sources of data, will not only help to ensure that the total scope of work is included in the schedule, but also consistency in the integration of cost and schedule data.

A key consideration for capturing all scope in the schedule is making the schedule understandable and easy to follow and use. While the content of each task in the schedule may be perfectly clear to the P/S, it must also be absolutely clear to the PM, Technical Lead (e.g., WBS Element Owner/Control Account Manager/Integrated Product Team Lead), and other P/p personnel (e.g., PP&C personnel). The phase and maturity of a P/p often dictate how the scope is modeled in the schedule. Figure 5-15 provides an overview of the expected schedule content and maturity at each phase of a Single-Project Program or project:

Phase	Expected Schedule Content and Maturity
Pre-Phase A ***Concept Studies***	Pre-Phase A schedules should include major development and integration milestones representing: key milestones, project reviews, integration points, external and internal interfaces or handoffs, and deliverables. Additionally, it is expected there should be high-level summary tasks reflecting the general time-phasing estimated for developing system/mission requirements, hardware design, fabrication, integration & test, and operational capabilities. These early, high level summary estimates are typically derived from parametric models or historical data from past similar projects. However, it should be noted that detailed information should be available and included at a discrete and measurable level of detail for each concept study that may be involved during this incremental phase.
Phase A ***Technology Development***	Phase A preliminary schedules should have significantly more detail than the Pre-Phase A schedules. During this phase of Formulation, the mission/system concept definition is completed, most concept and trade studies are completed, preliminary requirements are established, and a preliminary Project Plan is developed. Therefore, project definition becomes clear enough during Phase A to allow for a more discrete breakdown of work tasks and milestones. Milestones should have predecessor and successor activities. A preliminary critical path should be identifiable; there should be reasonable slack on the activities. Funded schedule margin should be included, and resources should be identified. Additional unfunded margin activities may also be included. The phased schedule should be synchronized with the project phase budget. Preliminary requirements by subsystem, remaining trade studies, preliminary and final design by subsystem, long lead procurements, preliminary systems engineering products, preliminary safety and mission assurance products, fabrications by subsystem, subsystem and system integration flow, subsystem and system testing, documentation development, flight simulations software development and deliverables, hardware development and test, test operations development for ground and flight should all be identified in the schedule during Phase A.

Phase B ***Preliminary Design and Technology Completion***	Phase B is the final incremental phase of Formulation, which should produce the necessary project definition to allow for discrete and measurable IMS detail, at least for the near-term of six to twelve months. Near-term effort should be scheduled in meaningful tasks with shorter durations. Durations not exceeding one month are preferable. IMS task detail down to the level where work is discretely planned and measured at the lowest levels of the WBS and potentially lower where necessary (i.e., subsystem, component, software function, test phase, procurement deliveries, GFE deliveries, interface points, facility modifications, miscellaneous documentation development stages, preliminary orbital debris assessment, etc.). A rolling wave approach for planning the out-years may be used providing that the total scope of the project is identified within the schedule and that all WBS elements are included. Durations for the out-year planning phases can be further decomposed as the schedule matures. However, in cases where far-term effort is well defined and task information is already available at the above described low level of detail, then it should also be included in the IMS at the earliest opportunity. Phase B schedule baselines are the foundation for measuring project schedule performance throughout implementation. Reporting and other schedule management criteria should be in place and in practice by the project. Regular status updates, reporting and performance analysis should be taking place in the project office. The schedule should be detailed enough to accommodate the collection of actuals (time and cost) at the appropriate WBS level. The IMS will receive final baseline approval at the end of Phase B. The baseline will then serve as the EVM performance measurement baseline.
Phase C ***Final Design and Fabrication***	Phase C is subject to the same guidance as Phase B. As time proceeds, far-term work tasks with longer durations should be broken down into clearly defined and meaningful tasks with shorter durations (not exceeding one month, or potentially shorter). Special focus should be given to providing clear schedule visibility into the completion of final design by specifying tasks and “release milestones” for specific design or component-level drawings. Fabrication tasks should clearly delineate the necessary work steps that reflect the planned manufacturing work flow. IT development should clearly provide detailed tasks for software functional design, code, debug, unit and integrated testing, software verification and validation, IT hardware development, integration, and test. Specific tasks for Quality Assurance and buy-off should also be clearly identified, as well as, orbital debris assessment baseline documentation. Product delivery milestones from various fabrication process completions should reflect the necessary handoff points to hardware assembly and systems integration.
Phase D ***System Assembly, Integration and Test, Launch and Checkout***	The above Phase C guidance also applies to Phase D. Again, as time proceeds, far-term work tasks with longer durations should be broken down into clearly defined and meaningful tasks with duration lengths similar to those recommended in Phase C. Special focus should be given to clearly defining the discrete flow of tasks necessary for requirements verification and for hardware and software components to be assembled and then integrated into subassemblies, subsystems, and systems, reflecting the work required for final assembly, integration and test. Schedule detail for this phase should clearly delineate the necessary and measurable work steps that reflect the assembly, integration and test flow of work. Specific tasks for Quality Assurance and buy-off, as-built hardware and software documentation, final systems acceptance reviews, operations procedure finalization, and Operations training, and certification should also be clearly identified. Specific hardware deliveries for Launch Operations activities should be included. It should be noted that all pre-launch work should be verified and closed by the Flight Readiness Review (FRR), which precedes KDP E.

Phase E ***Operations and Sustainment***	The focus of the schedule for the incremental Phase E is the definition of tasks for execution of the Mission Operations Plan: final verification and validation reports, flight readiness reviews, final processing of launch hardware, ground operations, service preparation for launch, launch activities through achieving operational orientation, or-orbit activities relating to mission tracking, commanding, telemetry, trajectory, systems analysis, mission payload initialization sustainment. Operations tasks with longer durations should be broken down into clearly defined and meaningful tasks with shorter durations. Special focus should be given to clearly defining the discrete flow of tasks necessary for Launch Operations and Sustainment.
Phase F ***Closeout***	The final phase, Phase F should also be defined in the same discrete and measurable level of detail as described above. The focus of this incremental phase should address tasks such as: on de-orbit preparation and execution, abandonment of in-place flight hardware, recovery of project assets, data/equipment disposition and storage, final environmental impact disposition and resolution, lessons learned, contract closeouts, and final public education and notification of reporting.

Figure 5-15. Relationship between the NASA life cycle phases and project schedule content.

Document the BoE for the Scope Included in the IMS

An important aspect of the schedule *BoE* is that it illustrates traceability to the complete P/p scope. Documenting the source of information that serves as a basis for the content included in each *IMS* element, most always the set of requirements set ratified by the P/p and its stakeholders, allows for direct traceability to P/p requirements and assumptions. Source information pertaining to requirements should be noted in the *IMS's* notes field, the *BoE* itself, and within the *SMP*. As in 5.5.4, the quality of the *IMS's* connection to the P/p's scope and requirements set should evaluated by executing the *Requirements Check* assessment procedure, as described in Section Procedure 1. Requirements Check6.2.2.1.1.

5.5.7 Develop Schedule Detail

It is a best practice for activities to be developed to the lowest level of detail appropriate, typically the work package level, as early in the P/p life cycle as possible. It is a widely accepted theory that advanced planning in the early stages of a P/p yield significant cost and time benefits when compared to the original cost and time investment. Starting with the Cost and *Schedule BoEs*, the WBS, and the *Milestone Registry*, all activities are loaded into the selected scheduling tool.

5.5.7.1 Define Work Activities and Milestones

The WBS is "decomposed" into discrete measurable tasks and milestones. It is a recommended practice to input schedule data using a predominantly task-oriented (activities with durations) approach, including milestones that are significant to the P/p. Activities should also be detailed enough so that interface points can be clearly identified. These interface points, such as phase conclusions and giver/receiver "handoffs", are places in the schedule where milestones would be appropriate.

All identified milestones should be incorporated into the *IMS*. P/p notification and control milestones, which are used as control points for work scope performance, are typically defined during pre-Phase A in the *Milestone Registry* and may also be identified as events in the IMP, if it exists. The *IMS* should always include a start milestone, which is a predecessor for the work activities at the beginning of a P/p, as well as a finish milestone, which is the successor to all logic paths at the end of the P/p. Milestones may also be used to identify major P/p events, such as LCRs, KDPs, or major test events. Contractual or acquisition milestones (e.g., procurements, hardware deliveries, etc.), interface milestones, and programmatic milestones should also be included in the *IMS*, if available. Locating P/p milestones at the top of the *IMS* also helps to facilitate analysis. In most cases, milestones should be tied to or represent a specific product deliverable or event and should have clear, objective (quantifiable) criteria for measuring accomplishment.

It is necessary to keep in mind when developing the *IMS*, every schedule activity will eventually be updated. The identified activities should facilitate the measure of progress. Schedule data that is task-oriented lends itself to a more meaningful approach to monitoring task progress through the Schedule Maintenance and Control process, as each activity is easily identifiable for updating purposes.

5.5.7.2 Define Level of Effort Activities

In addition to detailed activities and milestones, it is important to include tasks in the schedule that represent support efforts (e.g., P/p management, systems engineering, safety and mission assurance, etc.), which are typically referred to as "level of effort" (LOE) tasks. LOE tasks generally do not have discrete products associated with their efforts but are seen as contributing to the comprehensive plan of all work that is to be performed.[45] LOE tasks often involve work that must be periodically repeated. The duration of an LOE task is generally from the start to the finish of the work effort being supported. Thus, an LOE activity will never add time to the P/p itself because it is dependent on the duration of the work activity it supports. As such, an LOE task should never be on a P/p's critical path. For EVM purposes, LOE activities are measured "automatically by the passage of time" in terms of resources planned within a given fiscal period.

5.5.7.3 Consider Schedule Size and Granularity

The overall size of the *IMS* depends on many factors, including the complexity of the P/p and its technical, organizational, and external risks. In determining the appropriate level of schedule detail, it is important to understand who the stakeholders are. Integrated schedules are crucial for all levels of management oversight within NASA and its contractor community. The level of detail contained in the schedule should also be a reflection of the intended use of the schedule. P/p schedules summarized for management or presentations, as discussed in Section 5.6.2, may contain less detail than schedules used by personnel performing the schedule activities such as procurement, design, fabrication, or testing. Program Managers may require less detail for their evaluations than PMs. While it is true that all Program work scope must be included within a Program schedule, the level of detail of the individual project activities captured in the Program *IMS* may vary to accommodate the specific management needs established at the Program level.

Generally, the greater the level of detail in a schedule, the greater the level of fidelity the schedule has. In addition, more discrete task durations provide better insight into the real work integration points, leading to increased accuracy in task sequencing and critical path identification, as well as increased accuracy of progress measurement and *IMS* data credibility. The level of detail in the schedule can also

---

[45] GAO-16-89G. GAO Schedule Assessment Guide. Page 14. December 2015. http://www.gao.gov/assets/680/674404.pdf

impact other P/p management process. Task-oriented activities should be sufficiently detailed to allow for the practical establishment of defined finish-to-start network logic relationships. A lack of clear understanding of the effort involved in each task can make Schedule Assessment and Analysis cumbersome. However, using an excessive number of logical relationships to the same task or milestone complicates schedule analysis.[46]

Consistency in activity granularity is also important. It is a recommended practice for a schedule to be developed at a consistent level of detail. This allows PM to adequately plan the necessary resources and to ensure adequate budget will be available to accomplish the work when it is planned. It also enables greater decision-making capability related to discrete progress measurement, management visibility, and critical path identification and control. However, consistency in granularity may be difficult to achieve. Early in P/p life cycle, work is often based on high level assumptions because less detail is available. In addition, whereas some Program schedules may be composed of aggregated project-level milestones captured at a high-level and appear at a more consistent level of maturity throughout their life cycle, project schedules tend to grow in maturity over time.

One exception to having consistency in schedule granularity occurs when it is important to know exactly which detailed activities (and associated costs) are the most affected by risk and therefore constitute the critical or driving paths. It a recommended practice that high risk and/or high cost areas within the P/p should reflect more task detail within the *IMS* to support Schedule Analysis. Another example would be the addition of tracking milestones that would be used in some of the performance measurements. P/Ss should keep in mind that the level of detail used must lend itself to meaningful cost/schedule and schedule/risk integration. It should also be noted that the level of schedule detail may need to facilitate the type of EV measurement technique (e.g., 0-100, 50-50, weighted milestones, percent complete, level-of-effort) that will be assigned in each earned value work package, which are discussed in the NASA EVM Handbook. In addition, some placeholder activities that are not defined in the WBS, nor captured in the BoEs, may need to be added to support other P/p process interfaces, such as the Business Management System, EVMS, and Risk Management System or P/p-specific tracking tools.

- **Rolling Wave.** Rolling wave planning, is a method that allows for scheduling to occur in waves, through progressive elaboration, adding more detail as the P/p evolves and work activities become clearer. The rolling wave method involves the use of both detailed and summary tasks and can be applied to CPM scheduling. Rolling wave planning is useful when dealing with long development or repetitive production schedules. It is also is widely used across NASA P/ps in conjunction with EVM techniques, as illustrated in Figure 5-16.

---

[46] PASEG, Version 3.0. National Defense Industrial Association (NDIA), Integrated Program Management Division (IPMD). March 9, 2016. Page 61.

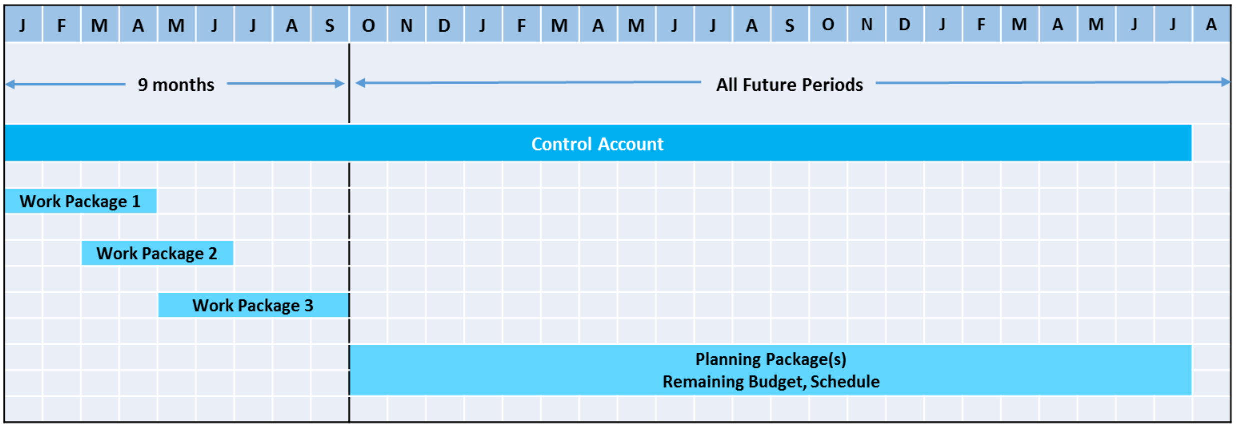


Figure 5-16. An example of the rolling wave planning approach used in conjunction with EVM.

When using the rolling wave method, near-term tasks (i.e., activities within 6-12 months of the current date) are planned to a lower, discrete level of detail. It is a recommended practice for schedule activity durations to be less than two times the update cycle (e.g., less than two months) for near-term activities, as this allows for reporting of the start finish of an activity within one or two update cycles, allowing management to focus on performance and corrective action if needed. Keeping durations to two months or less will certainly benefit P/ps where EVM is being employed and should result in increased accuracy in performance data. Tasks with durations longer than two months tend to make measurement of objective accomplishment more difficult to assess accurately. Exceptions to this recommended practice include procurement activities (e.g., long lead items) or level of effort (LOE) activities (e.g., administrative support).[47] This approach also enhances the P/S's ability to more accurately identify the P/p critical path.

Tasks that are scheduled to occur farther into the future should be included in the schedule but may be planned at a more summary level of detail or planning package level. These summary tasks, while reflecting less detail, should still provide enough definition of future work to allow for effective identification and tracking of the P/p critical path or other driving paths. However, rolling wave planning should not be used as a way around reflecting the most meaningful level of detail anywhere in the schedule if the information is already known. Tasks should be developed to a discrete level of detail as early as possible in the P/p life cycle to help to identify and mitigate P/p conflicts, risks, and problems. This is particularly important for EVM purposes, as no *Performance Measures* are taken on planning packages, only work packages. Durations should be revisited periodically as work progresses and as new information becomes available. Thus, as future summary-level tasks (or planning packages) come into the near-term window, they should be planned to a greater level of discrete and measurable detail and incorporated into the *IMS*. In addition, the use of the rolling wave approach should be defensible and supported by the *BoE*, since it is quite possible that future detailed planning will reveal situations that, if known earlier in the P/p, could have resulted in more efficient and less costly work plans.

---

[47] PMI. Practice Standard for Scheduling. Second Edition. Page 28.

Document the BoE for the Schedule Detail

While the level of detail in the P/p schedule should be as consistent as possible throughout, the granularity may evolve as the P/p progresses through its life cycle. It is important to document the expected schedule maturity and level of detail justification for each life cycle phase as part of the *BoE*. It is also necessary to provide rationale in the *BoE* for any inconsistencies in the level of detail for schedule elements, as lack of adequate detail in any area of the schedule may affect performance measurements, critical path or driving path identification, or how uncertainty is applied when performing a schedule risk analysis. This set of rationale should here be evaluated through the execution of the *Critical Path and Structural Check* to the extent that elements of it pertaining to level of detail considerations can be performed at this early stage. This aspect of the *IMS* is especially essential to its tractability; as such, level of detail will be continuously scrutinized over iterations of the assessment, analysis, and control processes. Assessment criteria for ensuring that the P/p has an appropriate level of detail can be found in Section 6.2.2.2.1.

5.5.8 Logically Link the Activities

Logical relationships are critical to accurately modeling a P/p's planned activities in the *IMS*. They provide the dependencies between activities that help create the schedule network diagram, which sequences the activities in a P/p across time. Understanding the dependencies between activities usually starts with the development of summary-level flow diagrams, followed by assigning specific activity relationships, paying special attention to avoid leads and lags and minimize activity constraints unless necessary to represent particular activity-to-activity relationships.

5.5.8.1 Assign Activity Dependencies

It is a best practice for schedule activities to demonstrate horizontal traceability, such that they are logically sequenced using proper relationship types that account for the interdependence of all activities and milestones. Activities have dependencies upon one another. Activity relationships provide the means to satisfy the need for horizontal traceability within the *IMS*. Establishing proper dependency relationship-types is necessary to accurately model the P/p's planned implementation. Network logic must be complete, accurate, and realistic for horizontal traceability to help ensure the ability to assess interim progress and forecast completion of key milestones and activities, as well as to perform critical path analysis, as work is performed. A simple example is that one cannot roof a house until the framing is complete. For a NASA spacecraft, the design is not started until the requirements are completed.

There are a number of integration points within any P/p development flow, for example SDR, PDR, CDR, SIR, Begin ATLO, etc. It is a recommended practice that summary-level flow diagrams be developed as an aid to facilitate the assignment of schedule dependencies. Laying out summary-level flow diagrams can help establish the flow of activities in early schedule development and is often employed before schedule activities are developed to the lowest level of detail (Section 5.5.7). Flow diagrams are useful not only as a guide for linking activities, but also as a communication tool to aid in the P/p's understanding and reporting of the activity relationships. Figure 5-17 is an example flow diagram from a NASA project.

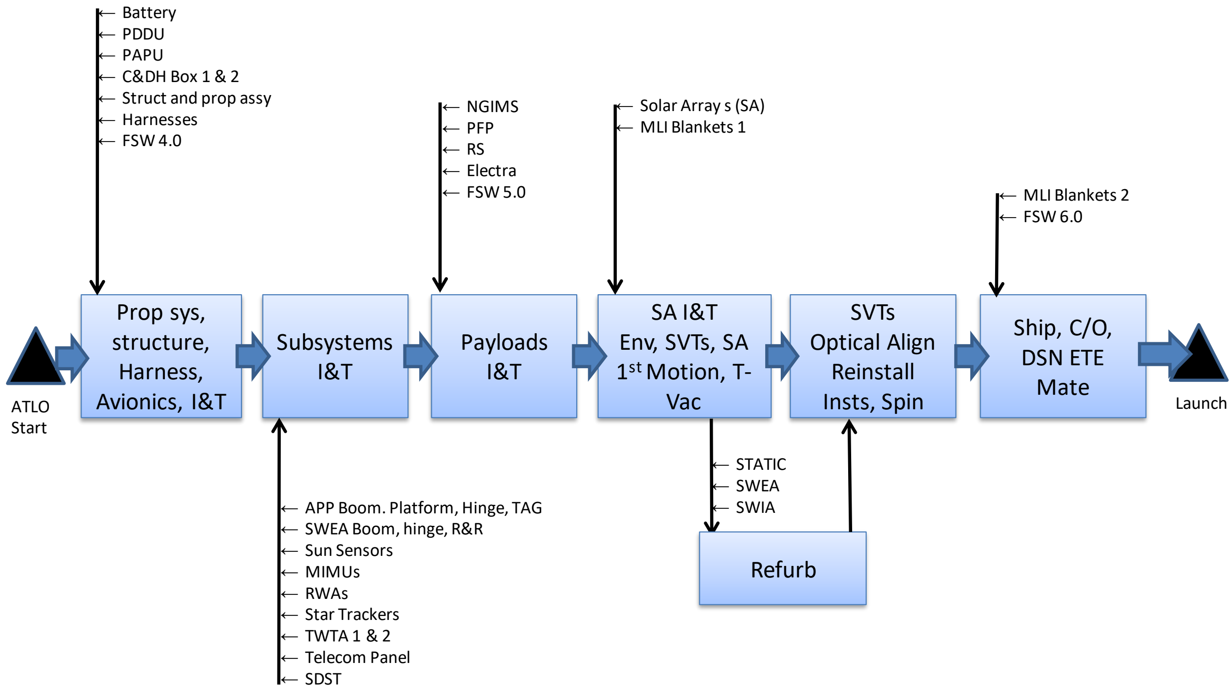


Figure 5-17. An example of a flow diagram showing where spacecraft, instrument subsystems and software drop into the system integration and test flow.

Flow diagrams generally show major integration points and which subsystems and/or components flow into them. For example, in the first box on the left of the figure, the major structure and the propulsion system are integrated. Also included in that first step are supporting subsystems and subsystems requiring early integration due to access problems. After these subsystems are integrated, various tests are performed. Following that step, the remaining spacecraft subsystems and some of the instruments are integrated and tested. The process continues through the remaining steps. These steps follow repetitive cycles of "integrate then test", culminating in the last step leading up to launch vehicle integration and launch.

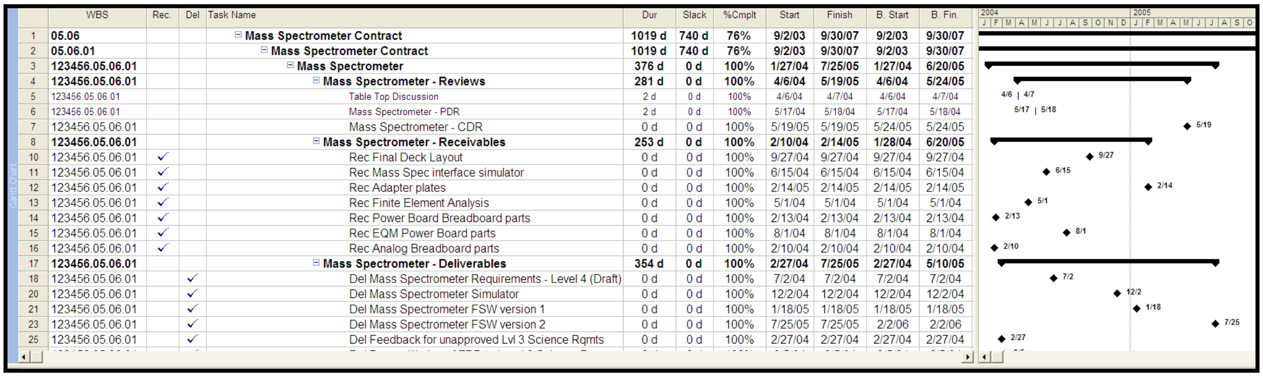
Once the overall workflow is sufficiently understood, activity dependencies can be assigned. Every milestone and activity in the schedule should have at least one predecessor and at least one successor (i.e., no "open ends"). Two acceptable exceptions are the P/p start milestone, which has no predecessor, and the P/p finish milestone, which has no successor. Another exception to this rule may occur for activities or milestones that represent receivables or deliverables (Rec/Del) as described below. Any other instances only occur with valid reasons that are accurately documented.

Activities should also not be arbitrarily restricted but should be logically linked such that progress driven effort determines remaining duration. Predecessor and successor relationships should be appropriate to the work needing performed and supported by the BoE. Redundant links should be avoided since they often confuse workflows and complicate analysis ((e.g., if Task A is linked to Task B, Task B is linked to Task C, and Task A is linked to Task C, then the link between Task A and Task C is a redundant link. Logic should never be assigned to summary activities, as summary Start and Finish Dates are derived from the detailed activities.

Note: MS Project allows for two scheduling modes: “Manually Schedule” and “Auto Schedule”. Manually Schedule is sometimes used for tasks lists or at the start of a P/p, when constraints or predecessors/successors are unknown, but an output with an overview of key dates is desired. Manually Schedule calculates the schedule based on dates entered by the P/S rather than the predecessors and their constraints. Auto Schedule is where the benefits of the scheduling tool tie into the Schedule Management process, as it considers the constraints and applies the logic to the relationships entered by the P/S to calculate the schedule.

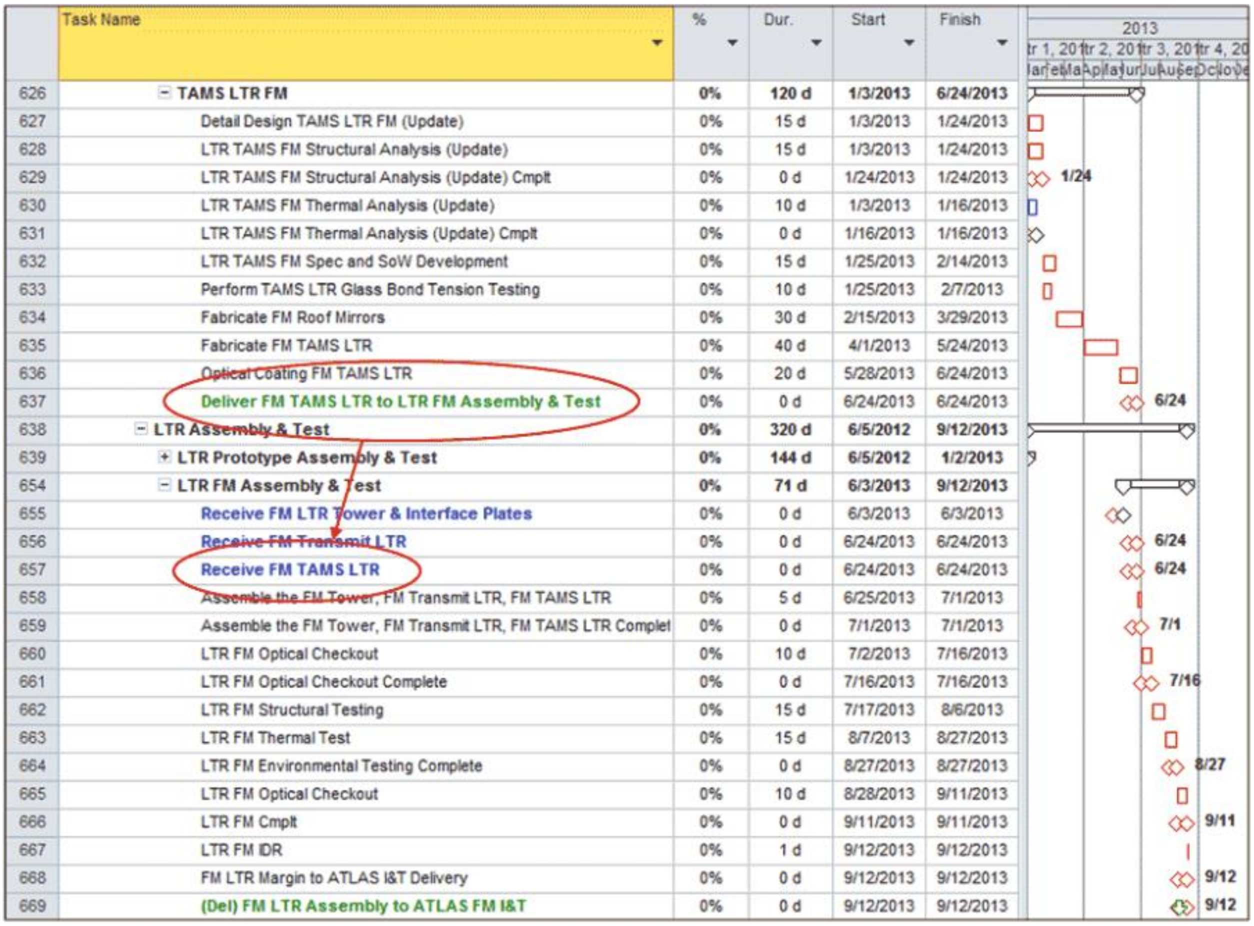
Receivables/Deliverables

Rec/Dels, also known as givers/receivers, formally document the schedule interfaces and handoffs of critical items or products. The P/S may choose to maintain the Rec/Dels at a separate section near the beginning of the *IMS* for easier visibility, as shown in Figure 5-18, or embedded in the workflow of the schedule and supporting schedules, as sown in Figure 5-19 and Figure 5-20.



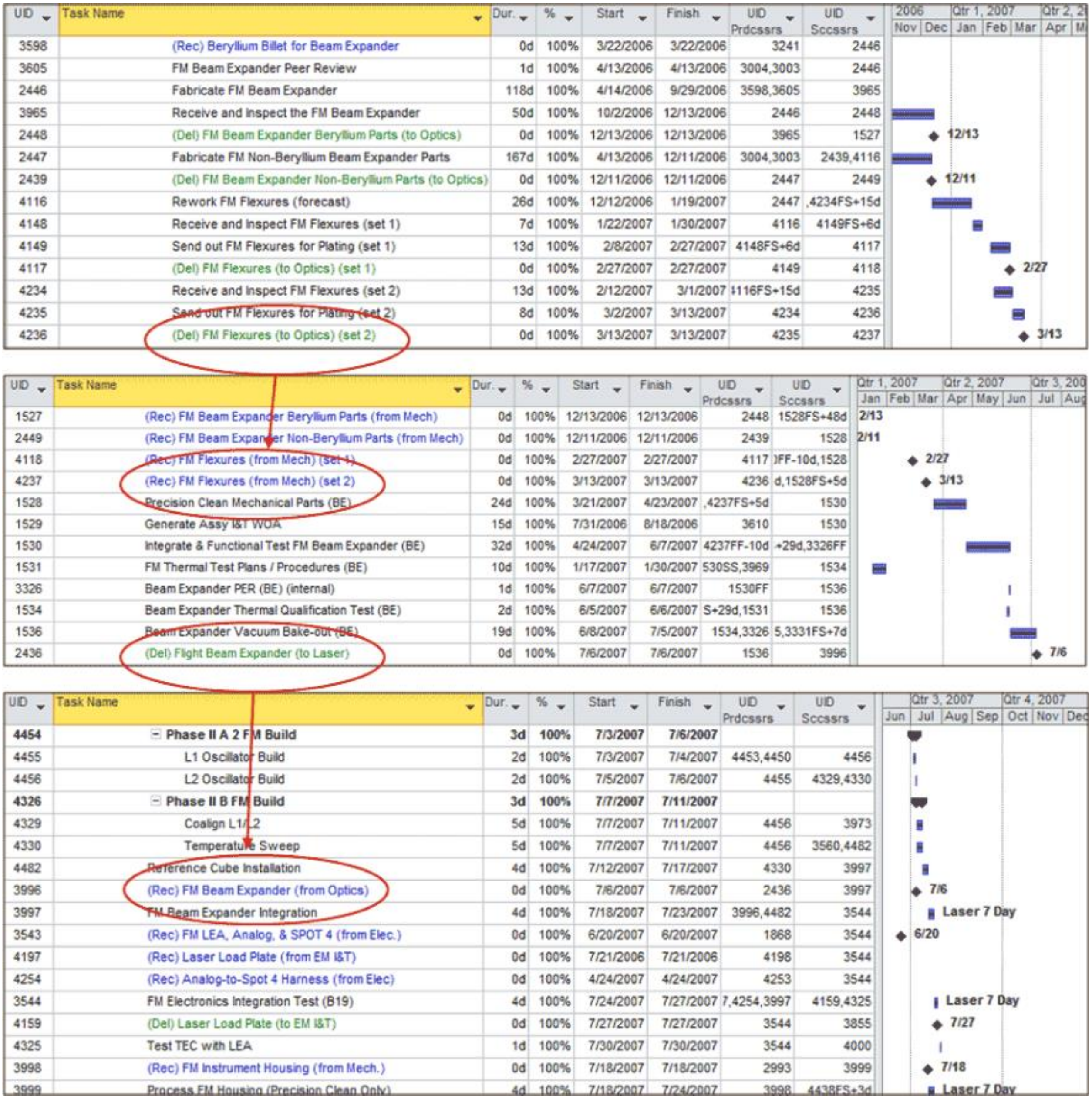
	WBS	Rec.	Del	Task Name	Dur	Slack	%Cmplt	Start	Finish	B. Start	B. Fin.
1	**05.06**			**Mass Spectrometer Contract**	**1019 d**	**740 d**	**76%**	**9/2/03**	**9/30/07**	**9/2/03**	**9/30/07**
2	**05.06.01**			**Mass Spectrometer Contract**	**1019 d**	**740 d**	**76%**	**9/2/03**	**9/30/07**	**9/2/03**	**9/30/07**
3	**123456.05.06.01**			**Mass Spectrometer**	**376 d**	**0 d**	**100%**	**1/27/04**	**7/25/05**	**1/27/04**	**6/20/05**
4	**123456.05.06.01**			**Mass Spectrometer - Reviews**	**281 d**	**0 d**	**100%**	**4/6/04**	**5/19/05**	**4/6/04**	**5/24/05**
5	123456.05.06.01			Table Top Discussion	2 d	0 d	100%	4/6/04	4/7/04	4/6/04	4/7/04
6	123456.05.06.01			Mass Spectrometer - PDR	2 d	0 d	100%	5/17/04	5/18/04	5/17/04	5/18/04
7	123456.05.06.01			Mass Spectrometer - CDR	0 d	0 d	100%	5/19/05	5/19/05	5/24/05	5/24/05
8	**123456.05.06.01**			**Mass Spectrometer - Receivables**	**253 d**	**0 d**	**100%**	**2/10/04**	**2/14/05**	**1/28/04**	**6/20/05**
10	123456.05.06.01	✓		Rec Final Deck Layout	0 d	0 d	100%	9/27/04	9/27/04	9/27/04	9/27/04
11	123456.05.06.01	✓		Rec Mass Spec interface simulator	0 d	0 d	100%	6/15/04	6/15/04	6/15/04	6/15/04
12	123456.05.06.01	✓		Rec Adapter plates	0 d	0 d	100%	2/14/05	2/14/05	2/14/05	2/14/05
13	123456.05.06.01	✓		Rec Finite Element Analysis	0 d	0 d	100%	5/1/04	5/1/04	5/1/04	5/1/04
14	123456.05.06.01	✓		Rec Power Board Breadboard parts	0 d	0 d	100%	2/13/04	2/13/04	2/13/04	2/13/04
15	123456.05.06.01	✓		Rec EQM Power Board parts	0 d	0 d	100%	8/1/04	8/1/04	8/1/04	8/1/04
16	123456.05.06.01	✓		Rec Analog Breadboard parts	0 d	0 d	100%	2/10/04	2/10/04	2/10/04	2/10/04
17	**123456.05.06.01**			**Mass Spectrometer - Deliverables**	**354 d**	**0 d**	**100%**	**2/27/04**	**7/25/05**	**2/27/04**	**5/10/05**
18	123456.05.06.01		✓	Del Mass Spectrometer Requirements - Level 4 (Draft)	0 d	0 d	100%	7/2/04	7/2/04	7/2/04	7/2/04
20	123456.05.06.01		✓	Del Mass Spectrometer Simulator	0 d	0 d	100%	12/2/04	12/2/04	12/2/04	12/2/04
21	123456.05.06.01		✓	Del Mass Spectrometer FSW version 1	0 d	0 d	100%	1/18/05	1/18/05	1/18/05	1/18/05
23	123456.05.06.01		✓	Del Mass Spectrometer FSW version 2	0 d	0 d	100%	7/25/05	7/25/05	2/2/06	2/2/06
25	123456.05.06.01		✓	Del Feedback for unapproved Lvl 3 Science Rqmts	0 d	0 d	100%	2/27/04	2/27/04	2/27/04	2/27/04

Figure 5-18. An example of a receivables/deliverables maintained near the beginning of the IMS*.*



	Task Name	%	Dur.	Start	Finish	2013 tr 1, 201 tr 2, 201 tr 3, 201 tr 4, 20
626	**TAMS LTR FM**	**0%**	**120 d**	**1/3/2013**	**6/24/2013**	
627	Detail Design TAMS LTR FM (Update)	0%	15 d	1/3/2013	1/24/2013	
628	LTR TAMS FM Structural Analysis (Update)	0%	15 d	1/3/2013	1/24/2013	
629	LTR TAMS FM Structural Analysis (Update) Cmplt	0%	0 d	1/24/2013	1/24/2013	1/24
630	LTR TAMS FM Thermal Analysis (Update)	0%	10 d	1/3/2013	1/16/2013	
631	LTR TAMS FM Thermal Analysis (Update) Cmplt	0%	0 d	1/16/2013	1/16/2013	
632	LTR TAMS FM Spec and SoW Development	0%	15 d	1/25/2013	2/14/2013	
633	Perform TAMS LTR Glass Bond Tension Testing	0%	10 d	1/25/2013	2/7/2013	
634	Fabricate FM Roof Mirrors	0%	30 d	2/15/2013	3/29/2013	
635	Fabricate FM TAMS LTR	0%	40 d	4/1/2013	5/24/2013	
636	Optical Coating FM TAMS LTR	0%	20 d	5/28/2013	6/24/2013	
637	**Deliver FM TAMS LTR to LTR FM Assembly & Test**	0%	0 d	6/24/2013	6/24/2013	6/24
638	**LTR Assembly & Test**	**0%**	**320 d**	**6/5/2012**	**9/12/2013**	
639	**LTR Prototype Assembly & Test**	**0%**	**144 d**	**6/5/2012**	**1/2/2013**	
654	**LTR FM Assembly & Test**	**0%**	**71 d**	**6/3/2013**	**9/12/2013**	
655	**Receive FM LTR Tower & Interface Plates**	0%	0 d	6/3/2013	6/3/2013	
656	**Receive FM Transmit LTR**	0%	0 d	6/24/2013	6/24/2013	6/24
657	**Receive FM TAMS LTR**	0%	0 d	6/24/2013	6/24/2013	6/24
658	Assemble the FM Tower, FM Transmit LTR, FM TAMS LTR	0%	5 d	6/25/2013	7/1/2013	
659	Assemble the FM Tower, FM Transmit LTR, FM TAMS LTR Complet	0%	0 d	7/1/2013	7/1/2013	7/1
660	LTR FM Optical Checkout	0%	10 d	7/2/2013	7/16/2013	
661	LTR FM Optical Checkout Complete	0%	0 d	7/16/2013	7/16/2013	7/16
662	LTR FM Structural Testing	0%	15 d	7/17/2013	8/6/2013	
663	LTR FM Thermal Test	0%	15 d	8/7/2013	8/27/2013	
664	LTR FM Environmental Testing Complete	0%	0 d	8/27/2013	8/27/2013	8/27
665	LTR FM Optical Checkout	0%	10 d	8/28/2013	9/11/2013	
666	LTR FM Cmplt	0%	0 d	9/11/2013	9/11/2013	9/11
667	LTR FM IDR	0%	1 d	9/12/2013	9/12/2013	
668	FM LTR Margin to ATLAS I&T Delivery	0%	0 d	9/12/2013	9/12/2013	9/12
669	**(Del) FM LTR Assembly to ATLAS FM I&T**	0%	0 d	9/12/2013	9/12/2013	9/12

Figure 5-19. An example showing Rec/Dels as they would appear within the workflow of a Single Consolidated P/p IMS.



UID	Task Name	Dur.	%	Start	Finish	UID Prdcssrs	UID Sccssrs
3598	(Rec) Beryllium Billet for Beam Expander	0d	100%	3/22/2006	3/22/2006	3241	2446
3605	FM Beam Expander Peer Review	1d	100%	4/13/2006	4/13/2006	3004,3003	2446
2446	Fabricate FM Beam Expander	118d	100%	4/14/2006	9/29/2006	3598,3605	3965
3965	Receive and Inspect the FM Beam Expander	50d	100%	10/2/2006	12/13/2006	2446	2448
2448	(Del) FM Beam Expander Beryllium Parts (to Optics)	0d	100%	12/13/2006	12/13/2006	3965	1527
2447	Fabricate FM Non-Beryllium Beam Expander Parts	167d	100%	4/13/2006	12/11/2006	3004,3003	2439,4116
2439	(Del) FM Beam Expander Non-Beryllium Parts (to Optics)	0d	100%	12/11/2006	12/11/2006	2447	2449
4116	Rework FM Flexures (forecast)	26d	100%	12/12/2006	1/19/2007	2447	,4234FS+15d
4148	Receive and Inspect FM Flexures (set 1)	7d	100%	1/22/2007	1/30/2007	4116	4149FS+6d
4149	Send out FM Flexures for Plating (set 1)	13d	100%	2/8/2007	2/27/2007	4148FS+6d	4117
4117	(Del) FM Flexures (to Optics) (set 1)	0d	100%	2/27/2007	2/27/2007	4149	4118
4234	Receive and Inspect FM Flexures (set 2)	13d	100%	2/12/2007	3/1/2007	116FS+15d	4235
4235	Send out FM Flexures for Plating (set 2)	8d	100%	3/2/2007	3/13/2007	4234	4236
4236	(Del) FM Flexures (to Optics) (set 2)	0d	100%	3/13/2007	3/13/2007	4235	4237

UID	Task Name	Dur.	%	Start	Finish	UID Prdcssrs	UID Sccssrs
1527	(Rec) FM Beam Expander Beryllium Parts (from Mech)	0d	100%	12/13/2006	12/13/2006	2448	1528FS+48d
2449	(Rec) FM Beam Expander Non-Beryllium Parts (from Mech)	0d	100%	12/11/2006	12/11/2006	2439	1528
4118	(Rec) FM Flexures (from Mech) (set 1)	0d	100%	2/27/2007	2/27/2007	4117	FF-10d,1528
4237	(Rec) FM Flexures (from Mech) (set 2)	0d	100%	3/13/2007	3/13/2007	4236	d,1528FS+5d
1528	Precision Clean Mechanical Parts (BE)	24d	100%	3/21/2007	4/23/2007	,4237FS+5d	1530
1529	Generate Assy I&T WOA	15d	100%	7/31/2006	8/18/2006	3610	1530
1530	Integrate & Functional Test FM Beam Expander (BE)	32d	100%	4/24/2007	6/7/2007	4237FF-10d	+29d,3326FF
1531	FM Thermal Test Plans / Procedures (BE)	10d	100%	1/17/2007	1/30/2007	530SS,3969	1534
3326	Beam Expander PER (BE) (internal)	1d	100%	6/7/2007	6/7/2007	1530FF	1536
1534	Beam Expander Thermal Qualification Test (BE)	2d	100%	6/5/2007	6/6/2007	S+29d,1531	1536
1536	Beam Expander Vacuum Bake-out (BE)	19d	100%	6/8/2007	7/5/2007	1534,3326	5,3331FS+7d
2436	(Del) Flight Beam Expander (to Laser)	0d	100%	7/6/2007	7/6/2007	1536	3996

UID	Task Name	Dur.	%	Start	Finish	UID Prdcssrs	UID Sccssrs
4454	**Phase II A 2 FM Build**	**3d**	**100%**	**7/3/2007**	**7/6/2007**		
4455	L1 Oscillator Build	2d	100%	7/3/2007	7/4/2007	4453,4450	4456
4456	L2 Oscillator Build	2d	100%	7/5/2007	7/6/2007	4455	4329,4330
4326	**Phase II B FM Build**	**3d**	**100%**	**7/7/2007**	**7/11/2007**		
4329	Coalign L1/L2	5d	100%	7/7/2007	7/11/2007	4456	3973
4330	Temperature Sweep	5d	100%	7/7/2007	7/11/2007	4456	3560,4482
4482	Reference Cube Installation	4d	100%	7/12/2007	7/17/2007	4330	3997
3996	(Rec) FM Beam Expander (from Optics)	0d	100%	7/6/2007	7/6/2007	2436	3997
3997	FM Beam Expander Integration	4d	100%	7/18/2007	7/23/2007	3996,4482	3544
3543	(Rec) FM LEA, Analog, & SPOT 4 (from Elec.)	0d	100%	6/20/2007	6/20/2007	1868	3544
4197	(Rec) Laser Load Plate (from EM I&T)	0d	100%	7/21/2006	7/21/2006	4198	3544
4254	(Rec) Analog-to-Spot 4 Harness (from Elec)	0d	100%	4/24/2007	4/24/2007	4253	3544
3544	FM Electronics Integration Test (B19)	4d	100%	7/24/2007	7/27/2007	7,4254,3997	4159,4325
4159	(Del) Laser Load Plate (to EM I&T)	0d	100%	7/27/2007	7/27/2007	3544	3855
4325	Test TEC with LEA	1d	100%	7/30/2007	7/30/2007	3544	4000
3998	(Rec) FM Instrument Housing (from Mech.)	0d	100%	7/18/2007	7/18/2007	2993	3999
3999	Process FM Housing (Precision Clean Only)	4d	100%	7/18/2007	7/24/2007	3998	4438FS+3d

Figure 5-20. An example showing a series of Rec/Dels as they would appear between multiple subsystems. Linked properly, the Rec/Dels can ensure all work is accounted for from the Mechanical Subsystem, to Optics, and finally to Laser.

Level-of-Effort Activities

LOE activities require careful consideration when being linked in the schedule as to not drive discrete work activities. LOE activities must be carefully modeled so that they do not inadvertently define the overall length of the P/p and drive the critical path. "For example, P/S may choose to avoid the use of logic links on LOE activities or they may create LOE activities that are one day shorter than the actual planned P/p length. Because these techniques are used to circumvent the impacts of long-duration LOE activities on traditional critical path calculations, their use and implications should be thoroughly documented in the schedule narrative and BoE documents."[48] Nonetheless, hammock tasks can have descriptions, codes, calendars, resources, costs and other attributes of a normal activity. Hammocks are very useful for carrying time related costs and determining the duration of supporting equipment needed for a P/p, as well as being used to create summary reports, which support Schedule Communication.

Activity Relationships

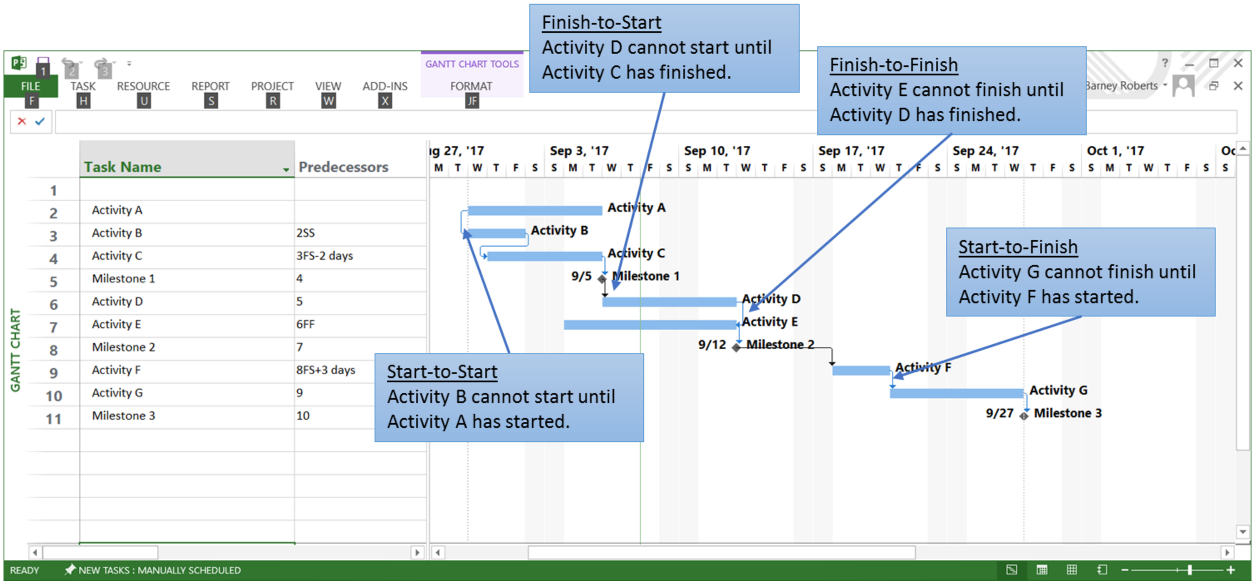
There are four relationship models for the activities:

- **Finish-to-Start (FS).** The successor activity cannot start until the predecessor activity has completed. This is the *most common linkage* because it follows the most common work flow; complete an activity and hand off the work to the next activity. It is a recommended practice that FS relationships be used as often as possible when establishing schedule logic. This relationship provides for the most accurate calculation of total float.
- **Start-to-Start (SS)**. The successor activity cannot start until the predecessor activity has started. This relationship is used when two activities need to begin at the same time. This linkage is commonly used at major integration points or at the beginning of the P/p. For example, Authority to Proceed (ATP) may trigger the start of a large number of activities. In most cases this relationship will be used with a lag value. Caution should be taken when using this type relationship in lieu of breaking the effort down into more meaningful and discrete segments of work that can more accurately represent the task sequence. Overuse and/or improper use of start-to-start relationships will potentially hinder true critical path identification.
- **Finish-to-Finish (FF).** The successor activity cannot finish until the predecessor activity has finished. This relationship is used when an activity needs to finish and provide something to another activity so that it too can finish. Sometimes activities may need to be constrained to finish at the same time because of a coordinated handoff of work to a successor activity. The same caution as noted for start-to-start relationships also applies to the overuse and/or improper use of finish-to-finish relationships.
- **Start-to-Finish (SF).** The successor activity cannot finish until the predecessor has started. For example, the first step in the predecessor activity may generate a fit-check template needed before the successor can start. This relationship is very uncommon, and caution should be exercised before using this relationship to ensure its use is valid.

Figure 5-21 is a screen shot from MS Project showing examples of the four linking techniques and how each impact the flow of the work.

---

[48] GAO-16-89G. GAO Schedule Assessment Guide. Page 14. December 2015. http://www.gao.gov/assets/680/674404.pdf



	Task Name	Predecessors
1		
2	Activity A	
3	Activity B	2SS
4	Activity C	3FS-2 days
5	Milestone 1	4
6	Activity D	5
7	Activity E	6FF
8	Milestone 2	7
9	Activity F	8FS+3 days
10	Activity G	9
11	Milestone 3	10

Finish-to-Start
Activity D cannot start until Activity C has finished.

Finish-to-Finish
Activity E cannot finish until Activity D has finished.

Start-to-Finish
Activity G cannot finish until Activity F has started.

Start-to-Start
Activity B cannot start until Activity A has started.

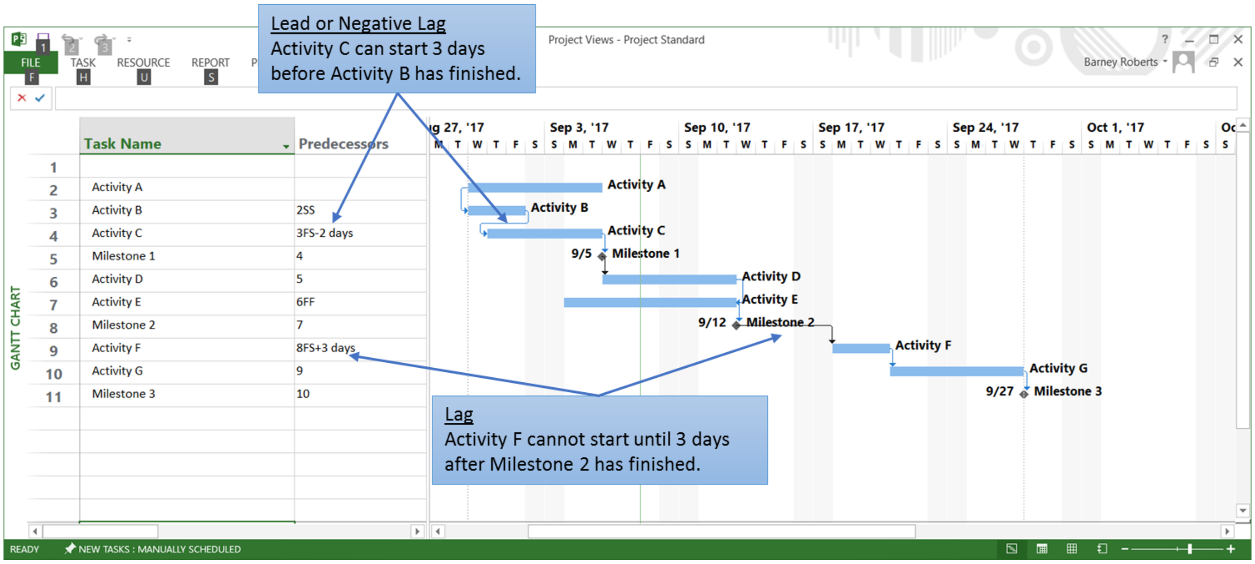
Figure 5-21. Examples of the four activity logic relationships.

5.5.8.2 Avoid Leads and Lags

It is a best practice for schedule activities to only use lead and lag relationships when the values represent real situations of needed acceleration or delay time between activities. A lag is a delay inserted between activities that delays the start of a successor activity. Likewise, a lead allows a successor to start before its predecessor has completed. A lead is the same thing as a negative lag. Further definition of leads and lags is as follows:

- **Lag.** Lag time is the period of time applied to a relationship between two tasks that delays the defined relationship execution. The amount of lag time (delay time) is assigned as a positive value. For example, a task logically tied to another task with a finish-to-start relationship and a 5-day lag will result in the successor task's start being delayed until 5 days after the completion of the predecessor. Typical examples of lag time would be cure times on concrete pours and bake-out times for conformal coating of printed circuit boards.
- **Lead.** Lead time is the period of time applied to a relationship between two tasks that accelerates the defined relationship execution. The amount of lead time (acceleration time) is assigned as a negative value. For example, a task logically tied to another task with a finish-to-start relationship and a negative 5-day lead will result in the successor task's start beginning 5 days prior to the completion of the predecessor. An example of using lead time would be where the drawings review needs to start several days before the drawings are scheduled to complete.

Leads and lags often mask lower-level activities that should have been defined. Figure 5-22 provides an example from MS Project showing how the leads and lags affect the successor-predecessor relationships.



Lead or Negative Lag
Activity C can start 3 days before Activity B has finished.

	Task Name	Predecessors
1		
2	Activity A	
3	Activity B	2SS
4	Activity C	3FS-2 days
5	Milestone 1	4
6	Activity D	5
7	Activity E	6FF
8	Milestone 2	7
9	Activity F	8FS+3 days
10	Activity G	9
11	Milestone 3	10

Lag
Activity F cannot start until 3 days after Milestone 2 has finished.

Figure 5-22. Example of the use of leads and lags as illustrated in MS Project.

There are instances where these types of relationships do exist and are reflected accurately by the correct use of lag and lead times (e.g., cure times on concrete pours, bake-out times for printed circuit board coating, and procurement order lead times). However, in most cases it would be preferable to use an additional task, appropriately labeled, to represent the lead or lag time and to describe the reason for the lag or lead (e.g., handoffs). This latter practice facilitates visibility and status updates and would likely result in a more accurate and maintainable schedule. In other cases, it may be appropriate to use a soft constraint. If using leads and/or lags, it is a recommended practice for justification to be provided in the task notes or in a separately identified field within the *IMS* and/or *Analysis Schedule*.

Caution. Lead and lag times should only be used when these values represent real situations of needed acceleration or delay time between tasks. Use of these techniques creates a maintenance issue should the basis for the lead or lag time change. Lead and lag times are difficult to identify and document, conceal actual activities that are not defined, and are often difficult to discern when analyzing a schedule, as well as when performing an *SRA* or *ICSRA*. They may also corrupt float/slack calculations and distort the critical path and driving paths. They also hinder the ability to capture EVM metrics (e.g., EVM cannot be taken against a lag because there is no scope associated with a lag).

5.5.8.3 Minimize Activity Constraints

A constraint is a fixed date assigned to a task to control when it starts or finishes. Caution should be exercised when using constraints because they are a significant factor in how float (slack) is calculated throughout the P/p schedule. While it is certainly true that there are various scheduling situations that require the use of constraints to more accurately model the implementation plan (e.g., facility availability, equipment availability, resource availability, vendor deliveries, etc.), careful thought should be given that they are used appropriately.

It is a best practice for the schedule logic to limit the use of constraints other than As Soon As Possible (ASAP) to situations that represent actual work flow. *Soft constraints* are preferable to *hard constraints* or the use of *leads* or *lags* and may be used to delay the Start or Finish of a task because they do not interfere with the logical flow of the schedule or the critical path calculations. For example, a soft constraint might be used to delay the start date of a task to the expected availability date of data, materials, or other resources that are not reflected in the *IMS*. Common soft constraint types that can be imposed on an activity include, but are not limited to, the following:

- **As Soon As Possible (ASAP).** An Activity or Milestone will finish as early as possible based on its assigned logical relationships and duration. This condition can also be described as the absence of any constraint.**As Late As Possible (ALAP)*.** An Activity or Milestone will finish as late as possible without affecting the schedule end date. It is a recommended practice that the ALAP constraint never be used (specific to MS Project). This constraint uses total float to calculate its Early Finish date instead of free float. This can cause the P/p end date to slip.
- **Start No Earlier Than (SNET)** or **Start On or After.** An Activity or Milestone will start no earlier than the assigned start date. However, it can start as late as necessary. This constraint is often used to phase the activities such that they align with budget allocation. Sometimes they are also used to align the activities with the availability of a facility.
- **Finish No Earlier Than (FNET)** or **Finish On or After.** An Activity or Milestone will finish no earlier than the assigned finish date. However, it can finish as late as necessary.

Hard constraints can prevent the logical flow of the schedule relationship logic, distorting the total float (slack) and critical path calculations throughout the P/p. Hard constraints should be avoided except where absolutely necessary. Instead, consider using *soft constraints* or *deadlines*. For awareness, hard constraint types include:

- **Start No Later Than (SNLT)*** or **Start On or Before.** An Activity or Milestone will start no later than the assigned start date. However, it can start as early as necessary. **Finish No Later Than (FNLT)*** or **Finish On or Before.** An Activity or Milestone will finish no later than the assigned finish date. However, it can finish as early as necessary. This is a useful constraint to use for a contract deliverable milestone or P/p completion milestone.
- **Must Start On (MSO)*** or **Start On** or **Mandatory Start.** An Activity or Milestone will start on the assigned date. Use of this constraint overrides schedule date calculations driven by logic, resulting in a date that may be physically impossible to achieve.
- **Must Finish On (MFO)*** or **Finish On** or **Mandatory Finish.** An Activity or Milestone will finish on the assigned date. Use of this constraint overrides schedule date calculations driven by logic, resulting in a date that may be physically impossible to achieve.

Note(*): These types of constraints are often used as completion points in the schedule from which the total float value is calculated. These constraints are often called "Hard Constraints" because they can inhibit the correct time-phasing of the schedule. Improper use can cause negative float to be calculated throughout the schedule.

Deadlines allow the P/S to place a target completion date on a task or milestone and do not interfere with the logical flow of the schedule network.

- **Deadline *(MS Project only)*.** While not listed as a constraint type, a deadline date assignment on any task or milestone has the same results as assigning a "Finish No Later Than" or "Must Finish On", without compromising the ability for schedule logic to drive the schedule. Float (slack) is calculated against the deadline date as if it were a "FNLT" or "MFO" constraint, generating negative float when the task slips past it, but still allows for accurate critical path analysis against important events in time. Figure 5-23 shows a deadline date represented by a downward pointing green arrow. The finish milestone will be allowed to slip past it; the deadline will not affect how the software schedules the tasks. However, total slack will be calculated against the deadline date.[49] P/S may choose to use deadline constraints in the routine (e.g., monthly) schedule status update process to inform management of impending issues, but deadlines should be removed from the approved *IMS* because of the hindrance they may cause in identifying and managing the P/p's true critical path.

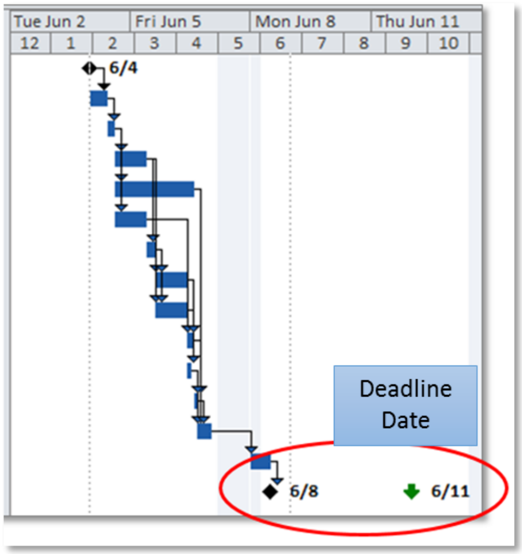


Figure 5-23. Example of the use of a deadline date in MS Project.

Minimal use of constraints, other than ASAP, is strongly encouraged. Remember that constraints override task interdependency relationships. Examples where constraints generally have a valid purpose include the following:

- Assigning a "Start No Earlier Than" on a scheduled receivable from an external source
- Assigning a "Start No Earlier Than" when resources will not be available until a specified date
- Using a "Finish No Later Than" or "Deadline" on the final product deliverable or P/p completion point

Constraints may also refer to limitations or conditions that affect the schedule. Typical examples of these situations may include test facility downtime or unavailability of specialized computer time/equipment. Take note that for schedules that are resource loaded, these situations are normally best modeled through the use of resource calendars/assignments within the automated scheduling tool.

---

[49] In MS Project should any predecessor push a task with a deadline that has zero slack, the task with the deadline will automatically show up as "critical" in the Gantt chart. This can be useful for understanding when key tasks hit trigger target completion dates.

Note: Different software tools may have different constraints or even different terminology to describe constraints. Other tools have additional constraints such as Zero Total Float and Zero Free Float. While these constraints may be necessary to reflect an actual work situation, *they are the exception and not the rule*.

In summary, constraint use other than ASAP should be considered only when necessary to accurately reflect the plan. When used, careful consideration should be given to which constraint type to apply. The type of constraint will dictate the impact on float (slack) calculations for the task in question and other tasks logically linked as successors. Furthermore, depending on the use, the proper calculation of critical path may be hindered. If using leads or lags, or constraints other than ASAP, it is a recommended practice to provide justification in the task notes or in a separately identified field within the *IMS*.

Document the BoE for Schedule Logic

Ensuring proper logic between activities is essential to understanding the time phasing of work. As part of the *BoE*, is important to document the rationale for non-standard dependencies between activities (e.g., relationships other than Finish-to-Start), as well as the use of leads, lags, or constraints, to ensure that the logic reflects the way in which the work is actually being performed. These departures from standard schedule practice, documented within the *BoE*, will be examined in depth via the *Health Check*, described in Section 6.2.2.1.2, and the *Critical Path and Structural Check*, described in Section 6.2.2.2.1, the former of which should be performed continuously after the schedule logic has been established.

5.5.9 Estimate Activity Durations

Duration is the length of "working time" expected for an activity to complete (e.g., number of man-hours), whether for a planning package or a work package. Activity duration may be dependent upon the amount of resources applied/available, as well as the calendar applied to the activity. Having the appropriate time units and calendars defined are necessary first steps so that the activity Start and Finish Dates can be accurately calculated once activity durations are estimated and assigned in the *IMS*.

5.5.9.1 Define Time Units

It is a best practice for all activity durations to be scheduled according to the same time units. Prior to assigning durations, a determination should be made as to the unit of measurement and level of accuracy required. From a schedule analysis perspective, mixing time units within the same schedule may result in slight differences and inconsistencies to float values internally calculated by the scheduling tool. This result complicates the identification and analysis of a P/p's critical path. Because of this, task durations should generally be assigned in workdays except in cases where more detailed definition in work hours is necessary. For example, short term, intense efforts (e.g. spacecraft vacuum testing, near-launch activities, etc.), may require activities to be measured in hours. For a long duration plan, the scheduler may round activities contained in the first year to the nearest day, and in subsequent years to the nearest week or month, refining the estimates as the activity gets closer (e.g., spacecraft vacuum testing). It is also important to establish whether activities will be measured by elapsed duration ("edays") or by the number of working days ("days") and to be consistent throughout the schedule. Elapsed duration allows activities to be calculated according to calendar days and ignores all non-working time, such as weekends or holidays, per the P/p's assigned calendar. In general, "days" is the preferred time unit.[50]

5.5.9.2 Define Calendars

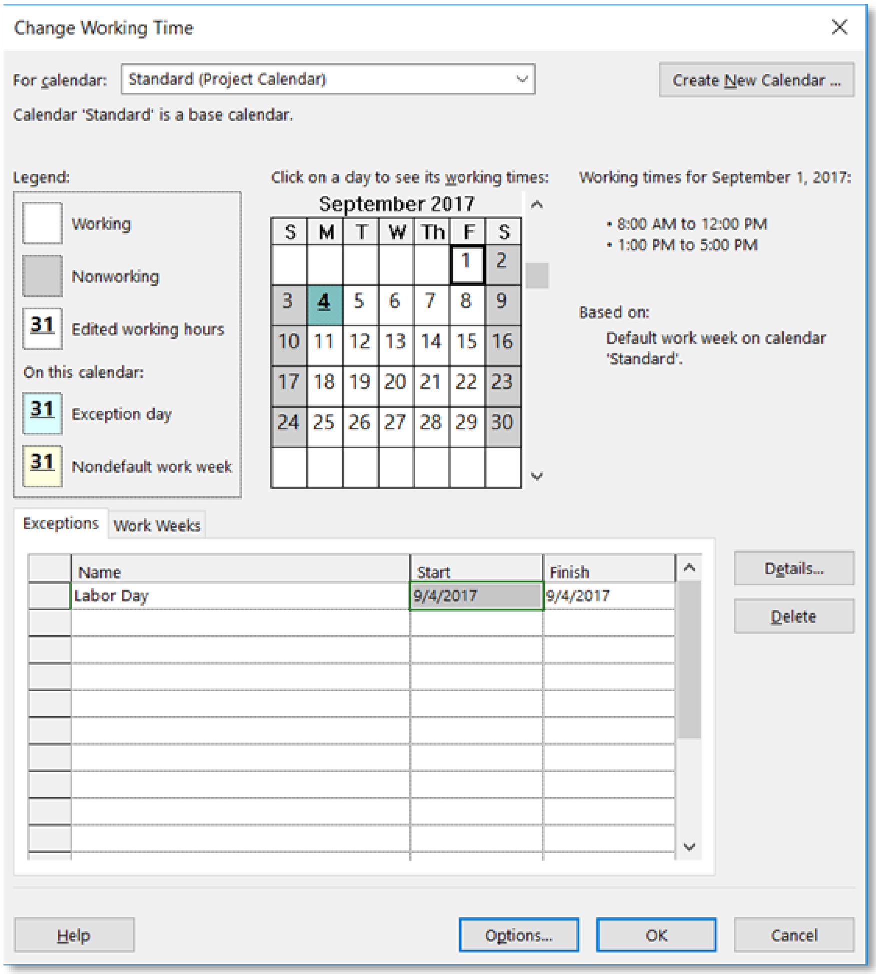
It is a best practice for activities to be scheduled according to representative calendars that appropriately distinguish between working and non-working days. P/p calendars dictate working and non-working times. Thus, the actual calendar-time for any activity is determined by using the work hours and work days as defined by the assigned P/p calendar. Typically, P/p will have a default calendar that defines the usual working and non-working periods for tasks or resources. However, it is acceptable that customized calendars be established to allow activities or resources with different work schedules to be more accurately planned. For instance, calendars may be different for each organization, contractor, or resource working for the P/p. Calendars may also vary with phase and activity. For example, some integration and testing activities are performed on a 24-hours per day, 7-days per week (24/7) basis. Other activities or possible contingency situations may necessitate the use of double shifts for a defined period of time.

If a P/p is resource loading the schedule, it may be necessary to use resource calendars, which specify valid time units that a resource may be available to do work. Both resource and P/p calendars should be used appropriately and be a key consideration when estimating task durations. When tracking costs and/or EVM performance within the scheduling tool, it is a recommended practice that the P/p calendar also be consistent with the accounting calendar to ensure accurate cost data. The P/S should be cognizant of the impact on task scheduling and schedule analysis when both types of calendars apply. Specific task and resource calendars should be established during initial schedule development.

Any of these customized calendars may be used throughout the P/p lifecycle, or intermittently, as necessary. It is a recommended practice that customized calendars be clearly labeled and documented with rationale as to any distinctions from the standard P/p schedule. Figure 5-24 is an example of a work calendar extracted from MS Project.

---

[50] GAO-16-89G. GAO Schedule Assessment Guide. December 2015. Page 65. https://www.gao.gov/assets/680/674404.pdf



For calendar: Standard (Project Calendar)

Calendar 'Standard' is a base calendar.

September 2017

S	M	T	W	Th	F	S
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30

Working times for September 1, 2017:

- 8:00 AM to 12:00 PM
- 1:00 PM to 5:00 PM

Based on:
Default work week on calendar 'Standard'.

Name	Start	Finish
Labor Day	9/4/2017	9/4/2017

Figure 5-24. Example of a work calendar extracted from MS Project.

Note: MS Project makes use of “elapsed days” or “edays”. When an elapsed duration is entered for an activity, MS Project calculates the activity duration according to calendar days and ignores all non-working time, such as weekends or holidays, per the P/p’s assigned calendar.

5.5.9.3 Derive and Assign Activity Durations

It is a best practice for schedule activity durations, including associated duration uncertainties, to be derived based on sources and/or processes that are appropriate and provide the best justification for their estimation. A key component of estimating schedule activity durations includes the use of schedule estimating methods and models. Activity durations are sometimes determined solely by the time “available” to complete the P/p. In this *top down* approach, a P/p’s terminal milestones are derived from contractual, agency, congressional, or executive branch stakeholders. In this case, all other schedule elements are also derived from these provided milestones, often embedding optimism into the schedule prior to its development. This contrasts with the *engineering build-up* or *unconstrained* style of schedule estimating that attempts to capture the entire work effort, as set forth by the requirements set, and derive schedule element estimates without a final milestone target date in mind. Using schedule estimating methods and models ensures that the dates in the schedule are determined by logic and durations rather than by wishful thinking or estimates that are constructed to meet a particular finish date objective.[51] The P/S should remain diligent in collaborating with P/p teams, especially Technical Leads, to determine the optimal basis rationale for each element. Documenting activity estimate rationale also aids the P/p in preparing for P/p reviews.

5.5.9.3.1 Schedule Estimating Methods and Schedule Estimating Relationships (SERs)

The process for estimating schedule durations is often influenced by how much information is known about the activity or set of activities in question. The selection of the schedule estimating method can also often be tied to the schedule's relationship with cost, data availability, estimate purpose, data maturity, and P/p maturity levels. Some common methods and sources for deriving or verifying overall *IMS*, lower-level subsystem, and/or individual activity duration estimates include the following:

- **Established Standards.** Well established, historically validated and recorded durations for routine or procedurally-based activities or operations, such as hourly or daily rates per required quantity.
- **Brainstorming.** P/p team members approximate durations based on a combination of factors (e.g., expert judgment, prior experience, and historic actuals).
- **Subject Matter Expert Experience and Judgment.** Time estimates based on personal knowledge and/or experience with the same personnel, or from similar P/p work or specialized training, often guided by historic (actual) data. In cases wherein verified data contradicts expert opinion, the burden of proof is on the expert to justify his or her judgment in light of the data.
- **Analogy.** Actual duration from similar activities (i.e., technical content) used as the basis for the new activity duration, often adjusted for differences in complexity. Careful consideration should be given to selecting the analogies. While the P/p can use any previous P/p as a relevant analogy, the NASA OCFO maintains the SMART tool, which uses a parametric approach, to assist in making this comparison for unmanned space flight missions. If the P/p is interested in a more granular comparison other databases, such as the CADRe or the NASA Schedule Repository may provide lower-level details. Furthermore, there may be generally accepted datasets for particular elements of the P/p schedule that can be referenced for comparison.
- **Parametric Analysis and Schedule Estimating Relationships (SERs).** Calculated time estimates derived from a mathematical relationship that defines schedule as a function of one or more parameters for factors, which may include technical parameters (e.g., weight, power, mass, etc.) as well as parameters for cost. Estimating schedule durations using a parametric approach involves the same fundamentals as estimating cost. The quantifiable relationships between the schedule and other P/p factors and influences can be captured as Schedule Estimating Relationships (SERs) and then used to estimate durations of schedule events, much like Cost Estimating Relationships (CERs) are used to estimate a particular price or cost. SERs are used to

---

[51] GAO-16-89G. GAO Schedule Assessment Guide. December 2015. Page 65. https://www.gao.gov/assets/680/674404.pdf

estimate schedule duration by connecting an established relationship with one or more independent variables to the duration time of an event.

Schedule duration data and independent variables are collected to conduct data analysis and determine if there are statistically significant relationships present to produce an SER. If an independent variable (driver) demonstrates a measurable relationship with schedule duration, an SER can be developed. SERs can contain many of the same independent variables as Cost Estimating Relationships (CERs) but could also be based on different datasets, normalization techniques, or analysis methods. While relatively simple in concept, the ability to get accurate and meaningful data that can be used to quantify a relationship between an independent variable and schedule duration can be difficult.

Because of the fundamental relationship between P/p schedule behavior and cost behavior, NASA offers a variety of cost-based databases, models, and tools, which contain schedule data and/or SERs that can be used effectively for estimating schedule durations. Cost-based resources are often a good source for parametric estimating of schedule durations, since the *IMS* needs to correspond to cost estimates to ensure that enough resources can be applied to activities to complete them within the expected duration. This should be done before the *IMS* is baselined so that the relation between accurate cost and schedule estimates can be verified.[52]

- **Extrapolations.** Predicted time estimates calculated from existing known data relationships and/or trends (e.g., 3-point time estimates).
- **Build-Up/Bottom-Up/Grassroots.** Decomposition of activities into lower-level tasks which are estimated and then aggregated at higher levels. Using a detailed engineering build-up estimate to develop a schedule estimate is a common technique. A highly detailed and logically linked schedule is the standard product generated by this schedule estimation method. Grassroots estimating for schedule requires strong attention to detail to be successful. Schedule Analysts should continue to be careful when differentiating between a build-up schedule estimate and a given detailed schedule plan. Both may employ the engineering build-up/grassroots approach; however, there are significant differences. The former reflects an attempt to capture the entire work effort to analyze durations and the program plan. A build-up schedule estimate, similar to cost, is an attempt to predict the actual (i.e., actual duration/actual finish date.) The latter reflects the result of a detailed P/p plan and may contain significant constraints, optimism, or undocumented assumptions. The plan duration and plan finish date from a given detailed schedule plan are attempts to organize future work with the goal of delivering on time.
- **Performance-Based.** Typically used for replanning or rebaselining purposes, actual P/p performance such as task duration growth or milestone burndown can be used to estimate schedule elements, via extrapolation or related techniques.

---

[52] Additional information the relationship between cost and schedule can be found in NASA Cost Estimating Handbook, Version 4.0. February 27, 2015. Appendix K. Pages K-1 and K-2.

5.5.9.3.2 Schedule Estimating Databases, Models, and Tools

The following sections describe the available databases, models, and tools used by the NASA Schedule Management community for schedule estimating.

Schedule Repository

In July 2019, NASA began an initiative to collect P/p schedules – *IMSs* in their native format files – in a *Schedule Repository*.[53] The purpose of the Schedule Repository is to formally archive P/p schedule data on a regular cadence. The Schedule Repository also serves a useful database containing planned versus actual schedule information over time. Once a P/p is complete, *IMS* files are made available to the SCoPe for use in future P/p Schedule Development, including establishing activity duration estimates and logic flows, as well as in Schedule Assessment, including performing comparisons of an *IMS* to analogous P/p *IMS*s.

Cost Analysis Data Requirement (CADRe) and the One NASA Cost Engineering (ONCE) Database

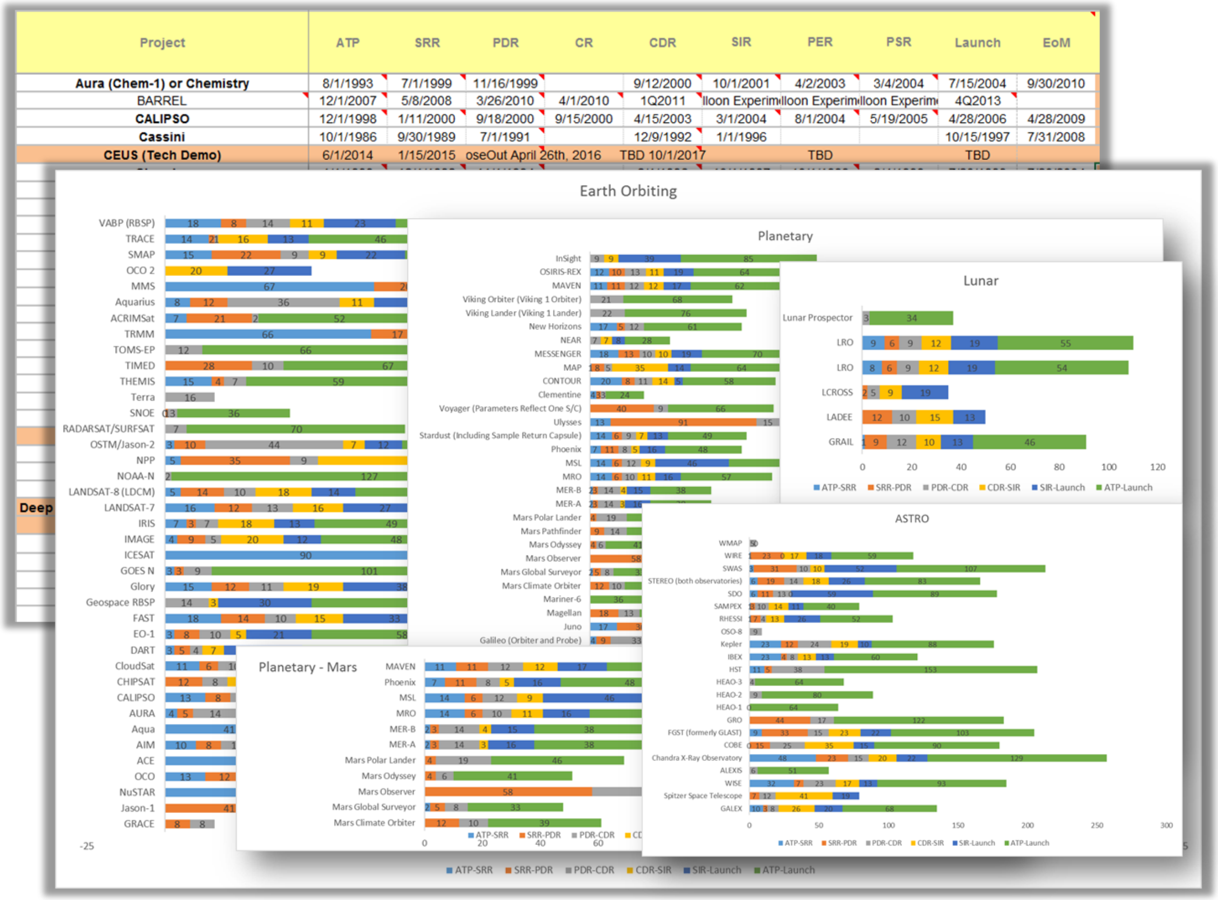
CADRe provides a common description of P/ps at a given point in time. CADRe is a formally required, three-part document that describes the programmatic, technical, LCC, and cost- and schedule-risk information of a P/p at each LCR milestone (SRR, PDR, CDR, SIR, Launch, End of Mission).[54] Both cost and schedule analysts can develop better estimates of future P/ps by using CADRe to pull historical records of cost, schedule, and technical attributes for analogous P/ps. CADRe data is also used to populate the Master List of P/p Schedules and can help analysts generate a variety of *Schedule Outputs*, as shown in Figure 5-25.[55]

---

[53] Agency Policy Guidance to Enhance Earned Value Management (EVM) and Create a Schedule Repository. June 4, 2019. https://community.max.gov/display/NASA/Schedule+Community+of+Practice

[54] CADRe/ONCE – Data Collection and Database. https://www.nasa.gov/offices/ocfo/functions/models_tools/CADRe_ONCE.html

[55] NASA's Master List of Project Schedules is maintained by OCFO's Strategic Investment Division and can be requested through SCoPe, hq-scope@nasa.gov.



Project	ATP	SRR	PDR	CR	CDR	SIR	PER	PSR	Launch	EoM
Aura (Chem-1) or Chemistry	8/1/1993	7/1/1999	11/16/1999		9/12/2000	10/1/2001	4/2/2003	3/4/2004	7/15/2004	9/30/2010
BARREL	12/1/2007	5/8/2008	3/26/2010	4/1/2010	1Q2011	lloon Experim	lloon Experim	lloon Experim	4Q2013	
CALIPSO	12/1/1998	1/11/2000	9/18/2000	9/15/2000	4/15/2003	3/1/2004	8/1/2004	5/19/2005	4/28/2006	4/28/2009
Cassini	10/1/1986	9/30/1989	7/1/1991		12/9/1992	1/1/1996			10/15/1997	7/31/2008
CEUS (Tech Demo)	6/1/2014	1/15/2015	oseOut April 26th, 2016		TBD 10/1/2017		TBD		TBD	

Figure 5-25. Examples of reports that can be manually generated from CADRe data.

Automated search and query of CADRe information is available via the One NASA Cost Engineering (ONCE) Database.[56] ONCE is a web-based database that provides controlled access to the CADRe data and information. The data stored in ONCE mimics the CADRe templates - Parts A, B, and C. Since CADRes represent snapshots of a P/p at successive key milestones, the ONCE Database captures all the changes that occurred to previous P/ps and their associated cost and schedule impacts.[57]

Schedule Management and Relationship Tool (SMART)

The SMART, which is available on the ONCE Model Portal, combines analogy-based and parametric methods in a schedule estimating tool for unmanned, Category-1 spacecraft P/ps from Authority to Proceed (ATP) to Launch.[58] The tool utilizes high-level technical and programmatic characteristics to determine a spacecraft's likely development schedule duration. Based on the spacecraft parameters,

---

[56] ONCE. https://oncedata.hq.nasa.gov

[57] One NASA Cost Engineering (ONCE) Database. https://oncedata.hq.nasa.gov/

[58] Schedule Management and Relationship Tool (SMART) can be accessed on the ONCE Database, https://oncedata.hq.nasa.gov. The creation of SMART resulted from an Office of Evaluation (OoE) research study in 2014. Analysts with questions about using SMART for SER capability should refer to www.nasa.gov/offices/ocfo/functions/models_tools/smart.

SMART produces a cumulative distribution function (CDF) that reflects the durations of the analogous missions. It also illustrates the confidence level of the P/p's estimate for further comparison. SMART incorporates NASA Schedule Estimating Relationships (SERs) for another point of comparison. Unlike other third party SERs, those within SMART are derived from a strictly NASA population for a more applicable assessment and comparison. The SMART can also help identify which spacecraft parameters are contributing factors to longer durations. SMART SER's schedule drivers (parameters which are highly correlated with schedule) include: mass, power, mission design life, year of development, number of instruments, mission class, and maximum data rate. SER's are developed for development life cycle as well as intermediate milestones (e.g. SRR to PDR). Figure 5-26 shows an example of SMART inputs and outputs.

SMART Tool

Point of Comparison (Project Estimate)

Project Schedule Estimate (months)	60
Desired Confidence Level	70%

SMART Inputs

		Filters (optional)	
Spacecraft Parameters		lower bound	upper bound
Dry Mass (kg)	2,400		
Design Life (months)	24		
BOL Power (W)	3,220		
Maximum Data Rate (kbps)	10,000		
Instrument Count	8		
Start Year	2020		

Mission Filters	
Mission Class	Planetary
Lead Government Organization	Any
Simulation Settings	
Number of Runs	10,000
Uncertainty Level	None

Alternative Methods

Schedule Estimating Relationship (SER) Inputs

Spacecraft Parameters		lower bound	upper bound
Dry Mass (kg)	2,400	2,400	2,400
Design Life (months)	24	24	24
Maximum Data Rate (kbps)	10,000	10,000	10,000

Max. Design Life (months)	24
BOL Power (W)	3,220
IMINT Remote Sensor?	No
Off-the-shelf Bus?	No
RTG Power Onboard?	No

SMART Spacecraft Schedule Database Analogies

A total of 31 analogies satisfied the filtering criteria.

Project Schedule Estimate

	mean
ATP to SRR	9.4 months
SRR to PDR	15.3 months
PDR to CDR	12.8 months
CDR to SIR	10.3 months
SIR to Launch	20.5 months
Total	68.2 months

ATP to Launch 72.8 months at 70% confidence level

Cumulative Distribution Function (ATP to Launch)

Comparison of SER Tools

Figure 5-26. Example of a SMART inputs and outputs.

NASA Instrument Cost Model (NICM)

Another NASA modeling tool that contains schedule data and SERs is NICM.[59] NICM, which is available via the ONCE Model Portal, focuses specifically on instrument estimation and contains a large database of many different types of instrumentation.[60] This database includes schedule data, and there is a component within NICM for estimating schedule duration using SERs. The NICM approach to calculating duration from SERs is unique in that cost is an input to the SER equation. In this way, NICM SERs establish a functional link between the calculated cost of an instrument and its schedule duration. In addition to utilizing *Cost As an Independent Variable* (CAIV), NICM relies on the mission type and instrument subtype in the SER equation. Figure 5-27 shows the NICM model schedule equations. Additional information on the instruments used in each SER can be found in the NICM User Guide.[61]

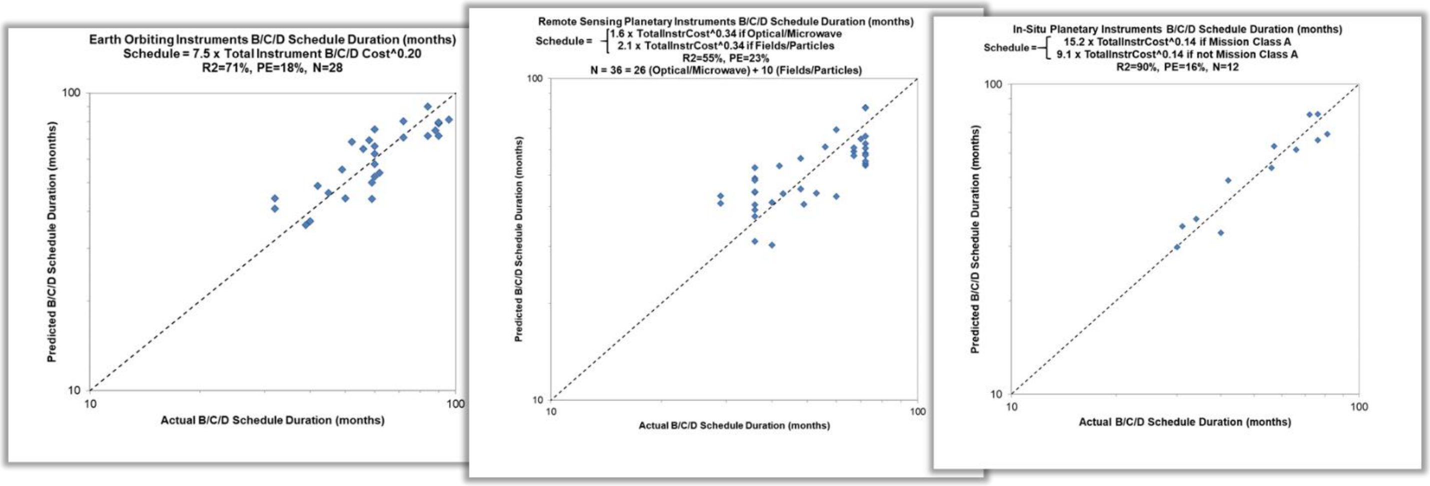


Figure 5-27. NICM SER equations.

5.5.9.3.3 Activity Durations

When determining activity duration estimates, it is a recommended practice that the optimistic duration (best case), the most likely duration, and the pessimistic duration (worst case) estimates (i.e., duration parameters) are collected based on the inherent duration uncertainty of the activity along with supporting rationale for each value. These values are often captured as minimum, most likely, and maximum (Min, M/L, Max). By considering the possible best case and worst-case durations, the intent is to capture the range of the activity duration uncertainty so that it can be modeled to reflect all possible outcomes. In cases where the duration of a task is very well defined and historically substantiated, the Min, M/L, Max estimates may be the same, or nearly the same value. Examples of this scenario may include the duration estimates for off-the-shelf procurements, standardized testing, and P/p reviews. In these situations, an uncertainty estimate may not be necessary. A key principle to remember is that the P/p team member who has the assigned responsibility for a task must also maintain ownership of the

---

[59] Analysts with questions about using the NICM for SER capability should contact Joe Mrozinski of the NICM development team at the Jet Propulsion Laboratory (JPL), at *jmrozins@jpl.nasa.gov*.

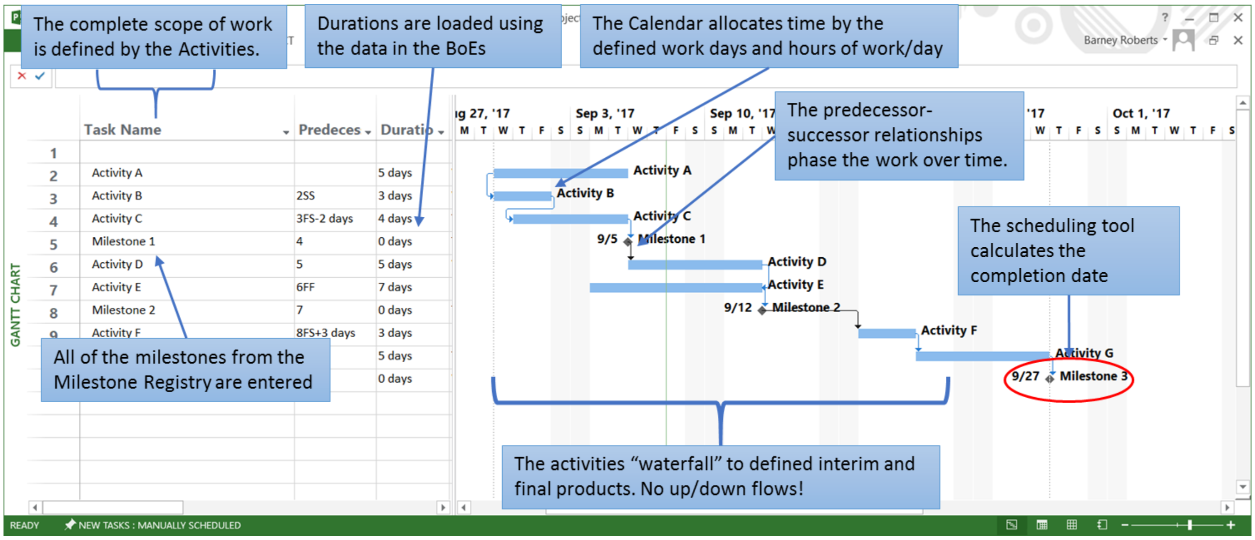
[60] NICM can be accessed on the ONCE Model Portal, https://oncedata.hq.nasa.gov.

[61] "982-0000 Rev. 8. NASA Instrument Cost Model (NICM) Version VIIIc." July 2018. Jet Propulsion Laboratory, California Institute of Technology. For more information, contact NICM@jpl.nasa.gov.

schedule for accomplishing that task. This includes their review and approval of the durations contained in the schedule. Thus, durations should not be padded in order to keep a hidden cushion, reduced to be unrealistically optimistic, or arbitrarily cut by management.

It is also helpful to know what labor resource skills are available and the experience levels of those skills to be assigned. An inexperienced technician or crew, for example, may take longer to perform the task than an experienced technician or crew. While equipment resources are reusable, they may not always be available during the time needed. Consumable resources must be closely monitored and replenished as needed to support schedule needs. All of these factors may not be known at the time of making the initial duration estimate for a task, but they are all considerations that may be used to later adjust a duration estimate, once their impact is known. In addition, labor and financial reports, reflecting actual hours and dollars from prior periods or previous P/ps, may also provide helpful information for estimating durations. These reports provide historical data that can be used for both initial and replanning efforts which involve work scope that is similar to previous activities or past P/ps. The P/S must constantly be vigilant in establishing and maintaining a P/p schedule that is current and accurate to help mitigate resource problems.

Figure 5-28 shows the durations loaded in the schedule after all attributes related to estimating the durations have been considered.



The complete scope of work is defined by the Activities.

Durations are loaded using the data in the BoEs

The Calendar allocates time by the defined work days and hours of work/day

The predecessor-successor relationships phase the work over time.

The scheduling tool calculates the completion date

All of the milestones from the Milestone Registry are entered

The activities “waterfall” to defined interim and final products. No up/down flows!

	Task Name	Predeces	Duratio
1			
2	Activity A		5 days
3	Activity B	2SS	3 days
4	Activity C	3FS-2 days	4 days
5	Milestone 1	4	0 days
6	Activity D	5	5 days
7	Activity E	6FF	7 days
8	Milestone 2	7	0 days
9	Activity F	8FS+3 days	3 days
			5 days
			0 days

Figure 5-28. Documented basis for durations in the IMS.

Document the BoE for Activity Durations

It is highly likely that a P/p schedule will be derived using multiple estimating techniques. Therefore, it is important to document the basis rationale for schedule estimating techniques and estimates themselves for each element of the schedule as part of the *BoE*; primary data used should also be included in the *BoE Dossier*, which should be evaluated continuously using the *Basis Check* assessment process after task durations are initially determined.

5.5.10 Identify the Critical Path(s)

It is a best practice for the P/p's critical path(s) to be clearly identifiable within the schedule throughout the P/p life cycle. In CPM scheduling, the critical path is generally defined as follows:

- **Critical Path.** A sequential path of activities in a network logic schedule that represents the longest overall duration from the status date through P/p completion, which determines the shortest possible P/p duration (i.e., least amount of float) and earliest possible P/p finish date. Any slippage of the tasks in the critical path will increase the P/p duration and slip the P/p finish date.

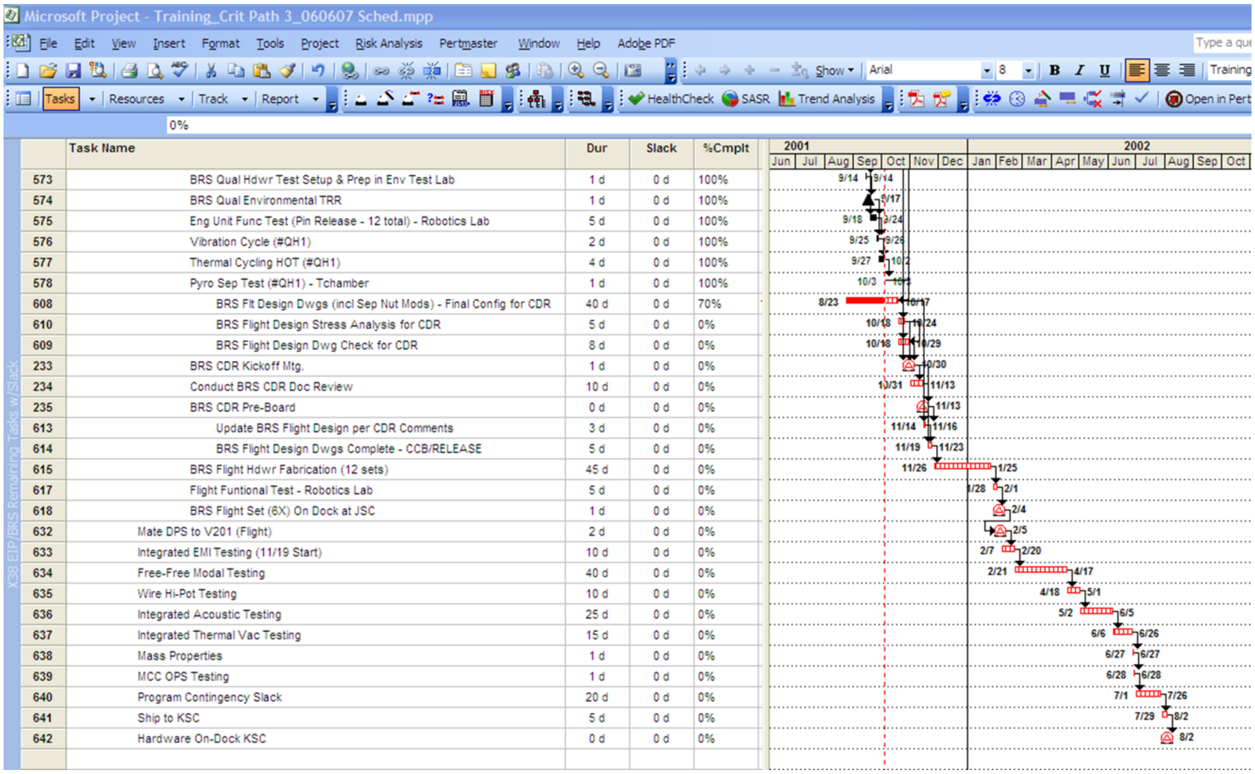
CPM is also used to determine the amount of flexibility, or float, in each of the logic network paths. There are two types of float (slack) common to most scheduling tools:

- **Total Float.** The amount of time that a task or milestone can slip before it becomes part of the critical path. Total Float directly relates each task to the P/p end date.
- **Free Float.** The amount of time a task or milestone may move into the future from its early finish date before affecting its immediate successor task(s).

The concept of float is further discussed in Section 5.5.11.

Given the basic principle that each activity will finish before its successor begins, CPM calculates the longest path of planned activities to logical end points or to the end of the P/p, and the earliest and latest that each activity can start and finish without making the P/p longer. The calculations are done by way of a "forward pass" and "backward pass" without regard for resource requirements/constraints. This automated process determines which activities are "critical" (i.e., on the longest path, usually a zero-float path) and which have "total float" (i.e., can be delayed without making the P/p longer).

It is important to note that if the terminal milestone of the P/p has a hard constraint date assigned to it, then the critical path could have a positive or negative total float value instead of zero. Figure 5-29 shows an example of a P/p's critical path calculated from total float.



0%

	Task Name	Dur	Slack	%Cmplt
573	BRS Qual Hdwr Test Setup & Prep in Env Test Lab	1 d	0 d	100%
574	BRS Qual Environmental TRR	1 d	0 d	100%
575	Eng Unit Func Test (Pin Release - 12 total) - Robotics Lab	5 d	0 d	100%
576	Vibration Cycle (#QH1)	2 d	0 d	100%
577	Thermal Cycling HOT (#QH1)	4 d	0 d	100%
578	Pyro Sep Test (#QH1) - Tchamber	1 d	0 d	100%
608	BRS Flt Design Dwgs (incl Sep Nut Mods) - Final Config for CDR	40 d	0 d	70%
610	BRS Flight Design Stress Analysis for CDR	5 d	0 d	0%
609	BRS Flight Design Dwg Check for CDR	8 d	0 d	0%
233	BRS CDR Kickoff Mtg.	1 d	0 d	0%
234	Conduct BRS CDR Doc Review	10 d	0 d	0%
235	BRS CDR Pre-Board	0 d	0 d	0%
613	Update BRS Flight Design per CDR Comments	3 d	0 d	0%
614	BRS Flight Design Dwgs Complete - CCB/RELEASE	5 d	0 d	0%
615	BRS Flight Hdwr Fabrication (12 sets)	45 d	0 d	0%
617	Flight Funtional Test - Robotics Lab	5 d	0 d	0%
618	BRS Flight Set (6X) On Dock at JSC	1 d	0 d	0%
632	Mate DPS to V201 (Flight)	2 d	0 d	0%
633	Integrated EMI Testing (11/19 Start)	10 d	0 d	0%
634	Free-Free Modal Testing	40 d	0 d	0%
635	Wire Hi-Pot Testing	10 d	0 d	0%
636	Integrated Acoustic Testing	25 d	0 d	0%
637	Integrated Thermal Vac Testing	15 d	0 d	0%
638	Mass Properties	1 d	0 d	0%
639	MCC OPS Testing	1 d	0 d	0%
640	Program Contingency Slack	20 d	0 d	0%
641	Ship to KSC	5 d	0 d	0%
642	Hardware On-Dock KSC	0 d	0 d	0%

Figure 5-29. An example showing the critical path based upon total float (i.e., slack).

It is important to note that unless the *IMS* represents the entire scope of effort and the effort is correctly sequenced through the logic network, the scheduling software will report an incorrect or invalid critical path (i.e., the critical path will not represent the activities affecting the P/p finish date).[62] Accurate float values can only be determined if a complete and valid network logic is in place. Figure 5-29 shows an example project schedule that shows the critical path based on the total float calculation.

For most NASA Space Flight P/p's, "P/p completion" may mean "launch" in the context of calculating the critical path. For Research and Technology P/ps, it may mean the delivery of an end-item, such as a technology demonstration or an analysis report.

There is an important difference between critical path activities and "critical activities" as potentially characterized by P/p management. In strict scheduling terms, the critical path is the sequence of activities that are tied together with network logic that have the longest overall duration through P/p completion, whereas a "critical activity" is often treated as a task which has been subjectively deemed important enough to have this distinction assigned to it. For example, KDPs, the development of a primary system component, important tests, or other high-risk technical activities may be considered "critical activities." However, these activities are not always on the P/p's critical path as calculated by

---

[62] GAO-16-89G. GAO Schedule Assessment Guide. Page 1. December 2015. http://www.gao.gov/assets/680/674404.pdf

the scheduling tool.[63] If the P/ps want to track the most "critical" paths to interim milestones of importance, these are identified as driving paths, as follows:

- **Driving Path.** The critical path to an end item other than P/p completion. It is based on zero free float identifying the drivers to any activity, rather than the effect on total float.

It's a recommended practice that the P/p identify near-critical and driving paths throughout the P/p lifecycle. A P/S can identify these near-critical or driving paths by isolating the sequences of activities that have less than some minimum threshold value of total float, as determined by the P/p management The number of paths identified usually depends on how "near critical" each path is; although, it is common practice to track the primary, secondary, and tertiary critical paths, at a minimum.

Document the BoE for the Scheduling Method

Proper horizontal traceability and validation of proper schedule dynamics via the *Shock Test,* described in Section 6.2.2.2.1*,* directly enable verification of terminal milestones' critical paths (and interim milestones' driving paths). This is a perquisite for properly identifying a schedule's critical paths, which enables understanding the various cascading effects of any task's or milestone's movement within the schedule network, determines the earliest schedule completion date, and focuses the P/p team's energy and management's attention on the activities that will lead to the P/p's success.[64]

5.5.11 Establish and Allocate Margin

It is a best practice for adequate margin to be established and allocated as part of the schedule baseline and clearly identifiable. At this point in schedule development, the *IMS* contains all activities needed to complete the total P/p scope of work and deliver the final product. All activity relationships are defined through the linking of the predecessors and successors. Constraints and durations are assigned to all activities. Although the scheduling tool has all that is needed to time-phase the activities and calculate a completion date based on the P/p scope, there remain a few more things that need to be done to make the *IMS* complete. Margin needs to be added based on quantified risks and uncertainties and phasing needs to be considered to make the schedule compatible with the available resources.

In order to establish and allocate margin, it is important to understand what margin is and how it differs from other schedule resiliency approaches, such as the use of contingency and float. Within the context of Schedule Management, the following definitions for schedule resiliency are used:

- **Schedule Margin**. Schedule margin is a separately planned quantity of time (working days) above the planned work duration estimate to be used specifically to address/absorb the impacts due to risks and uncertainties.[65] It is a risk-informed duration that is included as "activities" in the schedule prior to baselining. Margin is intentionally loaded in the *IMS* just like any other

---

[63] "Concurrently Verifying and Validating the Critical Path and Margin Allocation Using Probabilistic Analysis." Joint Space Cost Council (JSCC) Scheduler's Forum. Page 3. March 2017.

[64] GAO-16-89G. GAO Schedule Assessment Guide. Page 75. December 2015. http://www.gao.gov/assets/680/674404.pdf

[65] NPR 7120.5E, page 56, defines *Margin* as, "The allowances carried in budget, projected schedules, and technical performance parameters (e.g., weight, power, or memory) to account for uncertainties and risks. Margins are allocated in the formulation process, based on assessments of risks, and are typically consumed as the program/project proceeds through the life cycle."

activity; however, these activities do not have any defined scope, nor do they have any associated budget.

Note: Some organizations may use terms such as “reserves” or “integrated returns” to describe schedule margin, however the NASA preferred terminology is “margin.” Reserve is often used to refer to forms of funding (e.g., Management Reserve)[66]; however, NPR 7120.5 specifically states that “reserve” is an obsolete term and makes references instead to “schedule margin” for schedule and “UFE” for funding.

- **Contingency.** Within the context of Schedule Management, Contingency refers to non-working days or times in the schedule (such as holidays, weekends, or extra shifts) that could be used to overcome performance delays.

  Note: Contingency is not to be confused with margin (i.e., working-days) that are intended for use to overcome uncertainties and risks.[67]

- **Float or Slack.** In general terms, float is the number of workdays that an activity can be delayed without impacting the start of a later activity. Float is an automatic calculation performed by the scheduling tool using CPM scheduling. It is calculated by subtracting early dates from late dates (i.e., Float = Late Dates - Early Dates). A CPM schedule critical path is typically characterized as the path with the least amount of total float. Calculating the float in the schedule is particularly important for the space community because spaceflight missions are often constrained by launch dates, which limits the amount of available time in the schedule and makes the flexibility to revise various workflows more important with respect to managing risks. Float informs management as to which activities can be reassigned resources in order to mitigate slips in other activities. Because float is a calculated value, it can be either positive or negative, but the intent is to plan the P/p work such that the schedule has either positive or zero float on the critical path. In general, negative float arises when an activity’s completion date, or associated milestone, is constrained—that is, when the constraint date is earlier than an activity’s calculated late finish. In essence, the constraint states that an activity must finish before the date the activity is able to finish as calculated by network logic. Date constraints causing negative float need to be justified or removed. Zero float is an indication that an activity delay of a given number of days will result in a P/p delay of the same number of days. There are two types of float: *Free Float* and *Total Float*.
- **Free Float (Free Slack).** Free float refers to the amount of time a task can be delayed before impacting the early start date of its immediate successor(s). Zero Free Float is typically used to model “just-in-time” deliveries by making early dates equal to late dates (i.e., scheduling activities according to the late date), forcing the schedule to become equal to the “late

---

[66] Per NPR 7120.5E and the NASA Space Flight Program and Project Management Handbook, SP-2104-3705 “reserves” is an obsolete term that has been replaced by “Unallocated Future Expenses (UFE)”. However, a more general use of “reserves” tends to appear in terms of “cost reserves” held by the CAMs or PM on a given P/p and does not necessarily refer to Mission Directorate-held UFE. https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20150000400.pdf

[67] Whereas NASA differentiates between “margin” and “contingency”, GAO uses the terms interchangeably with respect schedule margin.

schedule". Zero Free Float can make an activity critical if the Free Float and Total Float are equal (i.e., applying Zero Free Float constraints consumes all activities free float as well as all activities total float, making them all critical).

- **Total Float (Total Slack).** Total Float is the amount of time an activity can be delayed before impacting the overall P/p completion (i.e., P/p critical path, finish date or end-item date). Total Float directly relates each task to the P/p finish or end-item date. Positive Total Float is an indication that an activity can be delayed without affecting the P/p completion. Negative Total Float is an indication that an activity will impact the P/p completion unless the time is recovered. Zero Total Float is an indication that an activity delay of a given number of days will result in a P/p delay of the same number of days.

It is important that the appropriate terms be used consistently across all P/p elements, such that assessment of the P/p's flexibility and ability to overcome or mitigate uncertainties and risks is easily identified and well understood. Whereas float is directly related to the logical sequencing of activities, margin is established through an understanding an analysis of P/p uncertainties and risks.

5.5.11.1 Key Guidelines for Incorporating Margin

When incorporating margin into the schedule, there are key guidelines that should always be addressed and maintained throughout P/p Implementation:

- Margin should be established and allocated throughout the schedule to aid in the management of uncertainties and risks
- Margin should always be identifiable in the schedule
- Margin should be managed and controlled by the PM
- Adequate amount of budget (dollars) must be available to cover the added margin duration

Section 7.3.2.1.4 discusses the processes for the management of schedule margin.

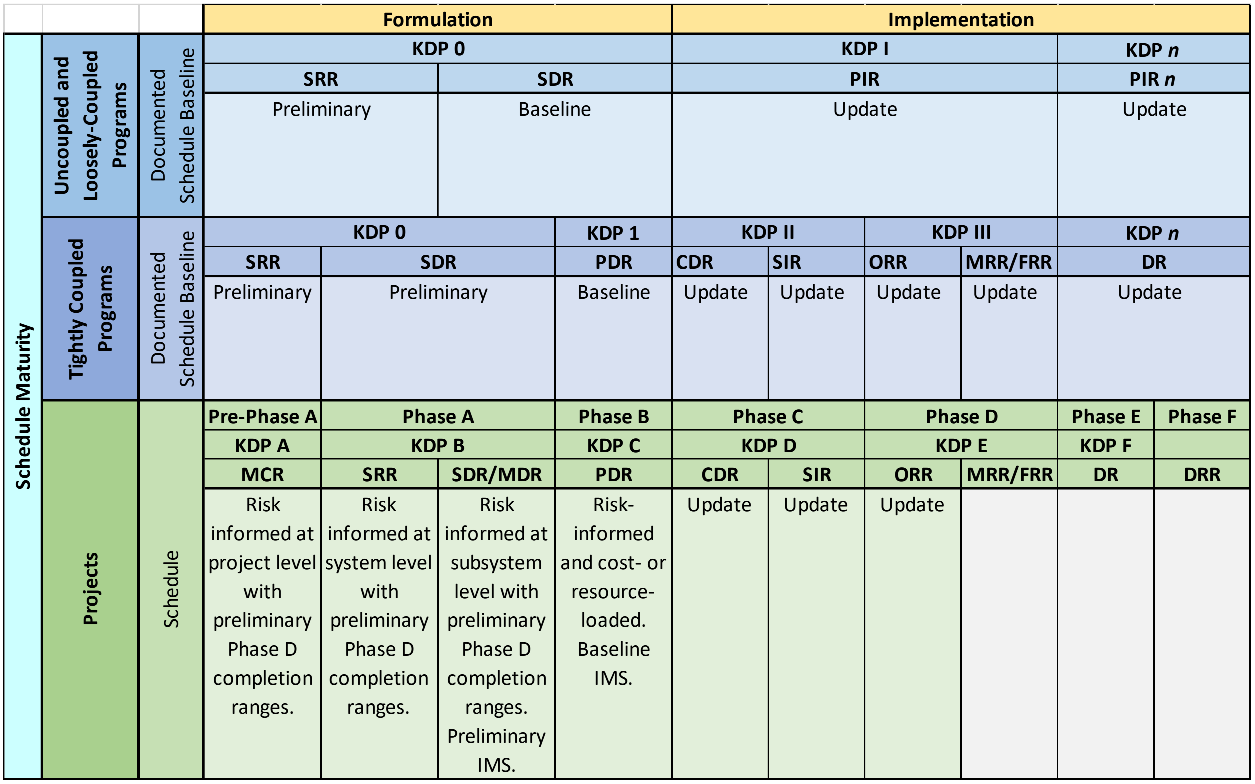
5.5.11.2 "How Much" Margin to Establish

Just as activity duration estimates can be based on other sources of information, early in P/p Formulation, it is a recommended practice that schedule margin estimates be informed by analogous missions, expert experience and judgement, or established standards. Example guidelines for established standards consolidated from several NASA Centers are shown in Figure 5-30.

From (Point in Life Cycle)	To (Point in Life Cycle)	Amount of Planned Margin
Confirmation Review	Beginning of Integration & Test	Varies: 1-2 month of schedule margin per year
Start of Integration & Test	Shipment to Launch Site	Varies: 2-2.5 months of schedule margin per year
Delivery to Launch Site	Launch	Varies: 1 day per week, 1 week per month, 1 month per year

Figure 5-30. Established standards for margin allocation.

These margin guidelines are suitable for early P/p planning; however, margin task durations can also be established in a way that corresponds to the likely impact of the P/p's associated uncertainty and risk based on the results of a probabilistic analysis. As early in the P/p life cycle as possible, margin durations should be demonstrated to be adequate using some form of risk analysis (see Best Practice in Section 6.3.2.5.3.6). Per NPR 7120.5, “margins are allocated in the Formulation process, based on assessments of risks, and are typically consumed as the P/p proceeds through the life cycle.”[68] Figure 5-31 shows the NPR 7120.5 requirements for risk-informed schedules. Furthermore, the NASA Cost Estimating Handbook characterizes a risk-informed schedule as having discrete risks and uncertainties accounted for within the schedule.[69]



			Formulation				**Implementation**					
Schedule Maturity	**Uncoupled and Loosely-Coupled Programs**	Documented Schedule Baseline	**KDP 0**				**KDP I**				**KDP *n***	
			SRR		**SDR**		**PIR**				**PIR *n***	
			Preliminary		Baseline		Update				Update	
	Tightly Coupled Programs	Documented Schedule Baseline	**KDP 0**			**KDP 1**	**KDP II**		**KDP III**		**KDP *n***	
			SRR	**SDR**		**PDR**	**CDR**	**SIR**	**ORR**	**MRR/FRR**	**DR**	
			Preliminary	Preliminary		Baseline	Update	Update	Update	Update	Update	
	Projects	Schedule	**Pre-Phase A**	**Phase A**		**Phase B**	**Phase C**		**Phase D**		**Phase E**	**Phase F**
			KDP A	**KDP B**		**KDP C**	**KDP D**		**KDP E**		**KDP F**	
			MCR	**SRR**	**SDR/MDR**	**PDR**	**CDR**	**SIR**	**ORR**	**MRR/FRR**	**DR**	**DRR**
			Risk informed at project level with preliminary Phase D completion ranges.	Risk informed at system level with preliminary Phase D completion ranges.	Risk informed at subsystem level with preliminary Phase D completion ranges. Preliminary IMS.	Risk-informed and cost- or resource-loaded. Baseline IMS.	Update	Update	Update			

Figure 5-31. The requirements for risk assessments and risk analysis by project phase are listed in this figure.

Early in the P/p life cycle, it is a recommended practice to perform a probabilistic schedule risk analysis to inform the adequacy and placement of schedule margin in the *IMS*. The amount of margin incorporated in the schedule should be enough to accommodate all identified duration uncertainties and discrete risks. Developing informed duration uncertainties requires that the P/p have a clear understanding of whether its task duration estimates are accurate, inflated, or overly optimistic. It is also important for the P/p to be aware that unexpected events may occur, which may cause the schedule to slip (e.g. extreme inclement weather, government shutdown, etc.). Discrete risks are identified through the P/p’s Risk Management process, the likelihood and impacts of which should be

---

[68] NPR 7120.5E. NASA Space Flight Program and Project Management Requirements. Effective Date: August 14, 2012. Expiration Date: August 14, 2020. Page 56.

[69] NASA Cost Estimating Handbook, V4.0. Appendix J. Page J-7. February 2015. https://www.nasa.gov/sites/default/files/files/CEH_Appj.pdf

discussed among the PM, Technical Lead, Risk Manager, Business Manager, and Scheduler. Considering the results of an *SRA* that incorporates both uncertainties and risks allows for increased accuracy in downstream forecasts. In addition, NPR 7120.5 requires a risk-informed schedule at the project level at KDP A, a risk-informed schedule at the system level at SRR, and a risk-informed schedule at the subsystem level at SDR, which are typically achieved through an *SRA*. Details on performing an *SRA*, including determining the uncertainty and discrete risk parameters to include in the *SRA Model*, are contained in Section 6.3.2.5.3.

An *ICSRA/JCL* is required at KDP I/KDP C just prior to setting the P/p baseline, as well as at rebaselines for tightly coupled programs, single-project programs, or projects with an estimated LCC greater than $250 million. For single-project programs and projects with an LCC of $1 billion or more, an ICSRA/JCL is required at KDP B, CDR, and KDP D.[70] During Implementation, it is important to take P/p float into consideration when establishing any new margin activities due to a better understanding of uncertainties or the identification of new risks. For instance, it is likely that the P/p has little flexibility in changing its finish date or end-item delivery date. It is also possible that the P/p has already identified margin in an amount equal to the available total float during the initial Schedule Development process. If not, the P/p may opt to take the remaining amount of days between the calculated early finish date and the P/p's finish date (which should be represented by total float) and add a margin activity that applies an equivalent duration in the schedule to absorb any remaining float. This will make the primary critical path a zero-float path and maximize the amount of margin the P/p has available to manage identified risks and uncertainties. If more margin is allocated than total float in the schedule, the float on critical path activities will become negative, indicating that the P/p requires time beyond its scheduled completion (see also Section 1.1.1.3, *At the End of the Schedule Logic Flow*).

This handbook places emphasis on identifying and managing schedule margin over float. With margin, it is possible to determine whether a P/p has "adequate" margin due to its direct relationship to uncertainties and risks. Managing margin allows for direct traceability to potential uncertainty and/or risk impacts. Because the allocation of margin requires available float in the deterministic schedule, by managing schedule margin, the float is often managed by default. Guidance on margin and float erosion tracking can be found in Section 7.3.3.1.6.

5.5.11.3 "Where" to Allocate Margin

Schedule margin must be introduced into the schedule at strategic locations so that it can effectively satisfy its intended purpose to absorb or mitigate risk and be easily accounted for as part of the critical path sequence.

Where Risks Occur

Deliberate locations for margin include placement along the critical path where risk impacts are expected to occur. Risks may also be identified on paths other than the deterministic, primary critical path. For instance, it is common to allocate margin to more than one development activity, usually along the primary, secondary, and tertiary critical paths, which are often risk-informed driving paths. A driving path is the longest path to an end item, such as a milestone or delivery, other than P/p

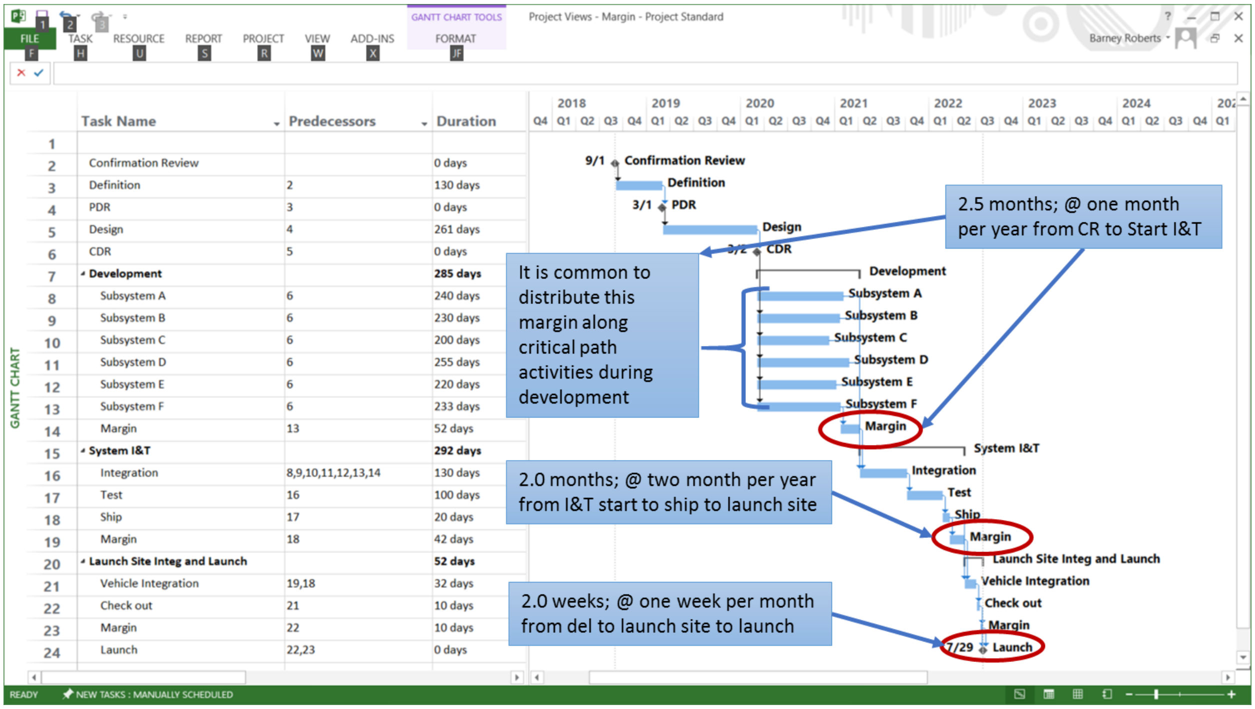
---

[70] Memo from the NASA Associate Administrator: "Joint Cost and Schedule (JCL) Requirements Updates." May 24. 2019

completion. A driving path is based on the zero free float identifying the drivers to any activity, rather than the effect on total float to P/p completion. Margin activities can be captured on these paths as well for better management insight and schedule control; however, margin calculations against the overall P/p finish date or end-item delivery date should be derived from the P/p's primary critical path for reporting purposes.

In general, for Space Flight P/ps, margin can be assigned to systems and subsystems during design and fabrication and placed just before delivery into I&T in order to protect the start of I&T. After I&T start, additional margin tasks are assigned throughout the I&T flow and are usually placed just before major test activities to protect time slots in the test facilities. At the end of I&T, another margin task is usually assigned to protect the ship date to the launch integration activity. Of course, there are variations on this approach depending on the actual P/p Planning (e.g., performing an <u>*SRA*</u> to establish risk-informed margin locations as described in Section 6.3.2.5.3.6).

Figure 5-32 is an example of margin allocation for a project early in Formulation using established standards. The margin from the subsystems into the Integration and Test (I&T) as shown here is a single margin allocation.



	Task Name	Predecessors	Duration
1			
2	Confirmation Review		0 days
3	Definition	2	130 days
4	PDR	3	0 days
5	Design	4	261 days
6	CDR	5	0 days
7	**Development**		**285 days**
8	Subsystem A	6	240 days
9	Subsystem B	6	230 days
10	Subsystem C	6	200 days
11	Subsystem D	6	255 days
12	Subsystem E	6	220 days
13	Subsystem F	6	233 days
14	Margin	13	52 days
15	**System I&T**		**292 days**
16	Integration	8,9,10,11,12,13,14	130 days
17	Test	16	100 days
18	Ship	17	20 days
19	Margin	18	42 days
20	**Launch Site Integ and Launch**		**52 days**
21	Vehicle Integration	19,18	32 days
22	Check out	21	10 days
23	Margin	22	10 days
24	Launch	22,23	0 days

2.5 months; @ one month per year from CR to Start I&T

It is common to distribute this margin along critical path activities during development

2.0 months; @ two month per year from I&T start to ship to launch site

2.0 weeks; @ one week per month from del to launch site to launch

Figure 5-32. An example of margin allocation using established standards.

Prior to Key Milestones/Events

Margin tasks may be placed just prior to key milestones or events, such as: significant assembly, integration, and test (AI&T) milestones, contractual milestones, or lifecycle review milestones. The duration of these types of margin tasks can be based on uncertainties in the schedule elements leading up to those key milestones or events. For example, more margin might be attributed to critical areas of the schedule where tasks carry higher uncertainties, whereas less margin might be attributed to less "risky" areas of the schedule. It is important to note that schedule margin durations should not be used to hold a deliverable forecast to a static date but should be based upon risks and uncertainties.

Prior to End-Item Deliverables, Contract Completion Milestone, or P/p Finish Milestone

It is a recommended practice that some margin be placed at the end of the schedule network logic flow just prior to the appropriate set of end-item deliverables, P/p or contract completion tasks, or P/p finish milestone. For spaceflight P/ps, the work near the end of the schedule becomes more serial or single-flow in nature and realized risks tend to be more problematic because of decreased flexibility in the schedule to incorporate workarounds.[71] However, P/ps should use caution when applying margin near the end of the P/p. P/p teams may interpret a lump sum of margin at the end of the schedule as being "up for grabs" to cover late activities. The intent of margin activities should be made clear; it is not to be consumed due to performance delays, rather any margin near the end of the schedule should be closely managed and used strategically to absorb any late risk impacts or implement risk mitigations. Should performance delays occur, Technical Leads may need to work weekends or extra hours to finish on time versus using margin.

5.5.11.4 Consider Budget for the Eventual Use of Margin

Margin is identified for future situations that are not clearly defined, such as potential risks and uncertainties, where there is no known or approved P/p scope involved. The use of margin will likely and eventually require the allocation of budget (dollars), either when risks are realized, or risk mitigation activities are identified, and the associated scope is added to the baseline plan. It is very important that an adequate, estimated amount of budget be "available" to cover a reasonable workforce level through the duration of the schedule margin activity, should the P/p need to "use" the margin.

It is possible that budget needed to support the new scope will either come from either P/p-held Management Reserve (MR) or NASA HQ-held Unallocated Future Expenses (UFE).[72] Because UFE is generally risk-informed as part of a risk analysis exercise to set the Agency Baseline Commitment (ABC)[73], it is likely that UFE will exist in an amount to cover the projected risks that may affect the schedule.[74]

It is a recommended practice that no specified budget be assigned to a schedule margin activity as part of the baseline. Instead, budget available for "planned" schedule margin activities should be maintained outside of the baseline. As part of the *SRA* activity, this may be handled by creating a discrete risk in the

---

[71] "Concurrently Verifying and Validating the Critical Path and Margin Allocation Using Probabilistic Analysis." Joint Space Cost Council (JSCC) Scheduler's Forum. Page 16. March 2017.

[72] Per the NASA EVM Implementation Handbook (NASA/SP-2018-599), ANSI/EIA-748 provides for the establishment and use of MR to handle risks (and uncertainty). https://www.nasa.gov/evm/handbooks

[73] NPR 7120.5E, page 52, defines Agency Baseline Commitment as, "Establishes and documents an integrated set of project requirements, cost, schedule, technical content, and an agreed-to JCL that forms the basis for NASA's commitment to the external entities of OMB and Congress. Only one official baseline exists for a NASA program or project, and it is the Agency Baseline Commitment."

[74] "The level of UFE or UFE percentage should be selected based upon achieving a particular level of confidence from the cost or joint cost and schedule risk analysis. The appropriate level of confidence is chosen by the appropriate NASA management council after the analysis, and the resulting UFE should be identified as the recommended level at all Confirmation Reviews." NASA Cost Estimating Handbook, V4.0. Page 28. February 2015. https://www.nasa.gov/sites/default/files/files/01_CEH_Main_Body_02_27_15.pdf

risk list, mapping it to a margin activity assigned at the appropriate point in the schedule, and then putting a lien against the MR or UFE until the margin is “used” – that is, converted to an activity with defined scope. Once management confirms that margin needs to be used for risks or uncertainties, activities with both scope and budget should be added to the baseline through the appropriate change control process. The original margin activity durations should be reduced accordingly.

Caution. Some organizations may choose to allocate budget to margin activities (i.e., “funded schedule margin”). This is not a best practice as it effectively inflates the P/p baseline and complicates EVM calculations by making metrics appear as though less work has been accomplished overall per the inflated baseline.

Document the BoE for Schedule Margin

While it is essential that schedule margin activities clearly identifiable in the schedule, it is equally important to document the rationale for the schedule margin allocation as part of the *BoE* in concert with the *SRA*. This could include, for example, any probabilistic analysis approaches used to estimate the necessary margin activity, including its location and duration in the schedule.

It is necessary to understand margin in the context of the *IMS’s* networked elements that affect it, so a *Schedule Risk Analysis-based Assessment* should be performed after margin is allocated to more completely understand the findings associated with all lower-tier assessments.

5.5.12 Perform Resource or Cost Loading

It is a best practice for the schedule to include resources and/or costs assigned to all applicable activities at the most appropriate WBS level. “Resource loading” is defined in Appendix J of the NASA Cost Estimation Handbook (J.1.3.4.1) as, “the process of recording resource requirements for a schedule task/activity or a group of tasks/activities.” Cost loading refers to mapping estimated costs to the *IMS*. The primary purpose of developing a resource- or cost-loaded schedule is to help ensure that NASA P/ps can meet their commitments by using a systematic approach that integrates cost, schedule, and risk. Resource loading or cost loading a schedule facilitates communication between the P/S or Schedule Analyst, the Business Manager or Cost Analyst, the Technical Lead, and the PM as assumptions and risks are documented. These practices encourage communication between Agency leadership and the PM, affording leadership an opportunity to consider the underlying programmatic assumptions; to discuss the analysis techniques; and ultimately, to build consensus around the conclusions (budget levels, amount of UFE, risks involved, probability of meeting commitments, etc.) for more informed decision making.

The following sections further describe resource loading and cost loading. These strategies should not be viewed as conflicting approaches, but rather as two different methods of applying “resources” to the *IMS* to satisfy different P/p management needs and purposes. While it is important to introduce and distinguish the differences between resource loading and cost loading techniques, specific guidance and information on this second approach is addressed in greater detail in Sections 6.3.2.2.1.3 and 6.3.2.2.3, as well as within other Agency *JCL* instructional documentation. It should be noted that although “resource loading” is an Agency requirement for those P/p that have a *JCL* requirement, cost loading is an acceptable method.

Note: An additional section on budget loading follows the resource loading and cost loading sections; however, budget loading is not a formally defined method within the Agency.

5.5.12.1 Resource Loading

Resource loading is a traditional approach involving the assignment of specific resources (i.e., workforce, materials, equipment, etc.) to tasks within the P/p's detailed *IMS*. Its basic purpose is to provide a tool that yields insight and assistance to the PM and his team in their management of weekly and monthly of resource allocations, and the on-going evolution of P/p budget estimates that satisfy various Agency, program, and project budget development requirements. It helps the P/p to determine how the availability of resources may impact the completion of tasks. This technique is sometimes referred to as a "grassroots" estimate because the resources assigned to each task are the basis of estimate for the cost of the task and are considered to be discrete in nature thus resulting in P/p estimates developed coming from "the ground up".

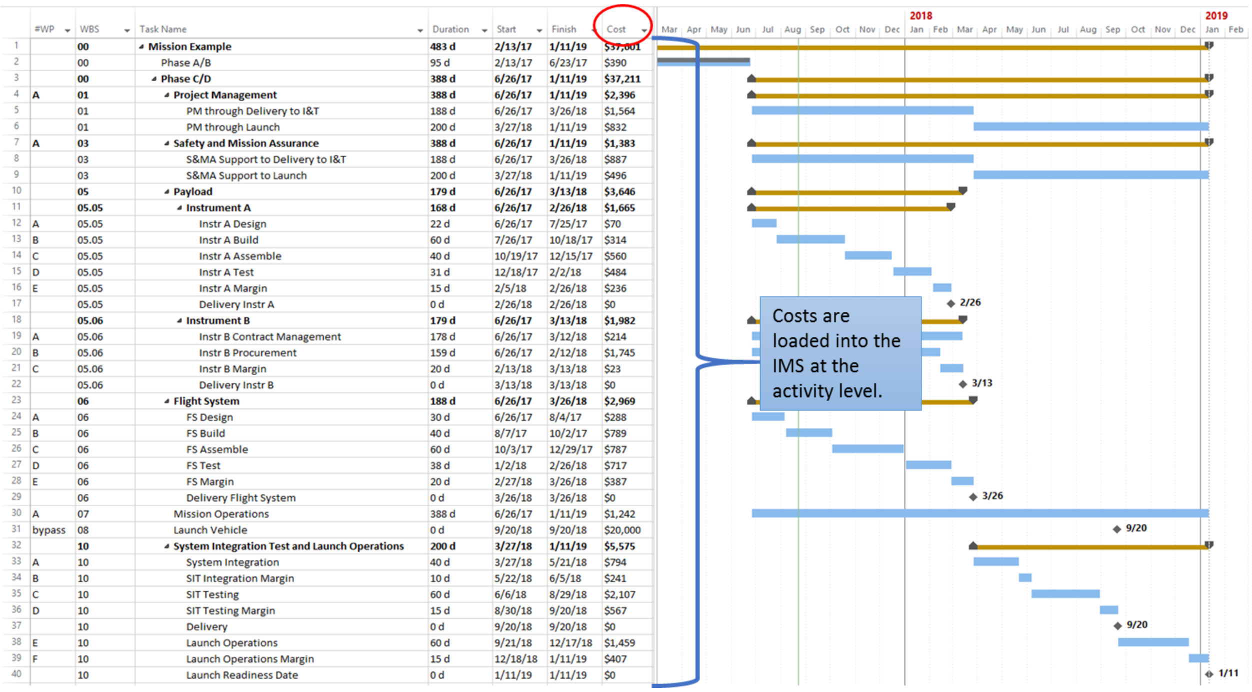
Resource loading provides many additional benefits that greatly enhance the P/p planning and control process including, but not limited to:

- Ensuring accurate integration of work and budget plans (e.g., to support EVM), thereby increasing confidence and reducing risk
- Ensuring resource availability to perform the work (e.g., labor, procurement, etc.)
- Providing greater insight into workforce adequacy and allocations
- Generating accurate inputs for the Agency Program Planning Budget Execution (PPBE) process
- Providing cash flow and budget profiles
- Providing quicker, more effective analysis for "what-if" exercises

There are however, cautions associated with resource loading which may indicate that it should not be done, such as:

- Insufficient team resource loading skills for effective implementation and maintenance
- Scheduling tools inadequate to perform resource loading
- An undefined P/p resource pool
- Lack of clarity in contractor or subcontractor allocation of specific resources to specific portions of the schedule (due to proprietary corporate information)
- A P/p team culture resistant to its use

Figure 5-33 provides an example of a resource-loaded schedule.



	#WP	WBS	Task Name	Duration	Start	Finish	Cost
1		00	Mission Example	483 d	2/13/17	1/11/19	$37,601
2		00	Phase A/B	95 d	2/13/17	6/23/17	$390
3		00	Phase C/D	388 d	6/26/17	1/11/19	$37,211
4	A	01	Project Management	388 d	6/26/17	1/11/19	$2,396
5		01	PM through Delivery to I&T	188 d	6/26/17	3/26/18	$1,564
6		01	PM through Launch	200 d	3/27/18	1/11/19	$832
7	A	03	Safety and Mission Assurance	388 d	6/26/17	1/11/19	$1,383
8		03	S&MA Support to Delivery to I&T	188 d	6/26/17	3/26/18	$887
9		03	S&MA Support to Launch	200 d	3/27/18	1/11/19	$496
10		05	Payload	179 d	6/26/17	3/13/18	$3,646
11		05.05	Instrument A	168 d	6/26/17	2/26/18	$1,665
12	A	05.05	Instr A Design	22 d	6/26/17	7/25/17	$70
13	B	05.05	Instr A Build	60 d	7/26/17	10/18/17	$314
14	C	05.05	Instr A Assemble	40 d	10/19/17	12/15/17	$560
15	D	05.05	Instr A Test	31 d	12/18/17	2/2/18	$484
16	E	05.05	Instr A Margin	15 d	2/5/18	2/26/18	$236
17		05.05	Delivery Instr A	0 d	2/26/18	2/26/18	$0
18		05.06	Instrument B	179 d	6/26/17	3/13/18	$1,982
19	A	05.06	Instr B Contract Management	178 d	6/26/17	3/12/18	$214
20	B	05.06	Instr B Procurement	159 d	6/26/17	2/12/18	$1,745
21	C	05.06	Instr B Margin	20 d	2/13/18	3/13/18	$23
22		05.06	Delivery Instr B	0 d	3/13/18	3/13/18	$0
23		06	Flight System	188 d	6/26/17	3/26/18	$2,969
24	A	06	FS Design	30 d	6/26/17	8/4/17	$288
25	B	06	FS Build	40 d	8/7/17	10/2/17	$789
26	C	06	FS Assemble	60 d	10/3/17	12/29/17	$787
27	D	06	FS Test	38 d	1/2/18	2/26/18	$717
28	E	06	FS Margin	20 d	2/27/18	3/26/18	$387
29		06	Delivery Flight System	0 d	3/26/18	3/26/18	$0
30	A	07	Mission Operations	388 d	6/26/17	1/11/19	$1,242
31	bypass	08	Launch Vehicle	0 d	9/20/18	9/20/18	$20,000
32		10	System Integration Test and Launch Operations	200 d	3/27/18	1/11/19	$5,575
33	A	10	System Integration	40 d	3/27/18	5/21/18	$794
34	B	10	SIT Integration Margin	10 d	5/22/18	6/5/18	$241
35	C	10	SIT Testing	60 d	6/6/18	8/29/18	$2,107
36	D	10	SIT Testing Margin	15 d	8/30/18	9/20/18	$567
37		10	Delivery	0 d	9/20/18	9/20/18	$0
38	E	10	Launch Operations	60 d	9/21/18	12/17/18	$1,459
39	F	10	Launch Operations Margin	15 d	12/18/18	1/11/19	$407
40		10	Launch Readiness Date	0 d	1/11/19	1/11/19	$0

Costs are loaded into the IMS at the activity level.

Figure 5-33. An example of a resource-loaded schedule.

5.5.12.1.1 Level Resources

Resource loading a schedule is the process of assigning specific people, materials, dollars, etc. to a schedule activity or a group of activities for the purposes of estimating P/p duration, cost, feasibility, and workforce planning. Resources can generally be put into three categories as follows:

- **Workforce.** The people resources assigned to do work.
- **Equipment.** The reusable resource items such as test or manufacturing equipment and facilities.
- **Consumables.** The resources that have a specified quantity. When that quantity is used up, the resources must be replaced (e.g., fuel, steel, cabling).

Resource loading can be done in an automated scheduling tool or in an external spreadsheet; however, to ensure adequate cost and schedule integration, it is a recommended practice to implement resource loading within an automated scheduling tool. Some standard practices for implementing resource loading within an automated scheduling tool include, but are not limited to, the following:

- Prior to assigning resources to *IMS* tasks, it is a recommended practice that a listing of potential resources be established within the automated schedule tool (see Figure 5-5). This resource "library" or "pool" should contain all types of resources that will be needed for the P/p, regardless if it is workforce, equipment, or consumables.
- It is a recommended practice that the resource pool uses a consistent resource naming convention. This will enhance accuracy and consistency in the planning, integration, analysis, and reporting of P/p resource data. Due to the size of P/ps and the need for flexibility to allow multiple people within a single organization to work specific tasks, P/ps may opt to use job

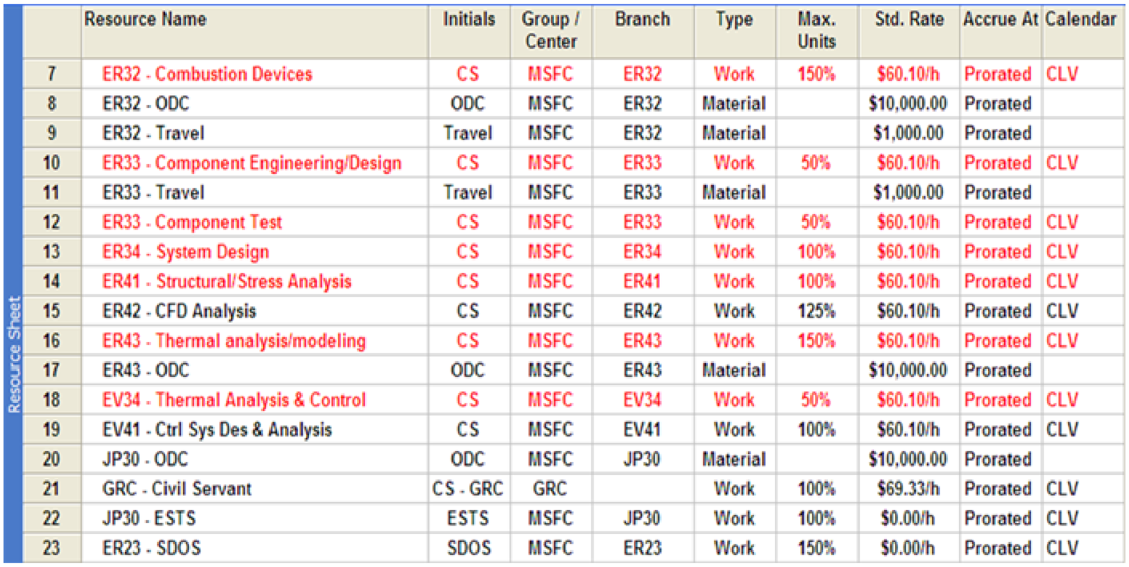
titles/levels (e.g., Engineer, Sr. Engineer, etc.) versus individual names of personnel in the resource pool.

Once the resource pool is complete, then task resource assignments can be made.

5.5.12.1.2 Assign Resource Rates

All resources required to perform a specific task should be selected and assigned to that task along with quantity required. Rates for each resource are determined and applied to calculate the cost of labor, material, or other resources assigned to each task. Resource rates are typically maintained within a scheduling software and applied to task resources contained in the *IMS*. Figure 5-34 provides an example of a "resource pool" where resource rates are maintained and applied to task resources that are assigned in the *IMS*. Resource rates or per-use costs may also be maintained and applied in a separate cost management tool that may be part of the P/p management process.

Applying resource rates to tasks is a bottom-up method of determining the time-phased budget baseline for a P/p. Thus, it is a recommended practice to apply resource rates to tasks. This process facilitates the implementation of EVM within the P/p and is also useful in facilitating evaluations of cost impacts due to schedule changes. It is a recommended practice that labor quantities should be loaded in hours. Non-labor resources may be input either as a specific dollar amount that corresponds to each assignment of the specified resource, or as a per use amount that has an associated cost rate that is applied within the automated tool.



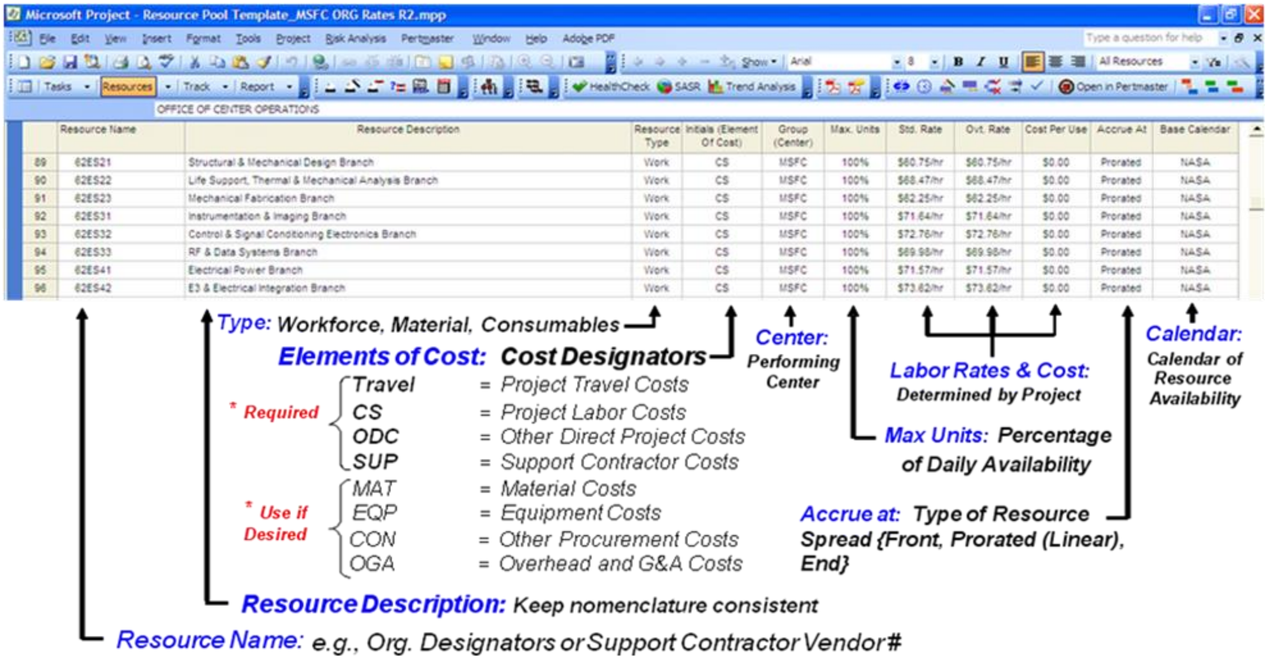
	Resource Name	Initials	Group / Center	Branch	Type	Max. Units	Std. Rate	Accrue At	Calendar
7	ER32 - Combustion Devices	CS	MSFC	ER32	Work	150%	$60.10/h	Prorated	CLV
8	ER32 - ODC	ODC	MSFC	ER32	Material		$10,000.00	Prorated	
9	ER32 - Travel	Travel	MSFC	ER32	Material		$1,000.00	Prorated	
10	ER33 - Component Engineering/Design	CS	MSFC	ER33	Work	50%	$60.10/h	Prorated	CLV
11	ER33 - Travel	Travel	MSFC	ER33	Material		$1,000.00	Prorated	
12	ER33 - Component Test	CS	MSFC	ER33	Work	50%	$60.10/h	Prorated	CLV
13	ER34 - System Design	CS	MSFC	ER34	Work	100%	$60.10/h	Prorated	CLV
14	ER41 - Structural/Stress Analysis	CS	MSFC	ER41	Work	100%	$60.10/h	Prorated	CLV
15	ER42 - CFD Analysis	CS	MSFC	ER42	Work	125%	$60.10/h	Prorated	CLV
16	ER43 - Thermal analysis/modeling	CS	MSFC	ER43	Work	150%	$60.10/h	Prorated	CLV
17	ER43 - ODC	ODC	MSFC	ER43	Material		$10,000.00	Prorated	
18	EV34 - Thermal Analysis & Control	CS	MSFC	EV34	Work	50%	$60.10/h	Prorated	CLV
19	EV41 - Ctrl Sys Des & Analysis	CS	MSFC	EV41	Work	100%	$60.10/h	Prorated	CLV
20	JP30 - ODC	ODC	MSFC	JP30	Material		$10,000.00	Prorated	
21	GRC - Civil Servant	CS - GRC	GRC		Work	100%	$69.33/h	Prorated	CLV
22	JP30 - ESTS	ESTS	MSFC	JP30	Work	100%	$0.00/h	Prorated	CLV
23	ER23 - SDOS	SDOS	MSFC	ER23	Work	150%	$0.00/h	Prorated	CLV

Figure 5-34. An example of a resource pool captured in MS Project.

Within the resource pool contained in the automated scheduling tool, there are also specific data elements as shown in Figure 5-35 that must be associated with each resource that are critical to accomplishing effective resource loading. It is a recommended practice that these resource data elements include, but are not limited to, the following (* indicates recommended minimum):

- *Resource name (*specific employee names are not recommended due to dynamic work assignment changes*); add new resource names as-needed

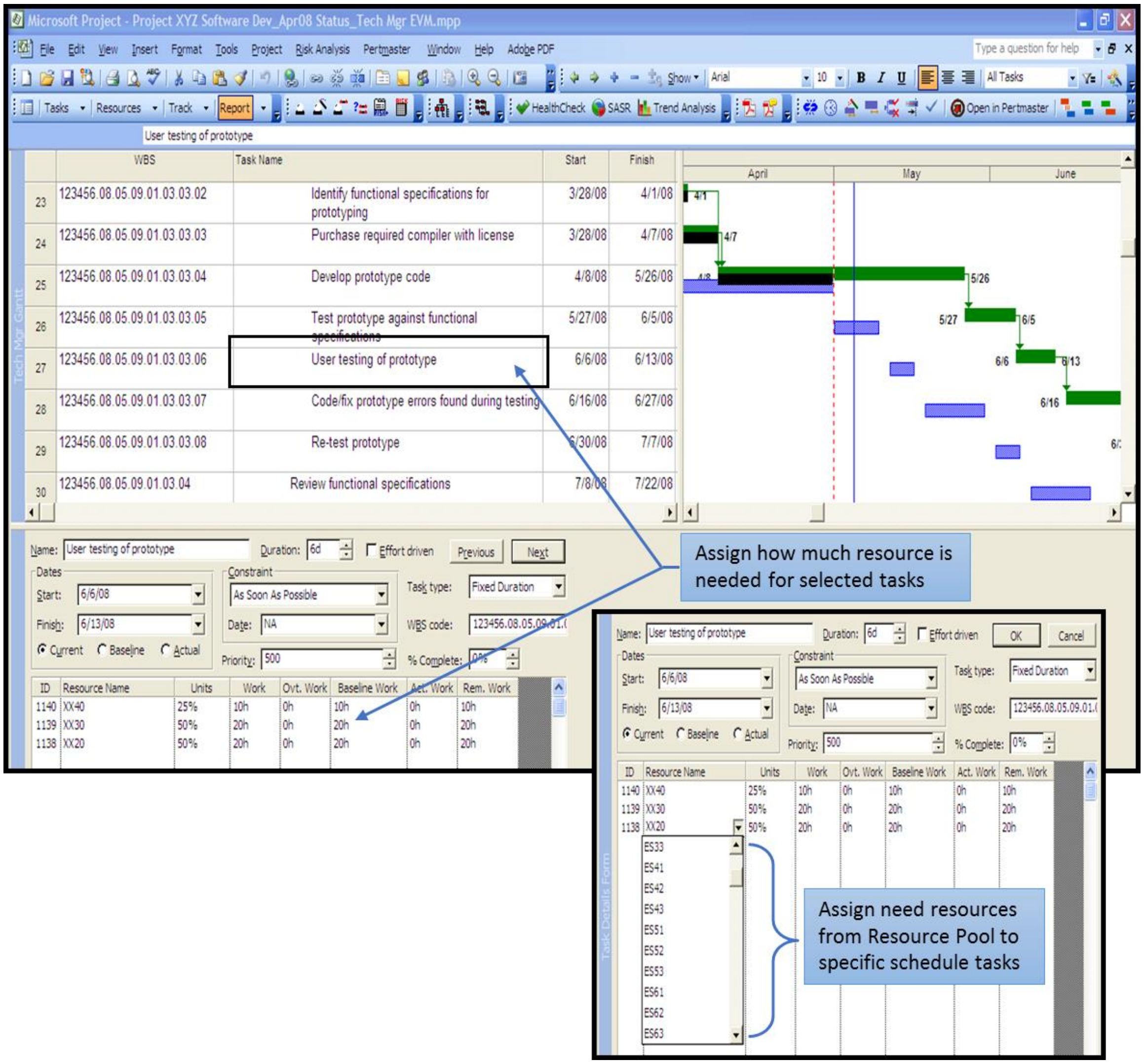
- *Resource description (e.g., organization name, support contractor company name)
    - Resource Types (e.g., workforce, material, or consumables)
- *Element of cost:
    - *Travel (designator = Travel)
    - *Personnel Cost (designator = CS)
    - *Other Direct Cost (designator = ODC)
    - *Support Contractor (designator = SUP)
    - Equipment (designator = EQP)
    - Contracts (designator = CON)
    - Material (designator = MAT)
    - Overhead and G&A (designator = OGA)
- *Center identifier (use official Center acronym)
- *Maximum number of units available Standard Unit Rate (P/p to determine)
- *Overtime Rate (P/p to determine)
- *Cost Per Use (P/p to determine)
- *Accrual method (start, prorated, end)
- *Resource Calendar (reflects active periods of resource availability - P/p to determine)



	Resource Name	Resource Description	Resource Type	Initials (Element Of Cost)	Group (Center)	Max. Units	Std. Rate	Ovt. Rate	Cost Per Use	Accrue At	Base Calendar
89	62ES21	Structural & Mechanical Design Branch	Work	CS	MSFC	100%	$60.75/hr	$60.75/hr	$0.00	Prorated	NASA
90	62ES22	Life Support, Thermal & Mechanical Analysis Branch	Work	CS	MSFC	100%	$68.47/hr	$68.47/hr	$0.00	Prorated	NASA
91	62ES23	Mechanical Fabrication Branch	Work	CS	MSFC	100%	$62.25/hr	$62.25/hr	$0.00	Prorated	NASA
92	62ES31	Instrumentation & Imaging Branch	Work	CS	MSFC	100%	$71.64/hr	$71.64/hr	$0.00	Prorated	NASA
93	62ES32	Control & Signal Conditioning Electronics Branch	Work	CS	MSFC	100%	$72.76/hr	$72.76/hr	$0.00	Prorated	NASA
94	62ES33	RF & Data Systems Branch	Work	CS	MSFC	100%	$69.98/hr	$69.98/hr	$0.00	Prorated	NASA
95	62ES41	Electrical Power Branch	Work	CS	MSFC	100%	$71.57/hr	$71.57/hr	$0.00	Prorated	NASA
96	62ES42	E3 & Electrical Integration Branch	Work	CS	MSFC	100%	$73.62/hr	$73.62/hr	$0.00	Prorated	NASA

Figure 5-35. Resource pool showing associated data elements.

Allocation of resources may be done in various units of measure, depending on the type of resources used. The P/S must also ensure that resources are distributed adequately across the specified task durations. Most automated scheduling tools distribute assigned resources in a linear fashion, evenly across the duration of a task, unless the user takes action to customize this distribution. To ensure that a reasonable and achievable schedule plan has been developed, it is important that the P/S diligently work through the resource loading process and establish a complete and credible basis from which to move forward during P/p implementation. Figure 5-36 illustrates the schedule resource loading process.



User testing of prototype

	WBS	Task Name	Start	Finish
23	123456.08.05.09.01.03.03.02	Identify functional specifications for prototyping	3/28/08	4/1/08
24	123456.08.05.09.01.03.03.03	Purchase required compiler with license	3/28/08	4/7/08
25	123456.08.05.09.01.03.03.04	Develop prototype code	4/8/08	5/26/08
26	123456.08.05.09.01.03.03.05	Test prototype against functional specifications	5/27/08	6/5/08
27	123456.08.05.09.01.03.03.06	User testing of prototype	6/6/08	6/13/08
28	123456.08.05.09.01.03.03.07	Code/fix prototype errors found during testing	6/16/08	6/27/08
29	123456.08.05.09.01.03.03.08	Re-test prototype	6/30/08	7/7/08
30	123456.08.05.09.01.03.04	Review functional specifications	7/8/08	7/22/08

Name: User testing of prototype Duration: 6d ☐ Effort driven

Dates
Start: 6/6/08
Finish: 6/13/08
● Current ○ Baseline ○ Actual

Constraint
As Soon As Possible
Date: NA
Priority: 500

Task type: Fixed Duration
WBS code: 123456.08.05.09.01.(
% Complete: 0%

ID	Resource Name	Units	Work	Ovt. Work	Baseline Work	Act. Work	Rem. Work
1140	XX40	25%	10h	0h	10h	0h	10h
1139	XX30	50%	20h	0h	20h	0h	20h
1138	XX20	50%	20h	0h	20h	0h	20h

Assign how much resource is needed for selected tasks

Assign need resources from Resource Pool to specific schedule tasks

Figure 5-36. The schedule resource loading process.

5.5.12.1.3 Level Resources

With respect to workforce adequacy and allocations, resource loading can provide valuable information regarding over or under allocations in the <u>*IMS*</u>. A resource-loaded schedule provides time-phased requirements for labor, material, and equipment. It helps to ensure cost and schedule integration and provide the resource requirements needed to ensure that P/p resources are available when needed. For example, this information can alert the PM where resource conflicts exist, if a task cannot be completed in the time scheduled due to a resource shortage, or if adding more resources can shorten the task duration. Most scheduling software provide the capability to identify over or under allocation of resources. If manual processes are used to integrate resources with the schedule, similar reporting is possible but can be much more difficult to produce. Resource leveling can help to optimize the use of resources.

Resource leveling is the process of moving schedule tasks without violating network logic or constraints in order to achieve a more consistent level of resources throughout the schedule duration. Analysis through resource leveling is a process that can only be accomplished when a schedule is traditionally resource loaded and should generally be left to the more experienced P/S. Additionally, for the process to provide credible data, the schedule must be structured as an end-to-end logic network with all interdependencies identified.

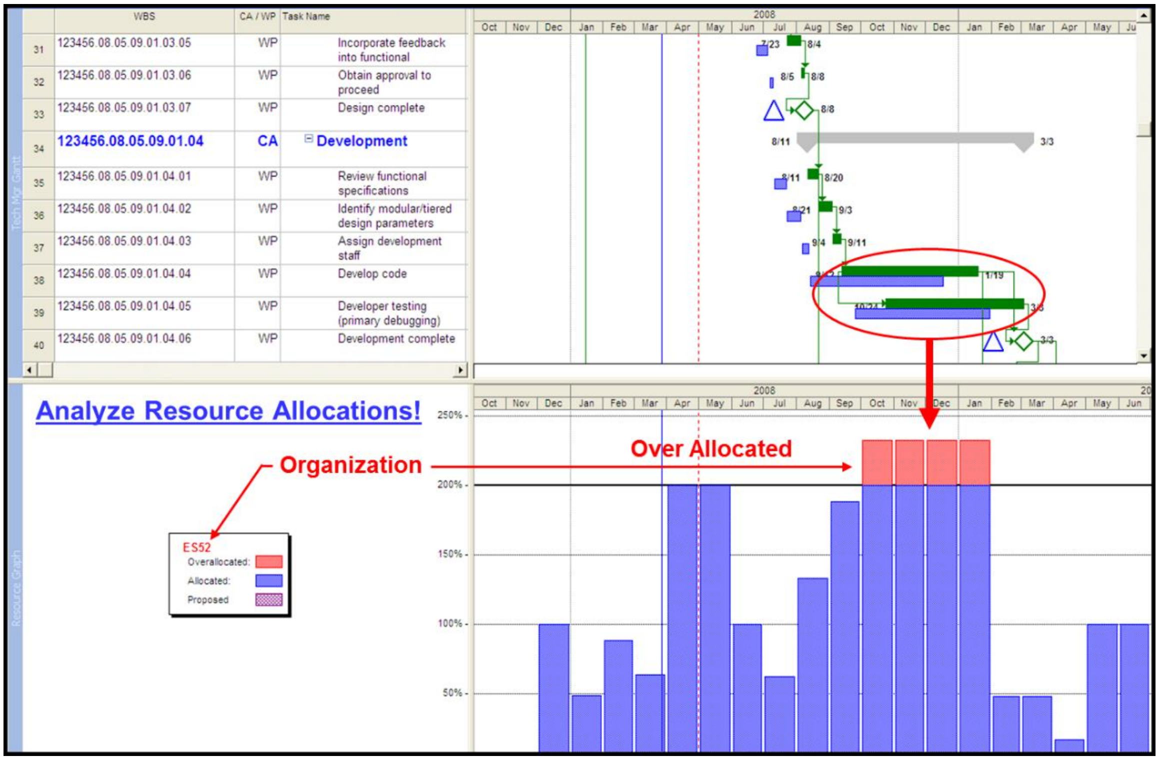
Resource leveling is generally accomplished through the use of a proven automated scheduling tool that has the capability of electronically evaluating total float values, logic relationships, constraints, and the amount of resources applied to each task or milestone in the schedule.

In carrying out this process, there are two possible methods to follow:

- **Automated Resource Leveling**. The scheduling tool will reschedule tasks as allowed based on the characteristics listed above to most efficiently utilize and level the number of resources in an effort to eliminate over allocations. Extreme caution should be used when automatically letting the schedule tool perform resource leveling because in doing so, the tool may change or add delays and constraints to the schedule which are not immediately detectable until a full critical path analysis is performed. As mentioned above, only skilled qualified P/S's should perform these actions and even when doing so, leveling should be done in small chunks of the schedule, if the tool allows, so the results can be seen and validated.
- **Manual Resource Leveling**. This method provides the most accuracy with the least amount of error as each step of the way an "undo" can be made to correct unwanted results. To performing manual resource leveling the user simply puts the scheduling tool in a split view with a Gantt chart in one split and resource histogram or time phased value view in the other. Moving from left to right, the scheduler manually accelerates or delays tasks until optimized resource levels are achieved.

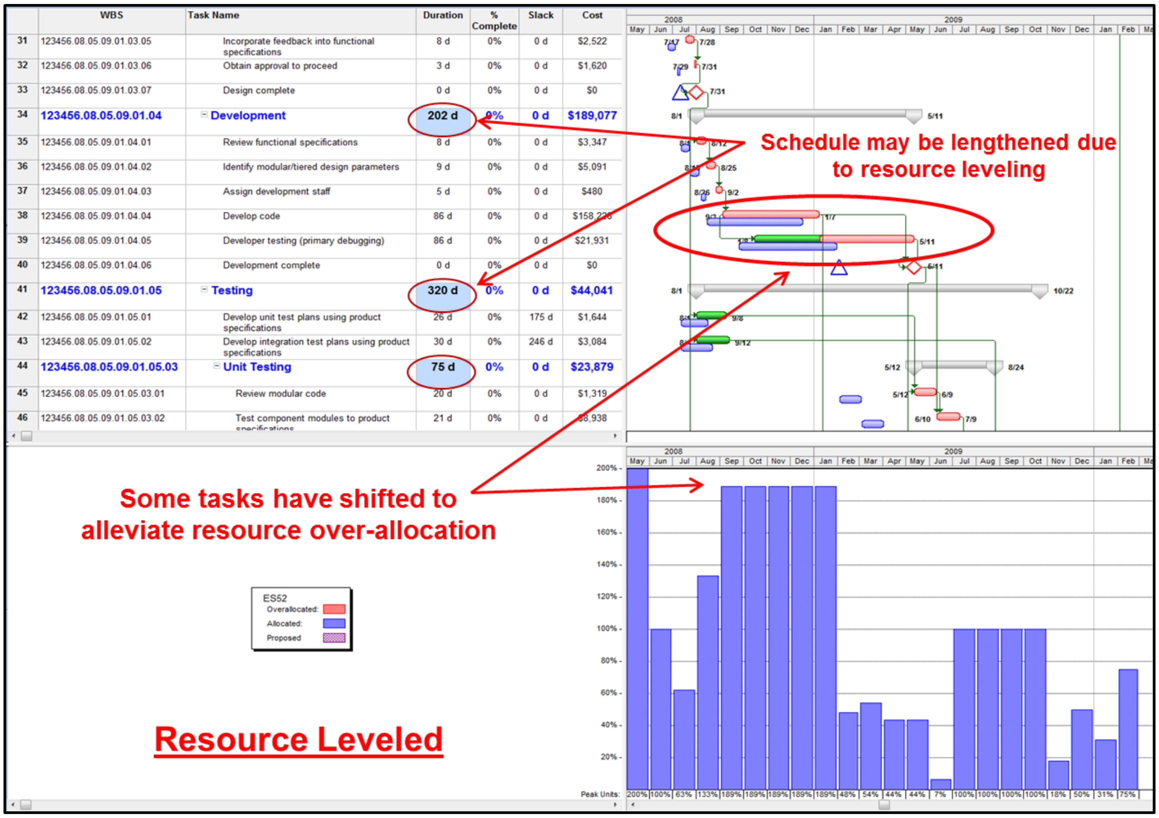
Caution. It is important to note that automated resource leveling does not factor in the varying skillsets and availability of specific resources (people).

Examples that illustrate the how a schedule is resource leveled are provided in Figure 5-37 and Figure 5-38. See also Section 5.5.13 – Time-Phase the Schedule.



	WBS	CA / WP	Task Name
31	123456.08.05.09.01.03.05	WP	Incorporate feedback into functional
32	123456.08.05.09.01.03.06	WP	Obtain approval to proceed
33	123456.08.05.09.01.03.07	WP	Design complete
34	**123456.08.05.09.01.04**	**CA**	**Development**
35	123456.08.05.09.01.04.01	WP	Review functional specifications
36	123456.08.05.09.01.04.02	WP	Identify modular/tiered design parameters
37	123456.08.05.09.01.04.03	WP	Assign development staff
38	123456.08.05.09.01.04.04	WP	Develop code
39	123456.08.05.09.01.04.05	WP	Developer testing (primary debugging)
40	123456.08.05.09.01.04.06	WP	Development complete

Figure 5-37. An example of a resource-loaded IMS with resource conflicts.



	WBS	Task Name	Duration	% Complete	Slack	Cost
31	123456.08.05.09.01.03.05	Incorporate feedback into functional specifications	8 d	0%	0 d	$2,522
32	123456.08.05.09.01.03.06	Obtain approval to proceed	3 d	0%	0 d	$1,620
33	123456.08.05.09.01.03.07	Design complete	0 d	0%	0 d	$0
34	**123456.08.05.09.01.04**	**Development**	**202 d**	**0%**	**0 d**	**$189,077**
35	123456.08.05.09.01.04.01	Review functional specifications	8 d	0%	0 d	$3,347
36	123456.08.05.09.01.04.02	Identify modular/tiered design parameters	9 d	0%	0 d	$5,091
37	123456.08.05.09.01.04.03	Assign development staff	5 d	0%	0 d	$480
38	123456.08.05.09.01.04.04	Develop code	86 d	0%	0 d	$158,22[illegible]
39	123456.08.05.09.01.04.05	Developer testing (primary debugging)	86 d	0%	0 d	$21,931
40	123456.08.05.09.01.04.06	Development complete	0 d	0%	0 d	$0
41	**123456.08.05.09.01.05**	**Testing**	**320 d**	**0%**	**0 d**	**$44,041**
42	123456.08.05.09.01.05.01	Develop unit test plans using product specifications	26 d	0%	175 d	$1,644
43	123456.08.05.09.01.05.02	Develop integration test plans using product specifications	30 d	0%	246 d	$3,084
44	**123456.08.05.09.01.05.03**	**Unit Testing**	**75 d**	**0%**	**0 d**	**$23,879**
45	123456.08.05.09.01.05.03.01	Review modular code	20 d	0%	0 d	$1,319
46	123456.08.05.09.01.05.03.02	Test component modules to product specifications	21 d	0%	0 d	$8,938

Figure 5-38. An example a resource loaded IMS with leveling to resolve resource conflicts.

It is very important that the resulting schedule data be reviewed by the P/p management team carefully, and not just taken at face value. This ensures credibility for P/p implementation as well as alleviates any other concerns that may exist relative to schedule data that are not necessarily related to float (slack), logic, or constraints that may require adjustments to be made before baselining the schedule.

It is a recommended practice that resource leveling be performed to accurately validate whether the scheduled P/p completion is achievable with the allotted resources (e.g., facilities, people, and budget) based on their availability. To baseline a P/p schedule without first resource loading and conducting leveling analysis is to assume a significant risk in achieving P/p completion within budget and on schedule. The P/p should also take this into consideration in terms of activity duration uncertainty when performing an *SRA* to analyze the achievability of the schedule.

5.5.12.2 Cost Loading

Cost loading is a cost and schedule integration approach defined in Appendix J of the NASA Cost Estimation Handbook (J.1.6.3).[75] This approach utilizes dollars as the only resource and involves the loading of projected costs (i.e., cost estimates, not to be confused with budget) to associated tasks within the *IMS* (or an *Analysis Schedule*, if appropriate for performing an *SRA/ICSRA*). Cost loading is often viewed as less cumbersome than traditional resource loading. Recall that resource loading has several "cautions" identified for when it should not be implemented. P/ps may also find it difficult to properly setup and implement resource loading due to the complexity of the P/p or lack of insight to contractor schedules that may make up a large portion of the P/p schedule. When resource loading is deemed impractical, it is a recommended practice to implement cost loading within an automated scheduling tool.

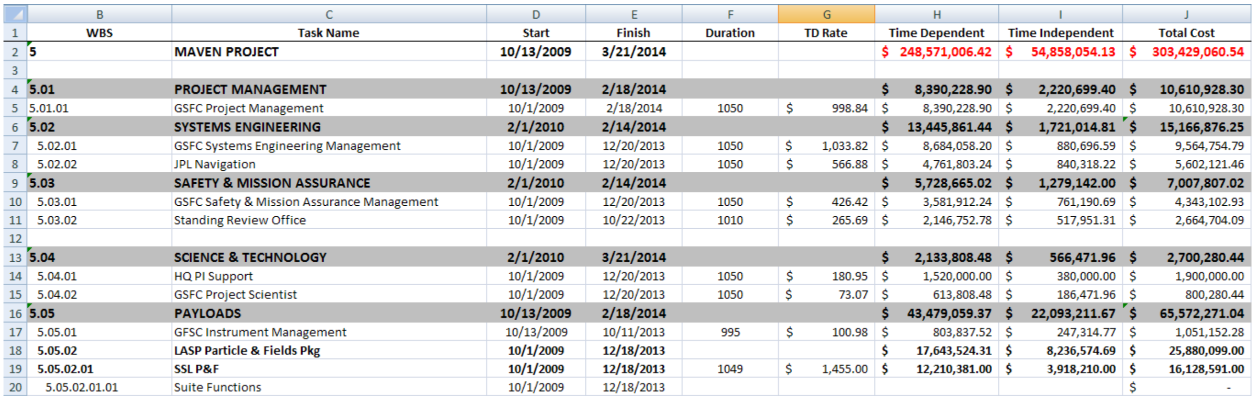
Per the NASA Cost Estimating Handbook, "the *IMS* needs to correspond to cost estimates to ensure that enough resources can be applied to activities to complete them within the expected duration. This should be done before the P/p schedule is baselined so that the relation between accurate cost and schedule estimates can be verified." Thus, cost loading is the time-phased estimate of the cost generated by the P/p, typically through a grassroots or parametric estimate, where all the ground rules and assumptions have been captured in a well-documented *BoE*.

Specifically, cost loading is accomplished by mapping cost estimates to schedule activities. The costs should be loaded for each task according to how the cost interacts with the schedule activity. To do this, costs are distinguished by whether they are time dependent (TD) or time independent (TI). TD costs are a function of activity duration multiplied by the periodic value (burn-rate). If the schedule is longer than planned, additional costs will be incurred; if the schedule is shorter than planned then less costs will be incurred. Examples of TD costs include labor (i.e., LOE activities, "marching army", or full-time equivalent (FTE)/whole time equivalent (WYE)) costs, typically found in program management, systems engineering, or safety and mission assurance activities, as well as rent, utilities, facility maintenance, sustaining operations, or any other costs that are charged by the amount of time they are employed. TI costs are defined as those that are fixed, irrespective of overall task duration. In other words, cost does

---

[75] NASA Cost Estimating Handbook, Version 4.0. February 27, 2015. Appendix J. https://www.nasa.gov/sites/default/files/files/CEH_Appj.pdf

not grow because of an increase in schedule duration. Examples of TI costs include procurements of components, materials, or even a set service, in addition to tests and other expenses. Figure 5-39 shows an Excel Workbook of the project CBS broken out by TI and TD costs.



	B	C	D	E	F	G	H	I	J
1	**WBS**	**Task Name**	**Start**	**Finish**	**Duration**	**TD Rate**	**Time Dependent**	**Time Independent**	**Total Cost**
2	**5**	**MAVEN PROJECT**	**10/13/2009**	**3/21/2014**			**$ 248,571,006.42**	**$ 54,858,054.13**	**$ 303,429,060.54**
3									
4	**5.01**	**PROJECT MANAGEMENT**	**10/13/2009**	**2/18/2014**			**$ 8,390,228.90**	**$ 2,220,699.40**	**$ 10,610,928.30**
5	5.01.01	GSFC Project Management	10/1/2009	2/18/2014	1050	$ 998.84	$ 8,390,228.90	$ 2,220,699.40	$ 10,610,928.30
6	**5.02**	**SYSTEMS ENGINEERING**	**2/1/2010**	**2/14/2014**			**$ 13,445,861.44**	**$ 1,721,014.81**	**$ 15,166,876.25**
7	5.02.01	GSFC Systems Engineering Management	10/1/2009	12/20/2013	1050	$ 1,033.82	$ 8,684,058.20	$ 880,696.59	$ 9,564,754.79
8	5.02.02	JPL Navigation	10/1/2009	12/20/2013	1050	$ 566.88	$ 4,761,803.24	$ 840,318.22	$ 5,602,121.46
9	**5.03**	**SAFETY & MISSION ASSURANCE**	**2/1/2010**	**2/14/2014**			**$ 5,728,665.02**	**$ 1,279,142.00**	**$ 7,007,807.02**
10	5.03.01	GSFC Safety & Mission Assurance Management	10/1/2009	12/20/2013	1050	$ 426.42	$ 3,581,912.24	$ 761,190.69	$ 4,343,102.93
11	5.03.02	Standing Review Office	10/1/2009	10/22/2013	1010	$ 265.69	$ 2,146,752.78	$ 517,951.31	$ 2,664,704.09
12									
13	**5.04**	**SCIENCE & TECHNOLOGY**	**2/1/2010**	**3/21/2014**			**$ 2,133,808.48**	**$ 566,471.96**	**$ 2,700,280.44**
14	5.04.01	HQ PI Support	10/1/2009	12/20/2013	1050	$ 180.95	$ 1,520,000.00	$ 380,000.00	$ 1,900,000.00
15	5.04.02	GSFC Project Scientist	10/1/2009	12/20/2013	1050	$ 73.07	$ 613,808.48	$ 186,471.96	$ 800,280.44
16	**5.05**	**PAYLOADS**	**10/13/2009**	**2/18/2014**			**$ 43,479,059.37**	**$ 22,093,211.67**	**$ 65,572,271.04**
17	5.05.01	GFSC Instrument Management	10/13/2009	10/11/2013	995	$ 100.98	$ 803,837.52	$ 247,314.77	$ 1,051,152.28
18	**5.05.02**	**LASP Particle & Fields Pkg**	**10/1/2009**	**12/18/2013**			**$ 17,643,524.31**	**$ 8,236,574.69**	**$ 25,880,099.00**
19	**5.05.02.01**	**SSL P&F**	**10/1/2009**	**12/18/2013**	1049	$ 1,455.00	**$ 12,210,381.00**	**$ 3,918,210.00**	**$ 16,128,591.00**
20	5.05.02.01.01	Suite Functions	10/1/2009	12/18/2013					$ -

Figure 5-39. Example of a cost loaded schedule with CBS broken out by time-dependent and time-independent costs.

Cost loading the *IMS* also provides a management tool that enables the P/p team to conduct an *ICSRA* (or *JCL*) assessment. The *JCL* is a probabilistic assessment that is usually administered prior to key designated P/p life cycle decision points to inform management regarding the likelihood of programmatic success. Specifically, a *JCL* will assess the probability that cost will be equal to or less than the targeted cost and schedule will be equal to or less than the targeted schedule date. Thus, it is sufficient to use cost loading for *JCL* purposes. Cost loading a schedule for the purposes of performing an *ICSRA* is further described in Section 6.3.2.4.

5.5.12.3 Budget Loading

Budget loading is not a formally defined "cost loading" method within the Agency. In fact, there may be instances where someone on the P/p team may attempt to interchange the term "budget loading" with "cost loading." Although these terms seem similar, there is a fundamental difference between budget and cost. The cost estimate, usually performed by the P/p, is simply the estimated costs associated with the work packages or activities in a schedule, and implies the *amount money needed (or required with a given set of conditions/assumptions)*; the budget is typically derived from an external source and can be described as the *amount of money available* over a set amount of time to complete the activities in the schedule.

Normally, a budget is imposed upon the P/p (i.e., comes from the top down) and is set early on in the P/p lifecycle when there is a lack of maturity in the requirements or understanding of the constraints. As a result, the budget numbers are likely underestimated due to the inability to understand the complete scope of work. In addition, the P/p usually plans to continue for a set duration according to a set budget (i.e., ABC). The purpose of integrating the "cost" and schedule is to determine whether the P/p can meet these commitments. Budget loading infers that budgeted dollars are assigned to the schedule activities. Unfortunately, the budget lacks the fidelity or necessary breakdown to be able to assign sub-budget elements to schedule activities. Consequently, the concept of budget loading a schedule offers limited feasibility for establishing and analyzing a P/p plan.

Sometimes, the budget and cost estimate are consistent at the beginning of the project, but an underperforming contractor on a cost-plus-fixed-fee (CPFF) contract causes the costs to quickly exceed the budget. In these instances, spreading the budget across activities, thereby budget loading the schedule, underestimates the potential actual costs. A budget may also have political implications and carry embedded risk. In addition, phasing constraints and funding profiles can impact a P/p's budget, which can then become a reduction from the grassroots estimates and/or modeled cost estimate. Given these factors, the budget may or may not be aligned with the P/p's cost estimate. An ICSRA performed on a budget-loaded schedule carries embedded risk, since the budget is generally assumed to be a reduction of the grassroots or modeled cost estimate. Because the budget does not reflect the expected costs of the project (e.g., historical resource costs/cost trends, risks and uncertainties that can cause schedule delays resulting in increased costs, etc.), budget loading may underestimate projected costs and ultimately not provide a credible confidence level. Thus, budget loading should be avoided.

Document the BoE for Resource or Cost Loading

It is important to document in the *BoE* any assumptions related to the resource or cost loading of the schedule, which may include rationale for the level at which costs or resources are loaded. It is also necessary to reference (and include where possible) any applicable source documentation (e.g., WBS Dictionary, PPBE, independent cost estimate(s), resource rates, etc.) as part of the *BoE*.

Marrying the financial and schedule domains together is perhaps the most delicate schedule development procedure. As such, its applicable assessment activity, the *Resource Integration Assessment* procedure, proves invaluable in affirming that this these domains are at least mechanically aligned.

5.5.13 Time-phase the Schedule to Align with the Availability of Funding

After completion of the above steps, ***it is a best practice for the schedule to be time-phased to align with the availability of funding to provide the earliest possible finish date***. The time-phasing of tasks included in the *IMS* in accordance with available funding is critical to successful development of an integrated baseline, or when applicable, the development of a formal PMB and implementation of EVM. Figure 5-40 illustrates the relationship between P/p funding, the P/p budget plan, and the P/p schedule.

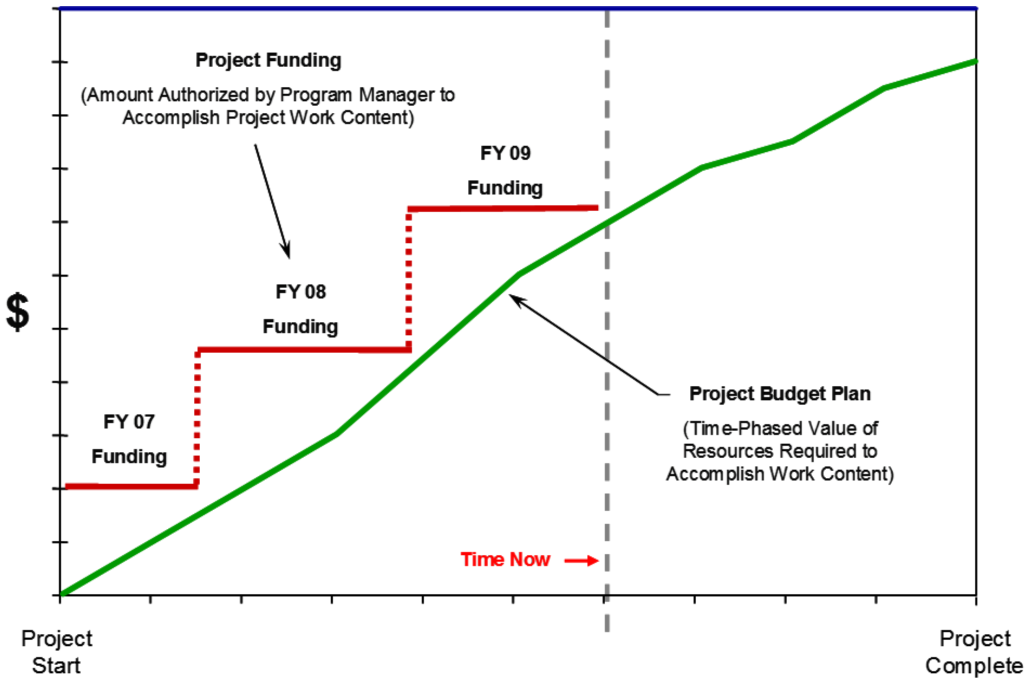


Figure 5-40. The relationship between P/p funding, the P/p budget plan, and the P/p schedule.

There are many situations related to the P/p budget and funding that may dictate when and how quickly activities can be performed, which directly contribute to how the schedule is time-phased. Still other situations may cause the P/p to intentionally re-phase the schedule such that those conditions can be met. Typical situations are as follows:

- **Budget Availability.** Often within NASA, the annual budgeting process and the most efficient P/p schedule do not match. The annual budgeting process tends to be a flat line, whereas the most efficient P/p schedules will follow a ramp-up, peaking before CDR, then ramp-down to a lower level for I&T and launch vehicle integration. Smoothing the peak funding can be accomplished by using the SNET constraint or lags to move activities into a subsequent fiscal year. When perfect leveling cannot be achieved, other techniques may also be utilized such as planning for budget carryover from underutilized years to over-utilized years. For time periods that underutilize available budget, schedule compression techniques are an option (See Section 7.3.4.5).
- **Continuing Resolution.** Continuing Resolution (CR) occurs when Congress is unable to pass the budget in time for the fiscal year start. The CR process will hold current spend levels flat until the new FY budget can be passed. CRs have become common recently and can last for several months or more. It may be worthwhile to consider planning the schedule such that the required budget will remain flat from October through December.
- **Facility Availability.** Major facilities such as wind tunnels, vibro-acoustic chambers, and vacuum chambers are in high demand and may not be available at the time the P/p needs them. In such cases, using a SNET may be a valid approach.

- **Human Resources.** Staffing and specialty skills may be limited or unavailable when the planned schedule activities require them. If the schedule is resource loaded, scheduling tools support resource-leveling which will stretch or move activities to bring the needed level into compliance with available resources. If the schedule is not resource-loaded, the SNET constraint and manual stretching the duration can be used to match the activities to available personnel.

Document the BoE for Time Phasing the Schedule to Align with the Availability of Funding

While resource or cost loading the schedule can help to ensure that the cost estimate is aligned with scheduled activities, it is also important to make sure that the P/p budget, and the availability of that funding, is adequate to support the time phasing of the activities. It is important to document any assumptions associated with the available funding as part of the schedule *BoE*, including any special circumstances related to how much budget is available and when. Further, like the *Schedule Risk Analysis-based Assessment* before it in Section 5.5.10, the *Integrated Cost and Schedule Analysis-based Assessment* procedure should be executed after this schedule development step to shed new light on assessment findings and augment the *BoE*.

5.5.14 Map Risks to the Schedule

It is a best practice for discrete risks to be quantified and mapped to appropriate activities within schedule. The Risk Management function needs to effectively collaborate with other PP&C functions to develop products and strategies that support the development of an integrated and executable P/p plan, and maintain risk-intensive assessments, analyses, tracking, and reporting throughout the P/p life cycle. The P/S should strive to integrate risk information into the schedule. Risks should always be treated by the P/S as elements inseparable from the *IMS* and worthy of close examination; their parameters, including placement in the *IMS*, should be assessed in similar manner to all other schedule elements. In the ideal case, a risk owner, in coordination with the P/S and Cost Analyst or Business Manager, should provide justified schedule likelihood and impact estimates in addition to the risk matrix scores.

Often the P/p will have identified risk mitigation plans for the actionable risks. Risk Mitigation is an action or series of actions put into place by P/p management to reduce the likelihood of risk occurrence or the impact from the risk event. Detailed risk mitigation plans include detailed information as to the mitigation action(s), timeframe for the mitigation, resources required for mitigation, expected results, alternatives, and costs of mitigation effort. When such risk mitigation burn-down plans are available, each mitigation activity should be mapped to the schedule at the appropriate location along with a justification for the expected risk score and quantification after the mitigation activity is complete. The level of post-mitigation risk is known as residual risk. Residual risk represents the likelihood of the risk event and impact of the risk event after mitigation activities are enacted.

Note: An "accepted" risk's schedule consequences should augment the baseline *IMS*; likewise, the accepted risk's cost consequences should be incorporated into P/p cost estimates and budget plans.

Document the BoE for the Schedule Risks

The *IMS* cannot be fully understood without examining the *DNA* of schedule risks. Each schedule risk's parameter set and assumptions, including location within the *IMS*, should be documented within the *BoE*. This information may be newly uncovered via the *Risk ID and Mapping Check*, as defined in Section

6.2.2.1.3, and the *Basis Check*, as defined in Section 6.2.2.2.2, all of which should be performed on a continuous basis. It is also possible that each risk's owner may have included basis rationale within the RMS. Regardless, all risk basis rationale and supporting data should be collected within the *BoE* to support cohesive schedule assessment and analysis.

5.6 Develop the Schedule Outputs

It is a best practice for the IMS to be the foundation for all schedule-related information. The *Schedule Database* must be developed such that it can output the following four key types of *Schedule Outputs*:

- **Integrated Master Schedule.** An *IMS* is the complete, time-phased, logically-linked network of all P/p effort that is required to ensure that all objectives are met within approved commitments. The use of the word "integrated" implies the incorporation of all activities, even contractor and subcontractor efforts, necessary to complete the P/p. The *IMS* is utilized as the P/p management tool that integrates the planned work, the resources necessary to accomplish that work, and the associated budget.[76] The *IMS* is the backbone for managing the P/p successfully, which includes establishing the PMB, measuring and forecasting performance, controlling the baseline, and communicating the overall progress against the plan.
- **Summary Schedule.** A *Summary Schedule* is a high-level roll-up of the *IMS* and is used for management reporting. It is a direct derivative of the *IMS* and should mimic the critical paths within the *IMS*.
- **Analysis Schedule.** An *Analysis Schedule*, if required, can be generated from the *Schedule Database* when needed for schedule risk analysis or integrated cost and schedule risk analysis (*SRA/ICSRA*). An *Analysis Schedule* should be directly traceable to the *IMS*, replicate the critical paths, and emulate the *IMS*; however, it may have additional tasks to model the potential impact of discrete risks.
- **Schedule Performance Measures.** *Schedule Performance Measures* are produced by incorporating current performance data with the planned performance in the *IMS*. *Schedule Performance Reports* are typically created monthly and may capture schedule status, progress, or forecasts. All are clearly identified and archived following the version control requirements within the configuration control process.
- **Schedule BoE.** The *Schedule BoE* is the documentation of the ground rules, assumptions, and drivers used in developing the cost and schedule estimate, including applicable model inputs, rationale or justification for analogies, and details supporting cost and schedule estimates."[77] The *Schedule BoE* dossier acts as a comprehensive, structured collection of technical and programmatic information necessary to fully develop, understand, assess, analyze, and theoretically reproduce the *IMS*, while also playing a supplementary role in schedule

---

[76] GAO-16-89G. GAO Schedule Assessment Guide. December 2015. Page 5. https://www.gao.gov/assets/680/674404.pdf

[77] NPR 7120.5E. NASA Space Flight Program and Project Management Requirements. Effective Date: August 14, 2012. Expiration Date: August 14, 2020. Appendix A. https://nodis3.gsfc.nasa.gov/npg_img/N_PR_7120_005E_/N_PR_7120_005E_.pdf

maintenance and control. (Because the *BoE* is described in Section 5.4, it is not repeated in the subsections that follow.)

5.6.1 Integrated Master Schedule (IMS)

The *IMS* is the primary output from the *Schedule Database*. The purpose of an *IMS* is to provide a time-phased plan, or "point estimate", for performing the P/p's approved total scope of work and achieving the P/p's goals and objectives within a determined timeframe and with acceptable risk. Whether developed for a Program or project, the *IMS* can be utilized as the P/p management tool that integrates the planned work (including both government and contractor work), the resources necessary to accomplish that work, and the associated budget, thereby facilitating other PP&C functions and supporting processes that help with maintaining the P/p baseline.

A properly prepared *IMS* provides a roadmap from which the P/p team can execute all authorized work and determine where deviations from the baseline plan have created a need for informal changes or formal corrective actions. Prior to establishing the baseline, the schedule is referred to as the preliminary schedule or preliminary *IMS*; once baselined, it is the "schedule baseline" or "baseline *IMS*". The *IMS* is baselined, usually through an Integrated Baseline Review (IBR), and progress is measured from this baseline throughout the P/p life cycle. The baseline *IMS* provides the approved, time-phased P/p schedule plan of the work to be performed that serves as the basis for performance measurement during P/p implementation. As performance variances exceed prescribed thresholds, or new content is added, corrective actions may be taken, or the baseline may be changed through the P/p's CM/DM process. The processes for establishing and controlling the schedule baseline are discussed in Chapter 7.

It is a best practice for the schedule to reflect vertical traceability in that any and all supporting schedules contain consistent information and can be traced to the IMS. The *IMS* is traceable to the WBS, the SOW, Contractor Performance Report (CPR), and the EVMS. P/p risks and risk mitigations should be traceable to the *IMS*, as applicable. Vertical traceability allows for total schedule integrity and enables different teams to work to the same schedule expectations. Schedules are typically categorized according to three levels of detail:

- **Summary Level.** A *Summary Schedule* is one-page report that represents a high-level roll up of the *IMS* and may be generated for a Program, for individual projects within a Program, or for sub-projects of a project. It contains key summary activities and milestones depicted in a Gantt chart, typically at the second-level WBS (e.g., subsystem level); although, the level of the roll-up depends on the level of detail that will offer the PM or other stakeholders the appropriate level of insight. The *Summary Schedule* should clearly identify the critical path at the summary level and also show any areas of the schedule that contain margin. A *Summary Schedule* is often referred to as a "Master Schedule" when it reflects a summary *IMS* for the complete P/p; however, a *Summary Schedule* is *not* an *IMS*, and should not be used as a substitution for an *IMS* when an *IMS* is required.
- **Intermediate Level.** The intermediate schedules are at a lower resolution of work to be performed than what is depicted in the *Summary Schedule*, but at a higher level than the Detailed Schedule(s). Early in the P/p life cycle, intermediate schedules may represent early stages of the rolling wave approach (i.e., top-down). Later in the life cycle, they may be slightly

summarized versions of more detailed schedules (i.e., bottoms-up). Intermediate schedules are logic network schedules (i.e., CPM schedules) and reflect relationships among key events, start, finish, and baseline dates for activities, as well as total float for each activity. Intermediate schedules should be organized according to the WBS and support the key dates in the *IMS*. Intermediate schedules should also clearly identify the critical path.

- **Detailed Schedules.** The detailed schedules are the lowest-level P/p element schedules available that identify discrete work packages for a specific schedule element, such as a specific WBS. Detailed schedules illustrate horizontal dependencies and are used to track and control work progress at the lowest level. Detailed schedules are logic network schedules (e.g., CPM), and should depict activity logic, start, finish, and baseline dates for detailed activities, as well as the total float for each detailed activity. Detailed schedules should also reflect any other activity attributes, such as leads/lags, uncertainty/risks, etc. It is critical that the activities in a detailed schedule be defined at a low enough level to allow for finish-to-start interdependency relationships where feasible, accurate progress measurement, issue identification, and traceability to higher level milestones. In addition, detailed schedules should clearly identify the critical path(s). If the detailed schedules are resource or cost loaded for the purposes of an *ICSRA/JCL*, they may also require traceability to the CBS.

Estimates for all work activities establish a logical hierarchy from the detailed activity level to intermediate to P/p summary levels, and contain baseline, actual, and forecast dates for each activity. Thus, the *IMS* is a hierarchical, tiered network capable of rolling up to high-level summary representations of activities, as well as breaking down to the lowest level of task details showing dependencies, resources, durations, and constraints. Using the assigned coding structure, the scheduling tool is able to filter and summarize schedule data to provide reports at each of these levels.

An activity owner should be able to trace detailed activities to higher-level summary activities within intermediate- and summary-level schedules. In much the same way, the PM should be able to trace summary activities down their more detailed components or work packages. As shown in Figure 5-41, sub-project schedules can be separately maintained by the owning organizations, and as required, be provided to the P/p on a regular basis with appropriate status/performance data to serve as an update to the P/p *IMS*. Even though the sub-project activities may be rolled into a higher-level summary task or milestone, Technical Leads (e.g., CAMs, WBS Element Owners, etc.) should be able to identify when and how their activities affect the overall P/p schedule. Any descriptive narrative associated with the traceability of different levels of the schedule to one another should be captured as part of the *BoE*.

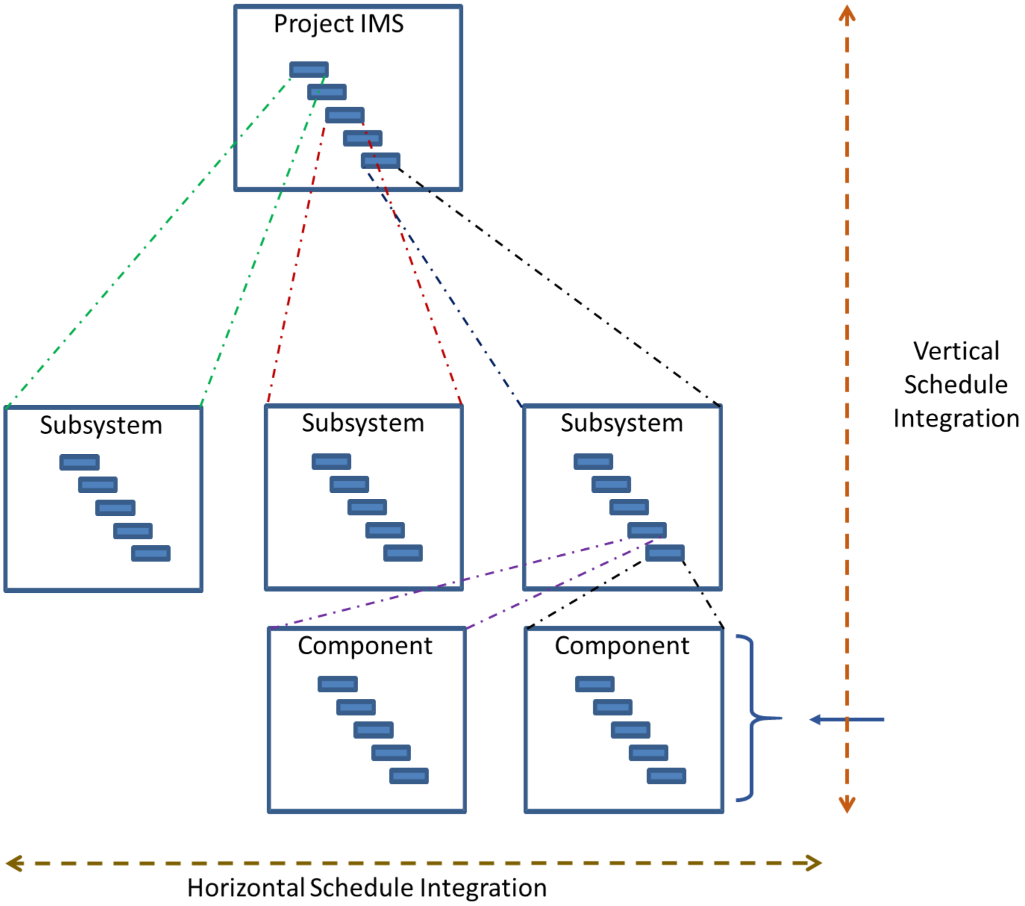


Figure 5-41. All levels of the P/p schedule should be vertically traceable to each other, reflecting consistent schedule data.

The level of insight and analysis that can be achieved from the schedule is heavily dependent on the level of detail contained in the *IMS*, which is important to accomplishing the three continuous schedule management processes: Schedule Assessment and Analysis, Schedule Maintenance and Control, and Schedule Documentation and Communication. For instance, detailed critical path identification and analysis, as well as detailed insight into P/p issues cannot be done with only summary-level schedule content. Instead, the detail in the *IMS* is sufficient to identify the longest path of activities through the entire P/p.[78] For any reporting requirements that specify an "*IMS*", the complete *IMS* in its native file format should be delivered (e.g., to the SRB during P/p Life Cycle Reviews, or as part of the NASA Corrective Action Plan Schedule Repository Initiative).

While each of the three levels of schedule detail likely exist for every element of the P/p (e.g., subsystem, instrument, sub-project), oftentimes, what goes into the P/p *IMS* is a mix of all three levels of the supporting work elements, depending on the relationships of the individual Element Owners to the P/p itself. For instance, a P/p *IMS* may have elements that are at a summary level, such as work

---

[78] GAO-16-89G. GAO Schedule Assessment Guide. December 2015. Page 11. https://www.gao.gov/assets/680/674404.pdf

performed by international partners or parts procured from vendors, where only summary tasks and delivery milestones are available. For contracted portions of the P/p *IMS*, the schedule may contain work defined at an intermediate level. Elements of work that are performed in-house may be carried at a detailed level to facilitate more rigorous Schedule Control.

A Program *IMS* may consist of one or more project schedules. Within NASA, Research and Technology Programs (NPR 7120.8) are those which are strictly comprised of R&T projects. Space Flight Programs (NPR 7120.5) are categorized according to the following four groups:

- **Tightly Coupled Programs** contain multiple projects that have a high degree of organizational, programmatic, and technical commonality. This type of Program requires a much higher degree of integration between the projects potentially resulting in numerous inter-project interdependencies in the Program *IMS*.
- **Loosely Coupled Programs** contain projects that have organizational commonality, but little programmatic or technical commonality. These projects will typically have minimal or no inter-project interdependencies in the Program *IMS*.
- **Uncoupled Programs** contain projects that are implemented under a broad scientific theme and/or a common implementation concept, but each project will be independent of other projects in the Program. These projects will have minimal or no inter-project interdependencies in the Program *IMS*.

The level of detail contained in the Program *IMS* will generally depend on two key factors:

- The level of management insight desired by the Program
- The magnitude of Program scope and the amount of project data to be maintained and analyzed at the Program level

Note: Potential compatibility issues between Program- and project-level schedule management tools should be worked out during Planning and should not be a constraint on a Program's ability to perform adequate Schedule Management.

Much in the same way a Program schedule may be composed of multiple project schedules, it is not unusual for a Single-project Program or project *IMS* to be an integration of several sub-projects.

- **Single-Project Programs** have only one project that makes up the Program. For this type, the Program *IMS* will most likely not have interdependencies to other projects. These Programs tend to have long development and/or operational lifetimes, represent a large investment of Agency resources, and have contributions from multiple organizations/agencies. These Programs frequently combine Program and project management approaches, which they document through tailoring.
- **Projects** often have interfaces with other projects, agencies, and/or international partners. In other cases, a space flight project may have a prime contractor developing the primary science instrument or spacecraft system. An R&T portfolio project may be made up of one or more groups of R&T investigations that address the goals and objectives of the R&T portfolio

project.[79] The sub-projects may be separately managed and maintained by other organizations or by external contractors. Whether primarily “in-house” or not, the project *IMS* will most likely have interdependencies to other organizations.

It is important to note that different organizations may use the term "integrated master schedule" as it pertains to them. For example, a project *IMS* may represent a detailed schedule that gets summarized at an intermediate or even summary level for inclusion in the Program *IMS*. Similarly, a sub-project work-package level schedule may be the sub-project’s *IMS*; however, the same schedule would serve as a detailed schedule for the “parent” project. When discussing the work of a prime contractor, the term “*IMS*” may be used to refer solely to the prime contractor’s schedule. In actual practice, the government *IMS* usually incorporates intermediate- or summary-level elements of the contractor's *IMS*, whereas the contractor's *IMS*, at its lowest level, includes the individual activities necessary to complete each work package. Should the government require more insight into the contractor schedule, it is possible that a request, by way of contract language, would be made for intermediate schedules or detailed schedules from the contractor for either specific elements of the contractors work or the entire contractor “*IMS*”. In general, there are five techniques for characterizing the P/p *IMS* as shown in Figure 5-42.

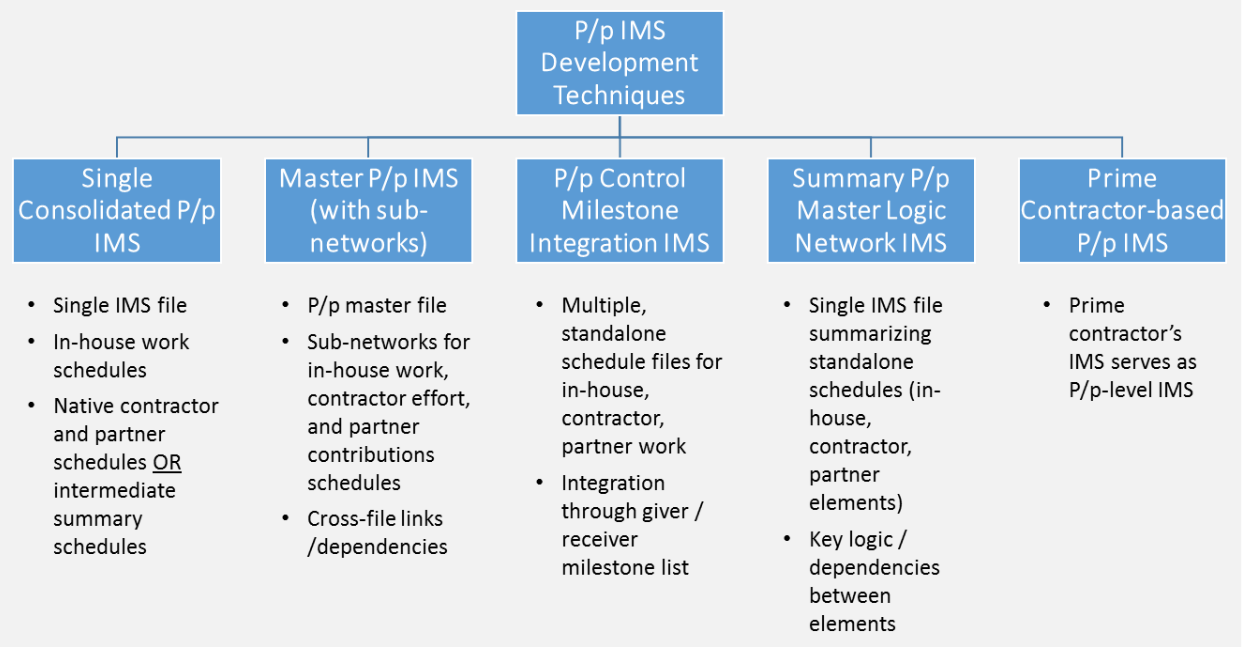


Figure 5-42. A summary of the five different techniques for developing the IMS.

---

[79] NPR 7120.5E. NASA Space Flight Program and Project Management Requirements. Effective Date: August 14, 2012. Expiration Date: August 14, 2020. Page 11. https://nodis3.gsfc.nasa.gov/npg_img/N_PR_7120_005E_/N_PR_7120_005E_.pdf

The five *IMS* development techniques acknowledge the differences among NASA's P/p types, acquisition strategies, external partnering agreements, and other factors. Similarly, the *IMS* development techniques have various advantages and disadvantages which are summarized in Figure 5-43.

IMS Development Techniques	Advantages	Disadvantages
Single P/p Consolidated IMS	All schedule data in one schedule file Highly reliable predecessor/successor links	Only one P/S can access IMS at a time Difficulty merging contractor-provided files
Master P/p IMS (with sub-networks)	Ability to directly include sub-project files from multiple organizations Better sub-project file access by multiple P/Ss	Complex to manage Multiple data/status dates of subprojects Slower processing Potential logic conflicts between sub-projects
P/p Control Milestone Integration IMS	Highly visible receivable/deliverable milestones for all providers	No end-to-end IMS Inability to calculate critical path
Summary P/p Master Logic Network IMS	Fast way to organize the overall schedule logic flow for the P/p	Increased chance of schedule errors Potential loss of traceability to provider schedules
Prime Contractor-based P/p IMS	Accurate tracking of prime contractor schedule	Reporting lag Government effort (if any) not in IMS

Figure 5-43. A summary of the advantages and disadvantages of each IMS development technique.

While there are no mandatory rules for matching *IMS* development with P/p types, Figure 5-44 offers some general guidance on which *IMS* technique is suitable for specific P/p types. The five techniques are further described below.

P/p Type IMS Technique	In-House Observatory P/p	Out-of-House Observatory P/p	Out-of-House Flight or Ground System P/p	In-House Instrument / Payload P/p	Out-of-House Instrument / Payload P/p	In-House Component / Subsystem P/p (supplier to external organization)	Special P/ps
Single Consolidated P/p IMS	X			X		X	X
Master P/p IMS (with sub-networks)	X	X	X	X	X		X
P/p Control Milestone Integration IMS		X	X		X		
Summary P/p Master Logic Network		X					X
Prime Contractor-based P/p IMS			X		X		

Figure 5-44. Suggested mapping of each IMS development technique to P/p types.

Single Consolidated P/p IMS

With the Single Consolidated P/p *IMS*, all of the P/p work scope is incorporated into a single *IMS* schedule file encompassing NASA in-house, contractor, and partner efforts. If interrelationships exist between any of the provider schedules, then appropriate logic relationships should be included to accurately model those interdependencies. Where these interdependencies exist, it is appropriate that the P/p manage agreements (e.g., MOAs, MOUs, etc.) between the elements.

This technique does not necessarily prescribe that the native *IMS* files from the providing organizations are directly integrated into the P/p *IMS*. For example, in some cases the P/S creates a summary or intermediate level version of a provider's schedule that is incorporated into the P/p *IMS*. However, it is a recommended practice that the entire scope of work be broken into schedule tasks and milestones at a consistent level of detail to allow discrete progress measurement and visibility into the overall design, fabrication, integration, assembly, test, and delivery phases of each end item deliverable. Additionally, all schedule tasks/milestones should be integrated with the appropriate sequence relationships to provide a total end-to-end logic network leading to each end-item delivery.

The Single Consolidated P/p *IMS* should contain all contract and controlled milestones, key subcontractor milestones, end item delivery dates, key data delivery dates, and key Government Furnished Property (GFP) need dates. For Programs, all tasks and milestones reflecting effort to be implemented specifically at the Program level must also be included, as well as all Program-level control milestones that have been established. The *IMS* should also contain the appropriate field codes necessary to provide sort, select, and summarization capabilities for, but not limited to, WBS element, project phase, and level-of-effort tasks. In-house and contractor schedules supporting the overall *IMS* should capture the necessary P/p information according to Agency or P/p required field codes.

Once the integration of all in-house and provider schedules into a Single Consolidated P/p *IMS* is complete, the P/S should validate the *IMS* through Schedule Assessment checks and reviews by the input stakeholders. Since the *IMS* serves as the basis for identification of critical paths and driving paths, as well as work-off and performance trending, schedule risk assessments, and "what-if" analysis, this strategy provides the overall capability for integrated insight and oversight of all project work.

Caution. Most scheduling software supports the integration of multiple or external schedules, assuming the schedules are built in the same tool. If using different tools, the schedule data may need to be exported into a data file and then imported into the consolidated *IMS*. For on-going schedule integration, capturing activity and milestone information may require reconciling status dates between in-house and contractor schedules, as well as a careful consideration of calendars and cost or resource loading techniques applied to each schedule.

Master P/p IMS (with sub-projects)

The Master P/p *IMS* technique is similar to the single consolidated P/p *IMS* technique described above, except that in this case, a Master *IMS* file is created that provides the schedule backbone for crosslinking the interdependencies among the supporting provider organizations' individual *IMS* sub-project schedule files.

P/p Control Milestone Integration IMS

With the P/p Control Milestone Integration *IMS* technique, in-house, contractor, and other partner-provided *IMS* files are retained and monitored in their native formats. Horizontal schedule integration is maintained through the identification and tracking of significant receivable and deliverable milestones between the individual schedules.

Note: One of the challenges with the P/p Control Milestone Integration *IMS* technique is that external stakeholders may feel that a true end-to-end *IMS* does not exist for the P/p. Using milestone sets to reflect the major events in accomplishing the complete P/p effort is seldom an effective practice for the P/p's insight/oversight purposes, as it is not conducive to sound schedule analysis or meaningful insight into overall P/p performance. Underlying interdependencies are much more difficult to reflect accurately when using this technique. This difficulty is due to the technique in which the P/S must account for the effort being carried out in between the milestones. In order for the P/p *IMS* to keep the proper time-phasing for the numerous provider milestones the P/S must either incorporate appropriate schedule lag values between each milestone (not a best practice) or assign date constraints to each milestone included in the schedule (also not a best practice). A way to address this concern is for the P/S to periodically create either a Single Consolidated *IMS* file or Master P/p *IMS* file with sub-projects and directly link the predecessor and successor relationships to validate the logic among P/p elements. A recommendation is to perform this cross-check schedule integration in advance of major LCRs.

Summary P/p Master Logic Network IMS

With the Summary P/p Master Logic Network *IMS* technique, the P/S, in coordination with the P/p team, develops and maintains a summarized logic network derived from the detailed schedules from the provider organizations. When prime contractors are involved, the government *IMS* usually incorporates summary-level elements of the contractor's *IMS*, whereas the contractor's *IMS* includes the detail-level activities necessary to complete each work package. In these instances, although all contractor work-package level detail is not contained in the NASA P/p *IMS*, the term “integrated” implies the schedule's incorporation of representative activities and milestones, those of the provider organization's major efforts, which reflect the overall network logic necessary to complete the P/p and replicate critical paths and driving paths.

The P/S ensures that the Summary P/p Master Logic Network *IMS* traces to, and reconciles with, the provider *IMSs*. It is important to keep the level of summarization consistent with the desired level of insight, as influenced by cost, risk, and criticality (both schedule and technical). Interdependency relationships for all summary tasks and milestones should be established and maintained. Inter-organization logic relationships should be identified.

Caution. This approach may prove to be of limited use when performing critical path identification and analysis. Summary-level schedule data will not typically identify many of the detailed integration points needed for accurate task sequencing. The resulting impact is that accurate critical path logic flows cannot be identified. This potentially leads to erroneous summary-level critical path information which is not accurate or consistent with the detailed critical path information. It must be acknowledged and understood by the P/p team that when using summary-level *IMS* data, the level of insight, control, and analysis will also have to be raised to a higher level. This means that the P/p team will have to depend more heavily on the detailed schedule insight and analysis provided by the provider organizations, which is not usually adequate for achieving integrated Program insight.

Prime Contractor-based P/p IMS

With the Prime Contractor-based P/p ***IMS*** technique, the uses the prime contractor's IMS at the P/p IMS. This technique is used when the P/p's work essentially consists of overseeing a single prime contractor whose effort comprises the majority of the P/p work scope.

Caution. In the case of contracted efforts, the P/p needs to ensure that the contractor is required to deliver a schedule that reflects the level of detail necessary for PM oversight. It is recommended that Prime Contractor-based ***IMSs*** be composed of all supporting P/p schedule information at least at an intermediate level of detail for the contracted effort. The NASA P/p should also consider maintaining an "add-on" schedule reflecting effort that falls directly under the responsibility of the NASA P/p Office. The latter portion will allow for adequate P/p Office oversight and control of the work for which they are directly responsible.

5.6.2 Summary Schedule

A ***Summary Schedule*** is a high-level roll-up of the ***IMS*** and is used for management reporting. It is a direct derivative of the ***IMS*** and should mimic the critical paths calculated in the ***IMS***. It is important to note that tools other than the scheduling software may be needed to create a ***Summary Schedule*** that is useful to P/p Management; however, the ***IMS*** should be the source of the information used to create the ***Summary Schedule***. Typically, the ***Summary Schedule*** is rolled-up to the second-level WBS (e.g. subsystem level). However, it is important that the level of roll-up be determined by the critical paths because that is usually the detail that P/p management needs to review. For example, if it is necessary to show how a critical path flows through a third-level WBS item, that particular subsystem needs to be further decomposed. Figure 5-45 is an example from a NASA project. It is rolled-up to the subsystem level and shows key milestones, status date ("time now"), critical paths, available margin, and other information deemed important by P/p management. Additional examples of ***Summary Schedules*** are provided in Chapter 8.

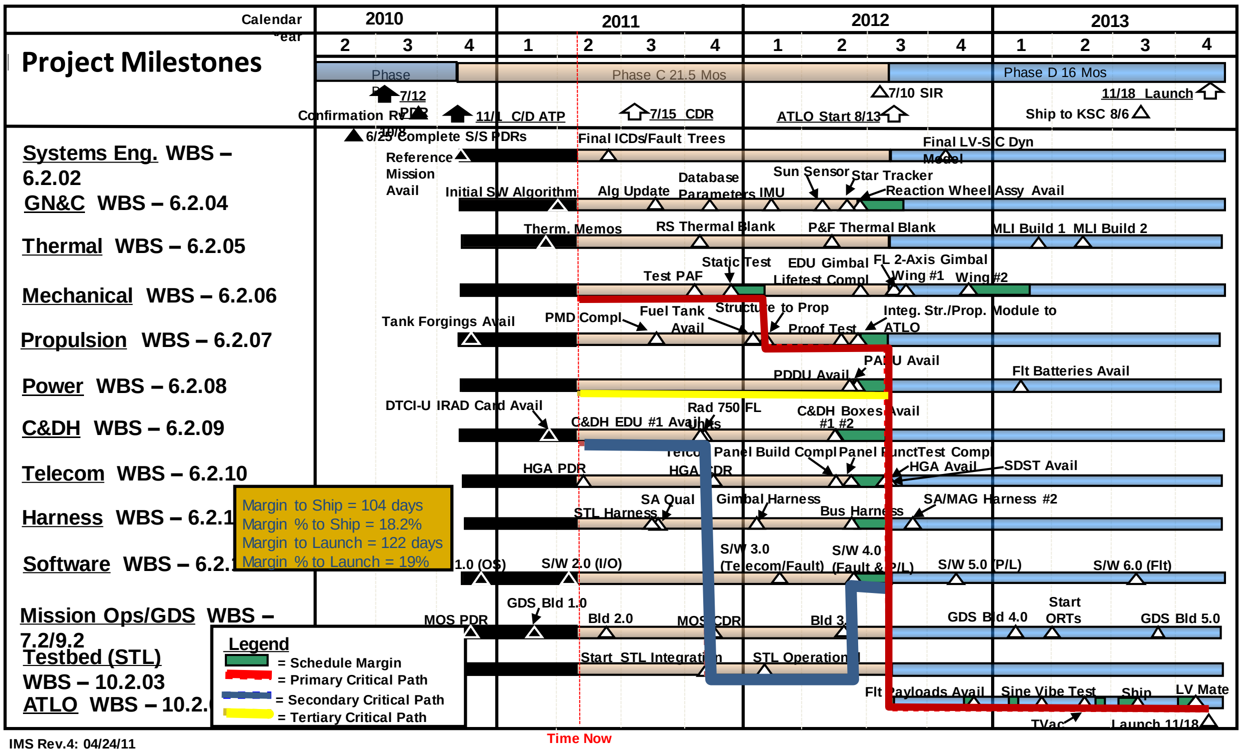


Figure 5-45. A typical Summary Schedule "output" from the Schedule Database is shown here. It includes the primary, secondary and tertiary critical paths.

While a *Summary Schedule* is often used for high-level schedule reporting, a *Summary Schedule* should never be used as a substitute for the P/p *IMS*, when an *IMS* is explicitly required. This is in direct contravention of the definition of an *IMS*.

5.6.3 Analysis Schedule

For complex projects, it is recommended that an *Analysis Schedule* be developed to perform *Schedule Risk Analysis (SRA)* and/or *Integrated Cost and Schedule Risk Analysis (ICSRA)*, as needed. An *Analysis Schedule*, while similar to the *Summary Schedule* in that it is a high-level overview of the *IMS*, should not be developed using a standard, across-the-board roll-up approach. One major difference is that the *Analysis Schedule* roll-up must be done such that WBS items that are impacted by risks or uncertainties must be included. Thus, the level of roll-up can vary across the schedule. For example, it may be appropriate to roll-up Command and Data Handling (C&DH) to the subsystem level because there are no significant risks affecting the C&DH. Whereas, the Power and Propulsion for the same schedule may need be detailed down to the component level to capture a risk on a new technology for valves on a reaction control jet. A second difference is the need for *Analysis Schedules* to capture additional activities for cost modeling, such as hammocks, or additional "placeholder activities" along with appropriate linkages provided for modeling potential interference at specialty work stations or test facilities.

- **Placeholder Activity.** Often placeholder activities or links need to be added to the *Analysis Schedule* network (or *IMS* if being used for the *SRA/ICSRA*) to cause it to behave as it should under the influence of risk and uncertainty. For example, assume the natural design of the schedule under normal circumstances will not allow two units to enter a test facility at the same time. Under risk and uncertainty, it may be possible for two units to arrive at the same time, thus necessitating the need for an extra link in the network. Another example is the addition of activities to resolve conflicts as risk and uncertainty move the activities around in the network, such as a swap-out of a flight unit for a development unit should a flight unit be delayed due to risk.

An *Analysis Schedule* should reflect the appropriate level of fidelity, such that it is directly traceable to the *IMS*, replicates the critical paths, and emulate the *IMS* under the influence of risks and uncertainties. Greater detail on how to develop an *Analysis Schedule* is discussed in Section 6.3.2.3.1.

5.6.4 Schedule Performance Measures/Reports

Schedule Performance Measures communicate vital information about the status or performance of a system, process, or activity for contractor and in-house efforts. Regular progress updates for work performed in-house by NASA organizations, as well as for contracted or external partner work, feeds the *Schedule Database* all data needed to output the necessary *Schedule Performance Measures*.

While the P/p may have specific performance measurements, as documented in the *SMP*,

Typical performance data utilized by most P/ps can be generated Schedule Analysis (Section 6.3.2.5) and Schedule Control (Section 7.3.3). This information feeds into the Schedule Communication and Documentation sub-function to support the reporting process.

Schedule Performance Reports are typically created monthly and may capture schedule status, progress, or forecasts. All are clearly identified and archived following the version control requirements within the configuration control process. Report types are described in Section 8.3.2.4 and include, but are not limited to:

- **IMS/Summary Schedule.** Used to facilitate additional analysis that will aid in both routine Schedule Management, as well as P/p Management decision making through various reporting forums, such as Center Management Councils (CMCs) or through Monthly Status Reports (MSRs).
- **Critical Path (Deterministic and Stochastic).** Used to show all tasks and milestones that make up the critical path(s) (primary, secondary, tertiary, etc.) with the associated amounts of total float.
- **Critical Path Length Index (CPLI).** Used to describe the efficiency required to complete a schedule milestone on time.
- **Margin Consumption and Total Float Status/Float (Slack) Erosion.** Used to feed float erosion tracking tables by activity.
- **Resource Leveling.** Used to show whether the scheduled P/p completion is achievable with the allotted resources (e.g., facilities, people, and budget) based on their availability.

- **Activity/Milestone Variances and Schedule Variance (SV).** Used to show status or track actual performance against planned progress of activities/milestones and to feed EVM calculations over time.
- **Activity/Milestone Performance Trends.** Used to communicate progress against baseline as well as changes in the schedule progress month-to-month.
- **Baseline Execution Index (BEI), Hit or Miss Index (HMI), and Current Execution Index (CEI).** Used to understand the difference between cumulative performance or performance within a certain window and planned performance.
- **Schedule Performance Index (SPI), Time-based SPI (SPI_t), and Earned Schedule.** Used to measure schedule performance against the plan through EVM-type calculations.
- **Probability of On-time Delivery of Critical Items.** Used to show where P/p management needs to focus attention and exercise controls based on probabilistic *SRA* results.
- **Risk-based Completion Trend.** Used to show where P/p management needs to focus attention and exercise controls based on probabilistic *SRA* results over time.
- **Margin Status/Sufficiency of Margin.** Used to compare margin availability for key activities to the probabilistic *SRA* forecasted delivery/completion dates.
- **Risk-Based Tracking against the MA and ABC.** Used to track the results from periodic *ICSRA* against the MA and ABC.
- **Confidence Level Reports.** Used to communicate the confidence levels associated with possible dates and/or costs resulting from an *SRA/ICSRA* (e.g. *JCL*).

5.7 Schedule Development Summary

Schedule development is accomplished by following the requirements and development plan in the *SMP*. When complete, the P/p will have a *Schedule Database* contained within a scheduling tool that has the capability to produce *Schedule Outputs*, including an *IMS* with:

- All the required *Schedule Performance Measures* needed to support Schedule Maintenance and Control to produce the necessary *Schedule Performance Reports*
- A preliminary *BoE*, which provides a roadmap for Schedule Assessment and can be continually updated through Schedule Maintenance
- An *Analysis Schedule* to be used for the schedule risk analyses performed in Schedule Analysis
- A *Summary Schedule* to support management reporting through Schedule Documentation and Communication

5.8 Skills and Competencies Required for Schedule Development

The skills and competencies required for Schedule Development can be found on the SCoPe website.[80]

6 Schedule Assessment and Analysis

It is a best practice for the schedule to be assessed and analyzed in accordance with the Schedule Management Plan. Schedule Assessment and Schedule Analysis are two sub-functions of Schedule Management that are initiated early and utilized routinely throughout the P/p life cycle. Per Section 4.3, the Schedule Management Planning sub-function produces the *SMP*, which provides instruction to guide the development of the IMS and associated schedule products. The *Schedule Assessment and Analysis Plan*, the second of four sub-plans in the *SMP*, describes the assessment and analysis activities to be executed throughout the P/p life cycle.

Schedule Assessment is the sub-function for determining the validity and integrity of the schedule, and Schedule Analysis is the sub-function for evaluating the magnitude, impact, and significance of P/p uncertainties and risks. The sub-functions are complementary: Schedule Analysis cannot be performed without first assuring that the schedule has been validated through Schedule Assessment. Schedule Assessment tests the credibility of the schedule, whereas Schedule Analysis tests the likelihood of accomplishing the P/p's technical goals on-time, within budget, and with acceptable risk. The P/p should integrate these sub-functions with other P/p management functions to ensure consistency among programmatic products.

As Figure 6-1 shows, the Schedule Assessment sub-function is initiated when the *Schedule Database* is first developed and whenever a change is made. Changes to the schedule may occur as part of the Schedule Development, Maintenance, or Control sub-functions. The changes can be formal or informal and internal or external. For example, changes orders can be generated by processes external to this process (e.g., scope change), or internally generated to correct for findings from either of the two sub-functions.

---

[80] SCoPe website, https://community.max.gov/x/9rjRYg

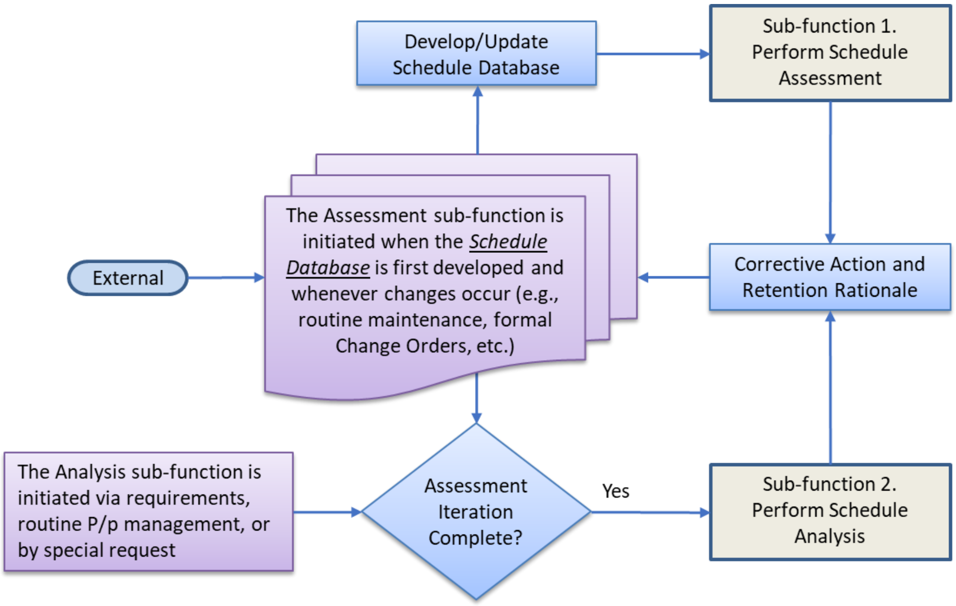


Figure 6-1. The figure shows the relationship of the two sub-functions Schedule Assessment and Analysis.

The execution frequency of these sub-functions is dependent on the how often the risk posture changes and how often changes are made to the schedule. In addition, many factors affect the level of penetration required for Schedule Assessment and Analysis, such as:

- Technical risk levels
- Amount of confidence in the performing organization's management abilities
- How well the PP&C processes are defined and followed
- Public visibility of P/p and impact of failure
- Design complexity, manufacturing complexity, and the ability to be produced
- Value of asset
- Past cost and schedule performance

Figure 6-2 illustrates the relationship of these factors with the level of Assessment and Analysis required.

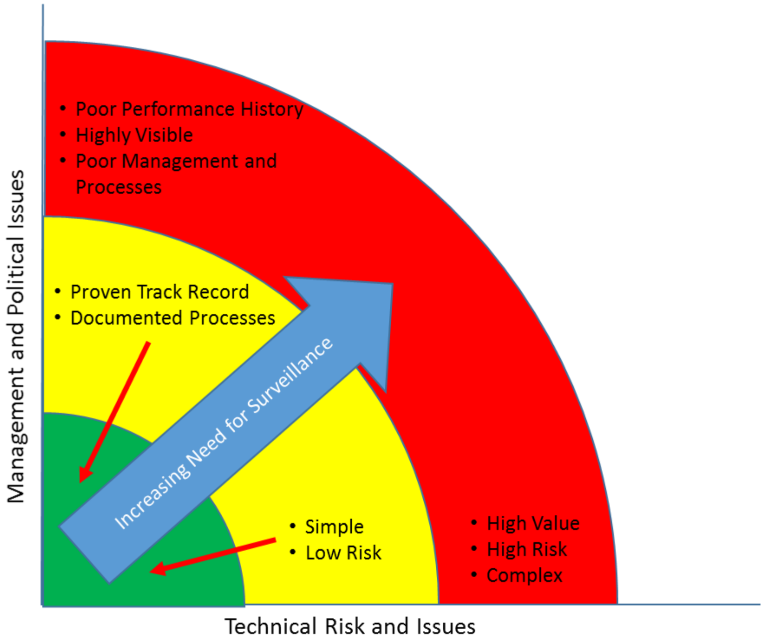


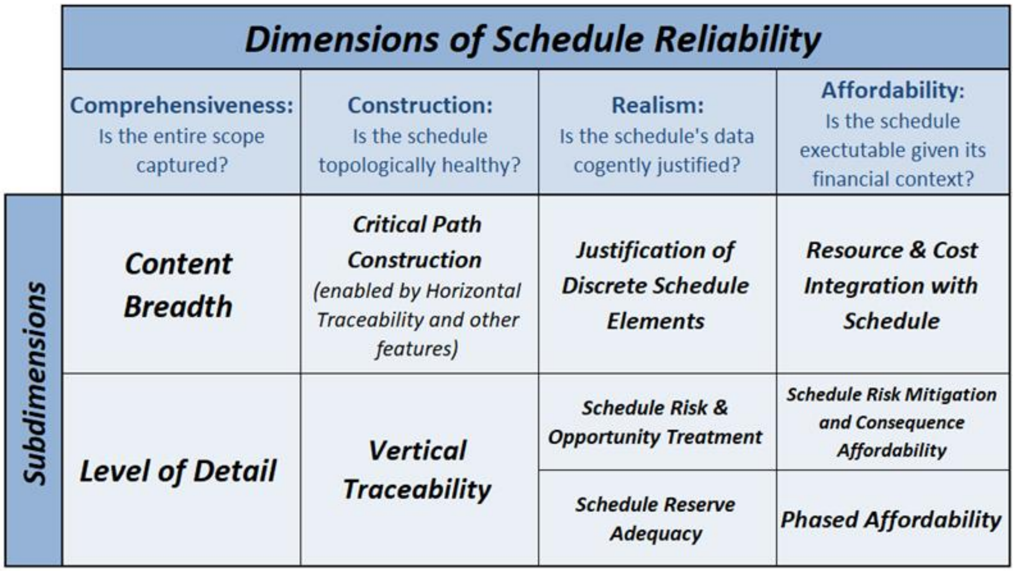
Figure 6-2. Frequency of reviews is a function of several management and technical issues.

The goal for applying the appropriate schedule insight penetration strategy is to enhance the probability of mission success for NASA P/p. Mission success must be achieved within the workforce, budget, and time limitations that are levied through all phases of development and operation. Analysis begins with an assessment of the complexity, maturity, and risks of the P/p being evaluated. Different levels of insight are appropriate when taking these factors into consideration throughout the P/p life cycle.

By consulting NASA's SCoPe and GAO guidance, the Agency has constructed classes of standards it uses to parse and measure the independent dimensions of schedule *reliability*. These classes are designed to minimize, to the greatest extent possible, mutual overlap and redundancy; this condition allows the assessment process to unfold simply and modularly while preserving its precision and power. NASA has therefore identified the following schedule reliability dimensions, each of which are defined by the following questions:

- **Comprehensiveness →** Is the entire scope captured?
- **Construction →** Is the schedule topologically healthy?
- **Realism →** Is the schedule's data cogently justified?
- **Affordable →** Is the schedule executable given its financial context?

The goal of Schedule Assessment and Analysis is to satisfy each *reliability* dimension by fully addressing each question. To accomplish this methodically, each dimension is further divided into sub-dimensions that are more discretely mapped to actionable procedures. The dimensions are partitioned into sub-dimensions as shown in Figure 6-3:

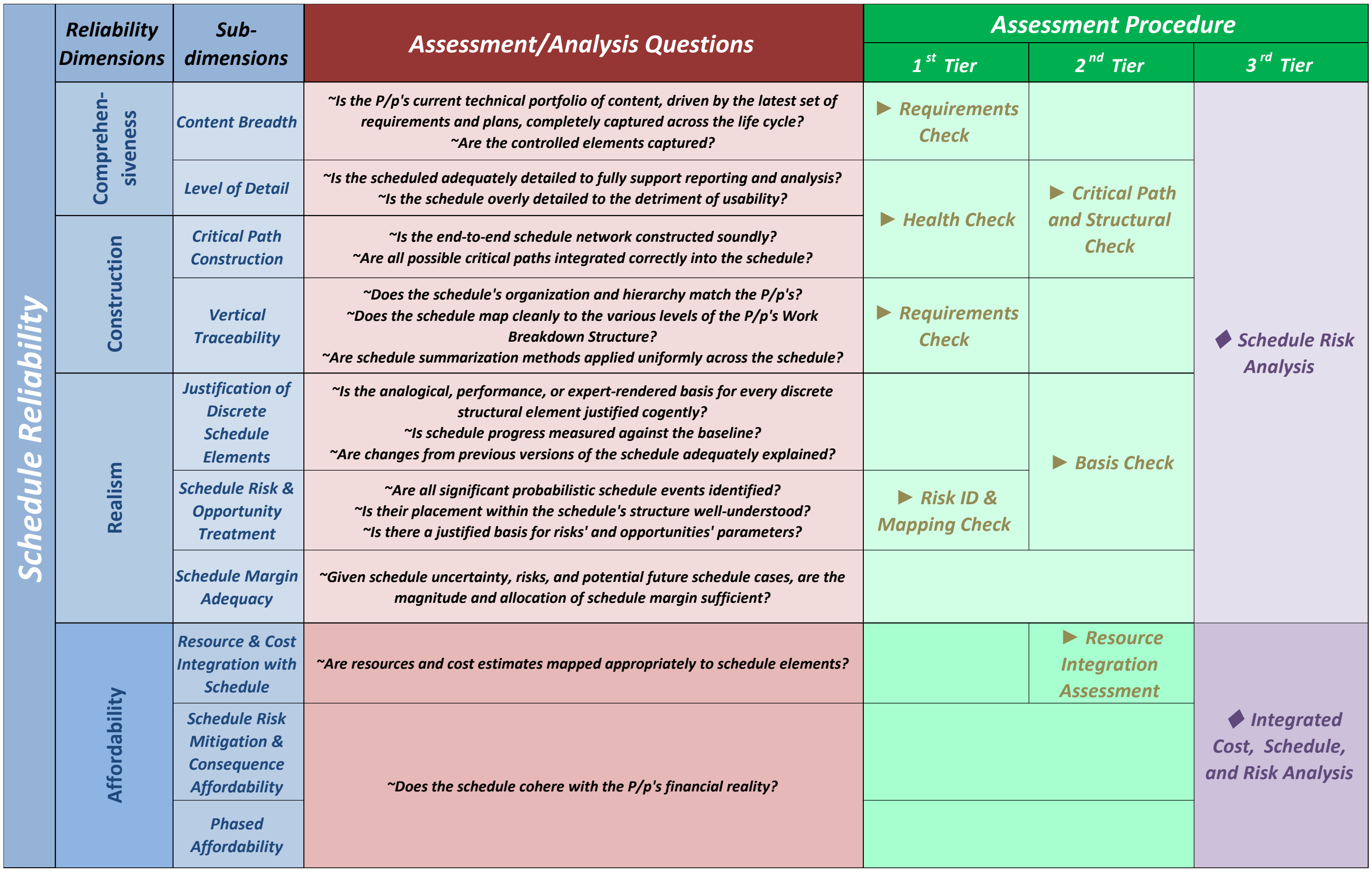


Dimensions of Schedule Reliability

	Comprehensiveness: Is the entire scope captured?	**Construction:** Is the schedule topologically healthy?	**Realism:** Is the schedule's data cogently justified?	**Affordability:** Is the schedule exectutable given its financial context?
Subdimensions	***Content Breadth***	***Critical Path Construction*** *(enabled by Horizontal Traceability and other features)*	***Justification of Discrete Schedule Elements***	***Resource & Cost Integration with Schedule***
	Level of Detail	***Vertical Traceability***	***Schedule Risk & Opportunity Treatment***	***Schedule Risk Mitigation and Consequence Affordability***
			Schedule Reserve Adequacy	***Phased Affordability***

Figure 6-3. Dimensions of Schedule Reliability and their sub-dimensions.

To answer each dimension's characteristic question, P/Ss must address the set of questions that satisfy each sub-dimension. The comprehensive trace from each reliability dimension and sub-dimension, through question sets, to the appropriate Schedule Assessment and Analysis procedures comprises the *Schedule Reliability Matrix.* As shown in Figure 6-5 below, this tool condenses the complete lexicon of the schedule assessment domain into a clean map of the Schedule Assessment process as shown in Figure 6-4.



	Reliability Dimensions	Sub-dimensions	Assessment/Analysis Questions	Assessment Procedure		
				1st Tier	2nd Tier	3rd Tier
Schedule Reliability	Comprehensiveness	Content Breadth	~Is the P/p's current technical portfolio of content, driven by the latest set of requirements and plans, completely captured across the life cycle? ~Are the controlled elements captured?	▶ Requirements Check		◆ Schedule Risk Analysis
		Level of Detail	~Is the scheduled adequately detailed to fully support reporting and analysis? ~Is the schedule overly detailed to the detriment of usability?	▶ Health Check	▶ Critical Path and Structural Check	
	Construction	Critical Path Construction	~Is the end-to-end schedule network constructed soundly? ~Are all possible critical paths integrated correctly into the schedule?			
		Vertical Traceability	~Does the schedule's organization and hierarchy match the P/p's? ~Does the schedule map cleanly to the various levels of the P/p's Work Breakdown Structure? ~Are schedule summarization methods applied uniformly across the schedule?	▶ Requirements Check		
	Realism	Justification of Discrete Schedule Elements	~Is the analogical, performance, or expert-rendered basis for every discrete structural element justified cogently? ~Is schedule progress measured against the baseline? ~Are changes from previous versions of the schedule adequately explained?		▶ Basis Check	
		Schedule Risk & Opportunity Treatment	~Are all significant probabilistic schedule events identified? ~Is their placement within the schedule's structure well-understood? ~Is there a justified basis for risks' and opportunities' parameters?	▶ Risk ID & Mapping Check		
		Schedule Margin Adequacy	~Given schedule uncertainty, risks, and potential future schedule cases, are the magnitude and allocation of schedule margin sufficient?			
	Affordability	Resource & Cost Integration with Schedule	~Are resources and cost estimates mapped appropriately to schedule elements?		▶ Resource Integration Assessment	◆ Integrated Cost, Schedule, and Risk Analysis
		Schedule Risk Mitigation & Consequence Affordability	~Does the schedule cohere with the P/p's financial reality?			
		Phased Affordability				

Figure 6-4. Schedule Reliability Matrix.

Each of these question sets drives one or more Schedule Assessment and Analysis procedures, ordered by logical precedence and defined by tiers. The 1st and 2nd Tiers provide the foundation for Schedule Assessment, while the 3rd Tier guides Schedule Analysis as follows:

- ❖ **1ST Tier**
  - ✓ **Requirements Check.** *Assesses the schedule's compliance with Agency and P/p requirements.*
  - ✓ **Health Check.** *Assesses the schedule's overall integrity by gauging its health aligning with various general best practice categories.*
  - ✓ **Risk ID & Mapping Check.** *Assess the existence and comprehensiveness of P/p schedule risks and their placement within the schedule's structure.*
- ❖ **2nd Tier**
  - ✓ **Critical/Driving Path and Structural Check.** *Assesses the structural quality & fidelity of all possible critical paths and driving paths and compliance with horizontal tractability standards. Depends upon a satisfactory Health Check.*

  - ✓ **Basis Check.** *Assesses the justification of each discrete schedule element, including risks. Depends, in part, upon a satisfactory Risk ID & Mapping Check.*
  - ✓ **Resource Integration Check.** *Affirms that P/p's budget, workforce, and cost estimates at any point in the P/p life cycle map to the corresponding IMS.*
- ❖ **3rd Tier**
  - ✓ ***SRA.*** *Using SRA or alternative risk-adjusted schedule analysis, measures the required schedule margin implied by the schedule and assesses its adequacy.*
  - ✓ ***ICSRA.*** *Using ICSRA or alternative integrated analyses, measures the required schedule margin implied by the schedule and assesses its adequacy and the adequacy of phased budgets to cover P/p cost estimates and discrete, risk-related costs.*

6.1 Best Practices

Figure 6-5 details the best practices for Schedule Assessment and Analysis.

SM.AA.1 Schedule Assessment and Analysis Follows the SMP	• The schedule is assessed and analyzed in accordance with the Schedule Management Plan.
SM.AA.2 Requirements Checks are Routinely Performed	• Requirements Checks are routinely performed to ensure that the IMS is compliant with Agency and P/p requirements.
SM.AA.3 Schedule Health Checks are Routinely Performed and Errors Investigated	• Schedule Health Checks are routinely performed to ensure that the schedule mechanics are not causing the schedule to calculate incorrectly, and any errors are investigated and corrected.
SM.AA.4 Risk Identification and Mapping Checks are Routinely Performed	• Risk Identification and Mapping Checks are routinely performed to ensure that the schedule risks are comprehensively identified and mapped appropriately to the IMS.
SM.AA.5 Critical Path and Structural Checks are Routinely Performed	• Critical Path and Structural Checks are routinely performed to affirm the integrity of the IMS's overall network logic flow, including each potential critical path.
SM.AA.6 Basis Checks are Routinely Performed	• Basis Checks are routinely performed to affirm the quality of the estimate associated with each discrete schedule element.
SM.AA.7 Resource Integration Checks are Routinely Performed	• Resource Integration Checks are routinely performed to affirm that the P/p's budget, workforce, and cost estimates map to the P/p IMS.
SM.AA.8 SRA/I7SRA is Developed Using Appropriate Tools	• The Schedule Risk Analysis or Integrated Cost and Schedule Risk Analysis (SRA/ICSRA) is developed using appropriate tools.
SM.AA.9 Programmatic Data Products Used for the	• Programmatic products and data utilized to perform the SRA (or ICSRA) provide an adequate representation of the P/p plan and are consistent with each other with respect to their status dates.

SRA/ICSRA Represent the P/p Plan	
SM.AA.10 IMS is the Framework for the SRA	• The Integrated Master Schedule (IMS) is used as the framework for the SRA, when feasible.
SM.AA.11 Schedule Duration Uncertainties are Quantified in the SRA	• Schedule duration uncertainties are quantified with respect to appropriate activities for inclusion in the SRA.
SM.AA.12 Schedule Correlation is Accounted for in the SRA	• Schedule correlation is accounted for in the SRA.
SM.AA.13 Discrete Schedule Risks are Assessed and Quantified for the SRA	• Discrete risks are assessed and quantified with respect to schedule impacts for inclusion in the SRA.
SM.AA.14 Discrete Schedule Risks are Mapped to Appropriate Activities in the SRA	• Discrete risks with schedule impacts are mapped to appropriate activities in the SRA.
SM.AA.15 Discrete Risk SRA Inputs are Tested and Verified Prior to Simulation	• The discrete risk inputs to the SRA Model are reviewed to ensure that they are captured and calculating correctly prior to running the simulation, and that they represent the intended model of the schedule risk.
SM.AA.16 IMS is the Framework for the ICSRA	• The IMS is used as the framework for the ICSRA, when feasible.
SM.AA.17 Cost Model that Replicates the P/p Estimate is Defined and Formatted for the ICSRA	• A cost model that replicates the P/p cost estimate is defined and formatted for the purposes of performing the ICSRA.
SM.AA.18 Costs (or Resources) are Mapped to Appropriate Activities in the ICSRA	• Costs (or resources) are mapped to appropriate level of activities in the ICSRA.
SM.AA.19 Cost Uncertainties are Quantified in the SRA	• Cost uncertainties are quantified with respect to appropriate resources for inclusion in the SRA.
SM.AA.20 Cost Correlation is Accounted for in the SRA	• Cost correlation is accounted for in the SRA.
SM.AA.21 Discrete Cost Risks are Assessed and Quantified for the ICSRA	• Discrete risks are assessed and quantified with respect to cost impacts for inclusion in the ICSRA.
SM.AA.22 Discrete Cost Risks are Mapped to Appropriate Activities in the ICSRA	• Discrete risks with cost impacts are mapped to appropriate activities in the ICSRA.

SM.AA.23 Cost ICSRA Inputs are Tested and Verified Prior to Simulation	• The costs, cost uncertainties, and discrete cost inputs to the ICSRA Model are reviewed to ensure that they are captured and calculating correctly prior to running the simulation, and that they represent the intended model of the cost risk.
SM.AA.24 SRA/ICSRA Inputs are Tested and Verified through Initial Simulation	• The SRA/ICSRA inputs are reviewed through an initial simulation run to ensure that they are captured appropriately and calculating correctly through the outputs.
SM.AA.25 SRA/ICSRA is Performed to Explore Analysis of Alternatives	• SRA/ICSRA is performed for analysis of alternatives to explore schedule 23options as they pertain to technical, budget, and/or time frame constraints.
SM.AA.26 SRA/ICSRA is Performed to Identify/Validate Stochastic Critical Paths	• SRA/ICSRA is routinely performed to identify/validate the stochastic (probabilistic) critical paths.
SM.AA.27 SRA/ICSRA is Performed for Risk Sensitivity Analysis and Risk Prioritization	• SRA/ICSRA is routinely performed for risk sensitivity analysis and risk prioritization throughout the P/p life cycle.
SM.AA.28 SRA/ICSRA is Performed to Produce Schedule Confidence Levels	• SRA/ICSRA is routinely performed to produce schedule confidence level associated with achieving preliminary and baseline IMS milestones.
SM.AA.29 SRA/ICSRA is Performed to Estimate P/p Completion Ranges	• SRA/ICSRA is routinely performed to estimate P/p schedule completion ranges associated with achieving planned milestones (at least as often as required).
SM.AA.30 ICSRA is Performed to Estimate P/p Joint Confidence Level	• ICSRA is performed to produce a joint confidence level (JCL) for cost and schedule associated with achieving planned cost and schedule commitments (at least as often as required).
SM.AA.31 SRA/ICSRA is Performed to Establish/Allocate Margin to Accommodate Uncertainty and Risks	• SRA/ICSRA is routinely performed throughout the P/p life cycle to establish and allocate margin within the preliminary and/or baseline IMS, as well as routinely throughout the P/p life cycle, to ensure sufficiency of margin to accommodate uncertainties and risks.
SM.AA.32 ICSRA Demonstrates Schedule Consistency with Funding/Phasing Strategy	• ICSRA is routinely performed to demonstrate that the schedule of activities is consistent with the funding/phasing strategy.
SM.AA.33 ICSRA Demonstrates Sufficient Cost Reserves	• ICSRA is routinely performed to demonstrate the cost reserves are sufficient to accommodate schedule delays caused by anticipated uncertainty and risk impacts.
SM.AA.34 SRA/ICSRA is Performed to Support Management Decisions Regarding Performance Trends	• SRA/ICSRA is routinely performed to support P/p management decisions regarding schedule and schedule performance trends throughout the P/p life cycle.

Figure 6-5. Schedule Assessment and Analysis Best Practices.

6.2 Assess the Schedule

This sub-function determines and documents the reliability of the *IMS* for use in reporting, analysis, and control. Schedule Assessment characterizes the current state of the schedule, as informed by the latest P/p information and past performance narratives. In implementing the schedule assessment process, the P/S in coordination with the P/p programmatic team, independent assessors, or select stakeholders, as a natural extension of progressively-developed, prioritized dialogue and exploration, should execute a battery of procedures that: (1) identify schedule-manifesting deviations from P/p requirements, and (2) document departures from NASA-identified best practices that address the following general questions:

- "Has the P/p built the correct schedule?"
- "Has the P/p built the schedule correctly?"
- "Does it meet best practices?"
- "What tools/guides are available to assess the reliability of the schedule?" and "How do I use them?"
- "Can the schedule support accurate analysis, control, and reporting?"

While robust in satisfying the above points, Schedule Assessment does not guarantee that the *IMS* will produce the desired products on dates required by sanctioned plans and stakeholders but ensures that the *IMS* is sufficiently reliable to support reporting to stakeholders and the generation of analytical insight. The sum of assessment activity evidence, uncovered progressively over time across iterations of the assessment process, is collected in a *Schedule BoE Dossier*, herein referred to as the "*BoE*", which guides schedule evolution via specific improvements.

6.2.1 Prerequisites

Schedule Assessment can be initiated when:

- The *SMP* sub-plan, *Schedule Assessment and Analysis Plan,* which specifies the techniques used to determine the compliance of the *IMS* to requirements and sets of best practices, is available
- The *Schedule Database* is complete
- An *IMS* has been generated from the *Schedule Database* as a new output or update since the last assessment iteration
- *Milestone Registry* is available
- Risk register is available
- Relevant schedule data from subcontracts and agreements are available
- The schedule *BoE*, created during Schedule Development and capturing the schedule's basis rationale, is available

6.2.2 Perform Schedule Assessment

As a result of studying all possible dimensions of schedule quality by Agency practitioners, NASA has chosen *reliability* as its umbrella measure of schedule 'quality'. Reliable schedules are soundly reasoned along all dimensions, best suiting them to enable correct and earnest analysis, control, and reporting. Schedule Assessment should be pursued within the frame of continuous programmatic dialogue, thereby fostering informational discovery, exchange, and capture within the *BoE*.

As defined earlier in Section 6.2, the execution of the 1st and 2nd Tier procedures in a prioritized-yet-iterative fashion as the P/p matures defines the Schedule Assessment process, enabling collective and documented understanding of the *IMS* through disciplined dialogue and investigation. Though the constituent procedures are ordered by dependence-based precedence, each is not necessarily a discrete activity, especially those that are seminal. (See the 1st Tier assessment procedure set in section in section 6.2.2.1.) Schedule Assessment should develop progressively and iteratively over time, increasing in scope gradually as foundational issues are uncovered and resolved. It should also adapt to the needs of stakeholders and P/Ss throughout the P/p life cycle.

Schedule Assessment should not seem foreign or superfluous to P/p leadership and programmatic personnel since it arises naturally as a product of P/p maturation and self-examination, driving *BoE*-documented schedule justifications and introducing potential improvements. By design, it is flexible enough to be performed by a variety of parties (e.g., P/Ss, Schedule Analysts, independent assessors, and other stakeholders) early and throughout a P/p's life cycle, beginning with preliminary schedule development and iterations prior to baseline approval. During these initial stages, the P/p management team and various support personnel must thoroughly review and evaluate the early iterations of the *IMS* to ensure each one accurately reflects how the P/p effort will be formulated and implemented. It is also important for P/p leadership to ensure that the schedule continues to reflect the implementation plan as it is updated throughout the life cycle as a result, in part, of the continuously performed Schedule Assessment process and its interdependent Schedule Management sub- functions, primary among them Schedule Analysis, described in Section 6.3, and Schedule Maintenance and Control, as described in Chapter 7.

The iterative Schedule Assessment process flow is illustrated in Figure 6-6:

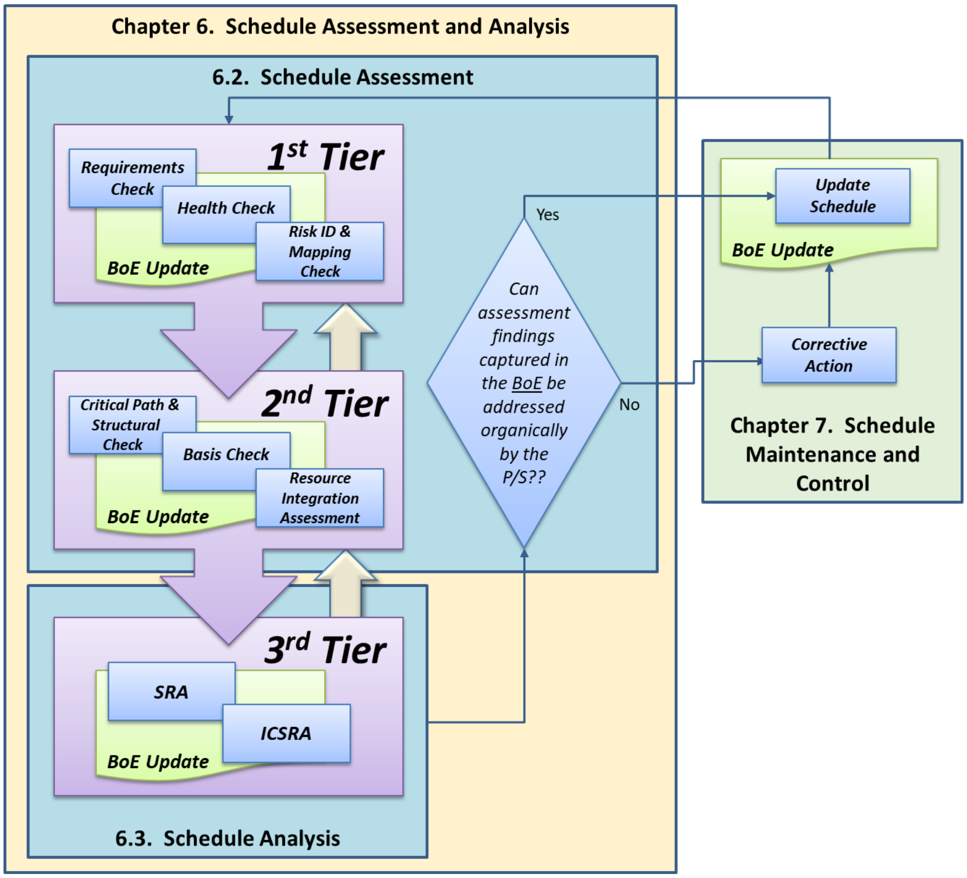


Figure 6-6. Overview of the Schedule Assessment (and Analysis) process.

As depicted, Schedule Assessment generally proceeds in order across each procedure tier. Regardless of who is spearheading the process (e.g., the P/S or an Independent Assessment's programmatic assessor), the results of each procedure iteration should augment the schedule's preexisting *BoE* with a collection of results and related investigational evidence accompanied by an integrated assessment narrative. A schedule is nothing more than an estimate itself; a schedule *BoE* documents the schedule basis rationale – and justification for best practice compliance and departures – in service of satisfying the reliability dimensions, various Agency requirements, and ultimately, NASA's Schedule Management body of knowledge.

As a living product of the Schedule Development process, the *BoE* serves as a roadmap for schedule evolution and primary agent of change. After each Schedule Assessment iteration, the *BoE* is evaluated to determine the best course of action for the corresponding versions of the *IMS*. (Each *BoE* update marks which incarnation of the schedule it addresses.) Very often, the majority of findings can be addressed by virtue of the normal Schedule Maintenance cadence. Many situations warrant P/Ss and Technical Leads, CAMs, or WVS Element Owners, and possibly P/p management, agreeing on incremental changes that do not require formal intervention by other parties. However, if the *BoE* illustrates serious non-compliances or defects that require more generalized awareness, leadership involvement, and adjudication, or a major change such as a replan or a rebaseline is forthcoming, the change control process should be engaged as outlined in Section 7.3.1.

The remainder of this chapter is devoted to the specific definition and discussion of each schedule assessment procedure, associated questions, and assessment artifacts that are appropriate for inclusion in the P/p's *BoE*.

6.2.2.1 1st Tier Assessment Procedures

To lay the groundwork for advancing the *IMS* towards *reliability* – the ultimate measure of schedule quality – and to prepare the schedule and related data for comprehensive and increasingly sophisticated examination, the P/S should iterate among 1st Order Tier procedures until the *BoE* has matured sufficiently for seamless absorption of 2nd Order Tier assessment information. With this in mind, the following three procedures are designed to span disparate, but not unrelated, corners of the *IMS*, thereby constructing an expansive foundation for schedule *reliability* through the development of the schedule *BoE*.

These 1st Order Tier procedures are particularly valuable during Schedule Development and its immediate aftermath since they directly enhance the schedule *BoE* stood up during the formative moments of the *IMS* as its foundation. As a result of these activities, the schedule *BoE*, having been only recently initialized, should mature into the form it will carry throughout the performance of each higher tier and future Schedule Assessment iterations.

If for any reason during the early phases of Schedule Development, the *BoE* was not prepared to accommodate the findings associated with the 1st Tier assessment procedures, the P/S must lead the alignment between the *BoE* and each procedure's requirements.

6.2.2.1.1 Procedure 1. Requirements Check

It is a best practice for a Requirements Check to be performed to ensure that the IMS is compliant with Agency and P/p requirements.

Assessment Questions Addressed:

- Reliability Dimensions: Comprehensiveness and Construction
  - Sub-dimension: Content Breadth
    - *Is the P/p's current technical portfolio of content, driven by the latest set of requirements and plans, completely captured across the life cycle?*
    - *Are the controlled elements captured?*
  - Sub-dimension: Vertical Traceability
    - *Does the schedule's organization and hierarchy match the P/p's?*
    - *Does the schedule map cleanly to the various levels of the P/p's Work Breakdown Structure?*
    - *Are schedule summarization methods applied uniformly across the schedule?*

6.2.2.1.1.1 Step 1. Verify that the IMS Reflects the Breadth of Content Dictated by Requirements

Procedure 1 of the 1st Tier opens with a step that sets the analytical foundation for the assessment process as a whole: checking the schedule against its most fundamental influence - the suite of requirements applicable to the P/p. These include, but are not limited to:

- Authoritative P/p technical requirements documents
- P/p Plans, including domain-related plans
- *SMP*, including schedule guidance and GR&As
- Other P/p GR&A documents
- *Milestone Registry*
- Technical hierarchy documents, including the WBS, OBS, and CBS
- Applicable budget cycle documents
- Subcontracts, along with relevant stipulations
- Official external agreements, including international partnership agreements (e.g., MOUs, MOAs, etc.)
- Stated, recorded stakeholder directives

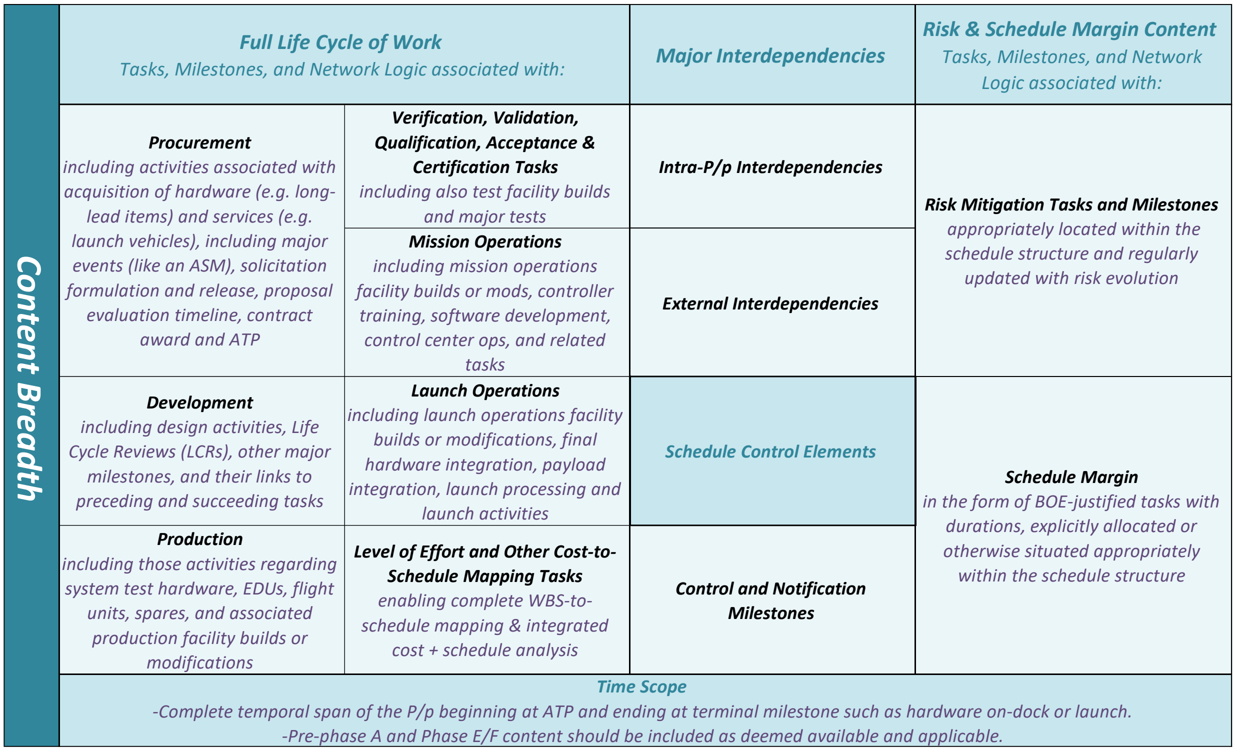
This set of requirements and supplementary information shape the breadth of technical and programmatic scope. The P/S should take special care to verify the full scope is reflected in the *IMS*, which should contain the complete end-to-end networked flow of work necessary to reach the terminal milestone, as described in Sections 5.5.3 and 5.5.6. GAO affirms this simply by stating:

> *The IMS should reflect all effort necessary to successfully complete the program, regardless of who performs it.*[81]

During this procedure, the P/S should check that the *IMS* incorporates the areas of content and features according to the scope of work set forth by the P/p's requirement set, as described Figure 6-7 for Space Flight P/ps and Figure 6-8 for Research and Technology P/ps.

---

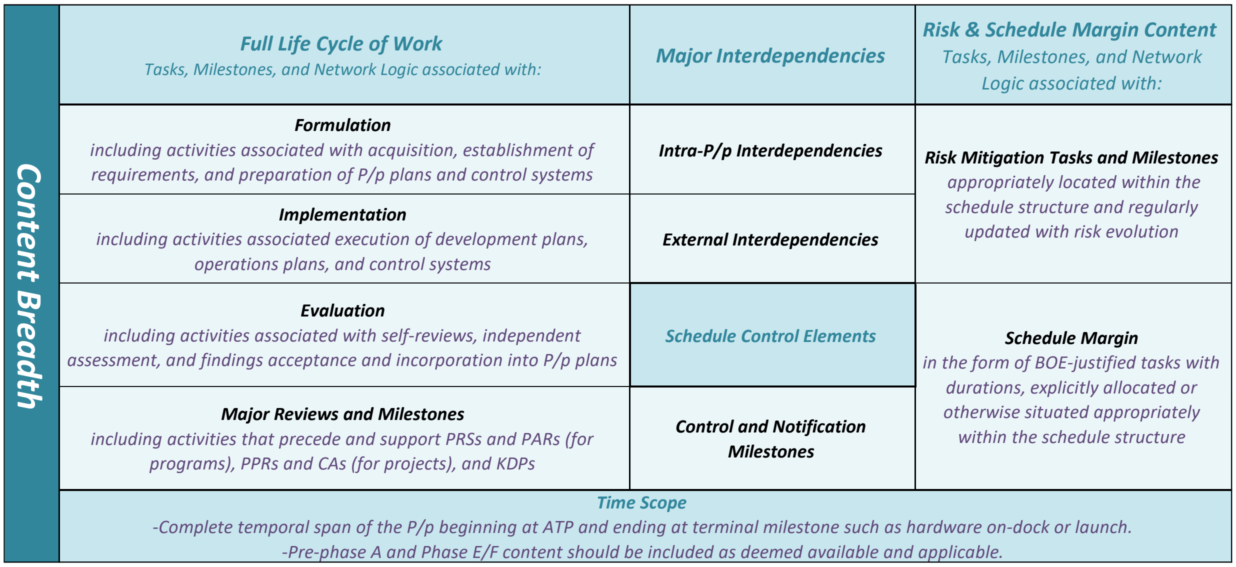
[81] GAO-16-89G. GAO Schedule Assessment Guide. Page 11. December 2015. http://www.gao.gov/assets/680/674404.pdf



Content Breadth

Full Life Cycle of Work *Tasks, Milestones, and Network Logic associated with:*		***Major Interdependencies***	***Risk & Schedule Margin Content*** *Tasks, Milestones, and Network Logic associated with:*
Procurement *including activities associated with acquisition of hardware (e.g. long-lead items) and services (e.g. launch vehicles), including major events (like an ASM), solicitation formulation and release, proposal evaluation timeline, contract award and ATP*	***Verification, Validation, Qualification, Acceptance & Certification Tasks*** *including also test facility builds and major tests*	***Intra-P/p Interdependencies***	***Risk Mitigation Tasks and Milestones*** *appropriately located within the schedule structure and regularly updated with risk evolution*
	Mission Operations *including mission operations facility builds or mods, controller training, software development, control center ops, and related tasks*	***External Interdependencies***	
Development *including design activities, Life Cycle Reviews (LCRs), other major milestones, and their links to preceding and succeeding tasks*	***Launch Operations*** *including launch operations facility builds or modifications, final hardware integration, payload integration, launch processing and launch activities*	***Schedule Control Elements***	***Schedule Margin*** *in the form of BOE-justified tasks with durations, explicitly allocated or otherwise situated appropriately within the schedule structure*
Production *including those activities regarding system test hardware, EDUs, flight units, spares, and associated production facility builds or modifications*	***Level of Effort and Other Cost-to-Schedule Mapping Tasks*** *enabling complete WBS-to-schedule mapping & integrated cost + schedule analysis*	***Control and Notification Milestones***	
Time Scope *-Complete temporal span of the P/p beginning at ATP and ending at terminal milestone such as hardware on-dock or launch.* *-Pre-phase A and Phase E/F content should be included as deemed available and applicable.*			

Figure 6-7. Matrix for Assessing the Breadth of Schedule Content included in an IMS for Space Flight P/ps.[82]



Content Breadth

Full Life Cycle of Work *Tasks, Milestones, and Network Logic associated with:*	***Major Interdependencies***	***Risk & Schedule Margin Content*** *Tasks, Milestones, and Network Logic associated with:*
Formulation *including activities associated with acquisition, establishment of requirements, and preparation of P/p plans and control systems*	***Intra-P/p Interdependencies***	***Risk Mitigation Tasks and Milestones*** *appropriately located within the schedule structure and regularly updated with risk evolution*
Implementation *including activities associated execution of development plans, operations plans, and control systems*	***External Interdependencies***	
Evaluation *including activities associated with self-reviews, independent assessment, and findings acceptance and incorporation into P/p plans*	***Schedule Control Elements***	***Schedule Margin*** *in the form of BOE-justified tasks with durations, explicitly allocated or otherwise situated appropriately within the schedule structure*
Major Reviews and Milestones *including activities that precede and support PRSs and PARs (for programs), PPRs and CAs (for projects), and KDPs*	***Control and Notification Milestones***	
Time Scope *-Complete temporal span of the P/p beginning at ATP and ending at terminal milestone such as hardware on-dock or launch.* *-Pre-phase A and Phase E/F content should be included as deemed available and applicable.*		

Figure 6-8. Matrix for Assessing the Breadth of Schedule Content included in an IMS for Research and Technology P/ps.[83]

---

[82] Missing risks and their mapping are handled by *Procedure 3*.

[83] Missing risks and their mapping are handled by *Procedure 3*.

Within the schedule *BoE* dossier and within the *IMS* itself via custom fields (see sections 5.3.5 and 5.5.2), the P/S should examine (or create) a trace from the schedule content, in the form of tasks, milestones, logical links, or other schedule elements, to the appropriate requirement or authoritative document. This trace should be two-way: any requirements not manifested as content in the schedule should be noted in the *BoE* dossier's missing content registry for disposition.

It is also important that the schedule temporally span the life of the P/p, which includes the activities near the termination of the overall effort. Often, the proper breadth of content is represented well in a schedule's near-term window but loses fidelity (or is lost entirely) for future planned tasks. This is especially common in schedules that adhere to the rolling wave approach. The P/S should investigate what is missing downstream in the *IMS*, as dictated by the requirement set, in additional to their attention on the upstream elements. This step should be performed regardless of schedule detail, though, in many cases, less detailed network structure associated with the later stages of a P/p also lacks comprehensive breath in content. The P/S should further augment the *BoE* dossier's registry of missing content with those elements lost due to the improperly rendered temporal scope.

Among the most crucial elements are those associated with schedule control: notification and control milestones, as well as elements that fall within close proximity to them. As a formative effort, the P/S should take special care of noting, within the *BoE*, which of these items have not been incorporated accurately into the *IMS*, since they represent the essence of a baselined and otherwise management-dictated schedule. A schedule that informationally lags the true placement of controlled elements often, at best, loses its usefulness as a reporting and analytical tool and, at worst, clouds the schedule picture and misleads stakeholders.

6.2.2.1.1.2 Step 2. Verify that the IMS is Vertically Traceable.

Apart from the extent to which the full breadth of the schedule's content is contained within the downstream confluence of activity flows toward a terminal milestone is a perpendicular measure of *IMS* unity: *vertical traceability*, which entails that the schedule be constructed from nested blocks of user-navigable content according to the P/p's organizational and hierarchical motifs, as described in Section 5.6.1. To ensure proper summary representation of schedule activities at all levels, the P/S should verify that hierarchical documents like the OBS are either being used to explicitly drive the schedule's tiered structure or can map directly to it. Verification of vertical traceability benefits all assessment procedures not only with respect to schedule intelligibility and usability but also to the connection between all schedule elements and source documentation.

As a best practice, the document that most often and relevantly bears upon P/p schedules' vertical traceability is the P/p's WBS, as described in Sections 5.3.1 and 5.5.7, since it captures completely the products being developed, produced, and reflected within the schedule, along with their nested configurations. GAO also espouses this best practice and comments as follows:

> *At its summary level, the IMS gives a strategic view of activities and milestones necessary to start and complete a program. At its most detailed, the schedule clearly*

> *reflects the WBS and defines the activities necessary to produce and deliver each product.*[84]

The P/p's WBS should closely map to the *IMS* if not match its structure outright due to the documents' common calibration to work products. To that extent, the verification of proper vertical traceability within the *IMS* should also, in part, verify that the WBS is sensibly structured and captures the full scope of work. In lieu of a fully defined WBS, especially during early P/p stages far prior to the approval of a schedule baseline, the P/S should be mindful of developing realities and use the full suite of available programmatic documents to ascertain the extent of reasonable application of vertical traceability.

In many cases, the mapping of the schedule to the WBS will be covered by Step 1 of this procedure. However, often, P/p schedules map to authoritative documents like the WBS but in inconsistent ways. Regardless of whichever selection of programmatic plans or documents lends a tiered structure to the *IMS*, P/Ss should note the uniformity of summarization methods' application across the schedule and should augment the *BoE* with a WBS-to-*IMS* map and a hierarchical comparison, if one is not already being maintained.

Exit Criteria. The *Requirements Check* procedure is satisfied when the P/S has completed the following tasks:

- ✓ Verify that the *IMS* reflects the breath of content dictated by requirements.
- ✓ Verify that the *IMS* is vertically traceable.
- ✓ Mark the *BoE* with each data source's date according to the current schedule and assessment iterations. Alongside this, include the next steps of schedule evolution and a corrective action recommendation when organic schedule improvement is not sufficient.

Procedure Maturation. Over time, the *BoE* should collate a list of missing content and errors in schedule hierarchy. By iterating the assessment process during the beginning stages of the P/p's life cycle, the P/S should evolve the *IMS* to a point at or shortly after requirements have stabilized at which there are no significant P/p elements are missing from the schedule. At or before this point (ideally well before), a high degree of WBS-driven vertical traceability should be reflected within the *IMS.*

Create, update or verify the requirement-to-*IMS*-element map, citing P/p requirements and related authoritative documents. This will at least include, in most cases, a WBS-to-*IMS* map.

6.2.2.1.2 Procedure 2. Health Check

It is a best practice for routine Health Checks to be performed on the IMS to generally ensure that the schedule mechanics are not causing the schedule to calculate incorrectly, and any errors are investigated and corrected.

Assessment Questions Addressed:

- Reliability Dimension: Comprehensiveness and Construction

---

[84] GAO-16-89G. GAO Schedule Assessment Guide. Page 11. December 2015. http://www.gao.gov/assets/680/674404.pdf

- Sub-dimension: Level of Detail
  - *Is the schedule adequately detailed to fully support reporting and analysis?*
  - *Is the schedule overly detailed to the detriment of usability?*
- Sub-dimension: Critical Path Construction
  - *Is the end-to-end schedule network constructed soundly and vertically traceable?*
  - *Are all possible critical paths integrated correctly into the schedule?*

Procedure 2, another in the 1st Tier, pivots from the *Requirements Check's* pure content focus to an examination of the *IMS's* mechanics. The *Requirements Check* makes sure the proper 'what' is included in the schedule while the *Health Check* tests 'how' that content is expressed. To do so, this procedure assesses the *IMS* against a set of predefined, community-vetted metrics designed as indications of potential schedule construction issues. As such, the *Health Check*, properly executed, provides solid ground for deeper assessments of the schedule's task-logic flow, such as the 2nd Tier's *Structural and Critical Paths Check*.

6.2.2.1.2.1   Step 1. Execute an Automated Health Check

Of the procedures specified by the 1st Tier, an automated schedule *Health Check* using an Agency- or industry-standard schedule assessment tool often gathers the lowest hanging assessment fruit since most types are relatively easy to perform on any *IMS*. *Health Checks* are straightforward in identifying, tabulating, and reporting key schedule health indicators and providing a natural basis for schedule investigation and repair, which is, much of the time, addressed organically without the need for a formal corrective action. These automated assessments, quantitatively tracked over time within the schedule *BoE*, contribute significantly to the overall schedule narrative from an objective standpoint.

There are two general classes of schedule *Health Checks* tools: MS Project add-ons[85] like NASA's *Schedule Test and Assessment Tool (STAT)* and standalone scheduling analysis software packages, such as Polaris and Deltek Acumen Fuse.[86] These tools generally replicate or adhere closely to schedule community-accepted standard metric sets and are often tailorable to fit organization-specific metrics. Key indicators that conform to these industry standards are shown in Figure 6-9[87]:

---

[85] The NASA Schedule Test and Assessment Tool can be requested through the NASA Software Catalogue managed by the Marshall Technology Transfer Office, https://software.nasa.gov/software/MFS-33362-1

[86] Additional schedule health check tools are referenced in the Agency Schedule Management Tool Matrix located at the SCoPe website, https://community.max.gov/x/9rjRYg.

[87] Descriptions of key indicators were compiled from the NASA Schedule Test and Assessment Tool (STAT); "SAA Schedule Assessment and Analysis", NASA, February 14, 2013; the Deltek Acumen Fuse tool; and the DCMA Manual 3101-02: Program Support and Analysis Reporting, http://www.dcma.mil/Portals/31/Documents/Policy/DCMA-MAN-3101-02.pdf

Key Indicator / Metric	Description
Tasks	
High Durations	This metric counts the number of activities that have a duration longer than two months. High duration activities are generally an indication that a plan is at too high a level for adequate planning and control. Activity durations should be realistic and measurable. NASA's general use of rolling wave planning implies that near-term tasks are planned to a lower, discrete level of detail; whereas tasks scheduled to occur farther into the future may be planned may be planned at a more summary level of detail, when task details are as yet unknown. More discussion of schedule detail as it relates to rolling wave planning can be found in Section 5.5.7.3.
Incomplete Task Status	This metric counts the number of activities that have past due tasks and milestones with no revised forecast dates, i.e., the "status-as-of" date is too far in the past to be meaningful. For Schedule Assessment and Analysis purposes, it is helpful for all activities in the schedule to be statused with respect to the same date. (A note of caution: Some scheduling software will allow incomplete tasks/milestones to remain in the past with no revised forecast dates. Omission of task status reduces schedule credibility, thereby hindering accurate float calculations, critical path identification & analyses, and also task start/finish projections.)
High Float	This metric counts the number activities with high float. Schedule paths with high amounts of float often arise due to artificially constrained activities. In conjunction with margin analysis, float analysis provides key information for P/p management decision making. It is typically suggested that activities on paths with high float be considered for acceleration, prioritizing the activities with the highest amount of float. Further discussion of float can be found in Section More discussion of schedule detail as it relates to rolling wave planning can be found in Section 5.5.11.
Missed Tasks	This metric counts the number of activities that have slipped from their baseline dates. This is an indicator of execution performance and includes the activities that have completed or will complete after their baseline dates.
Invalid Actual Dates	This metric counts the number of activities with actual dates in the future. Activities cannot be statused into the future. Statusing activities into the future could lead to erroneous dates in the schedule. Invalid Actual Dates reduces schedule credibility, thereby hindering accurate float calculations, critical path identification & analyses, and also task start/finish projections.
Invalid Forecast Dates	This metric counts the number of activities planned in the future with status in the past. It is impossible to have future planned activities with status prior to the time now date. Statusing future planned activities could lead to erroneous dates in the schedule.
Activities Improperly Reflected as Milestones/Overuse of Milestones	This metric counts the number of activities that have a duration equal to zero days and/or are coded as milestones. If work/effort is involved, activities should have durations greater than zero days.
Tasks without a Baseline and Progress Status	All tasks should have stated baseline duration against which performance can be measured. This metric is a straight sum of tasks missing such information.

Inconsistent Vertical Integration of Tasks	All similar tasks, grouped by WBS or some other guidance, should roll up to a summary level in a similar fashion. This metric measures how many of the tasks fail to do so and should be aligned in the schedule hierarchy with like activities.
Tasks with Missing Field Information	All tasks' fields should be filled with current information. Those with missing field values should be noted and investigated.
LOE Tasks on the Critical Paths	Critical path cannot include LOE tasks because they do not capture measurable work. The metric is a sum of LOE tasks that should be removed from current or potential critical paths.
Logic and Lags	
Missing Logic/Open Ends	This metric counts the number of 'dangling' activities that are missing a predecessor, a successor, or both. These activities are often called “dangling activities”. All schedule activities should have at least one predecessor and successor (although there are a few exceptions noted in Section 5.5.8.1, which include P/p start and finish, external deliveries, etc.). Failure to incorporate at least one predecessor and successor for each activity will impact the ability of the schedule to calculate properly, which may lead to improper float/ critical path calculations, also preventing credible SRA/ICSRA and “what-if” analyses.
Logical Relationships other than FS	This metric counts the number of activities with logic relationships other than FS. Logic other than FS adds complexity to the schedule, potentially inhibiting clear identification of the critical path. It is important to ensure that any use of logic other than FS relationships are justified. Appropriate uses for each type of logic relationship is covered in Section 5.5.8.1.
Logic Applied to Summary Activities	Logic links on summary tasks are typically viewed as a poor scheduling technique, as the summary is not a true activity but instead a grouping of activities. Logic should be tied to the actual work in the schedule.
Improper Logic	This metric may include activities with circular logic or reverse logic. Circular logic often occurs in multi-project schedules. Reverse logic is typically the result of a lead, where successor activities are scheduled to start before their predecessors.
Redundant Logic	A redundant link occurs when in addition to the link in question, there is a more detailed logic link between the same two activities. For example, a link from Activity A to Activity C is made redundant by an existing link from Activity A to Activity B and another one from Activity B to Activity C. While redundant logic will not always create schedule calculation issues, it can make performing schedule updates as part of the Schedule Maintenance sub-function more cumbersome. It also makes logic traceability, such as critical path traces, more difficult for Schedule Assessment and Analysis.
Out-of-Sequence Logic	This metric checks for clashes between logic and progress/status updates. If a successor activity is in progress or complete before the predecessor activity has started (tied with a FS link), then either the status or the logic is wrong. Out-of-sequence task cause questionable total float calculations for the tasks involved and may prevent identification of the critical path. This may be an indicator that the level of task detail is not sufficient.

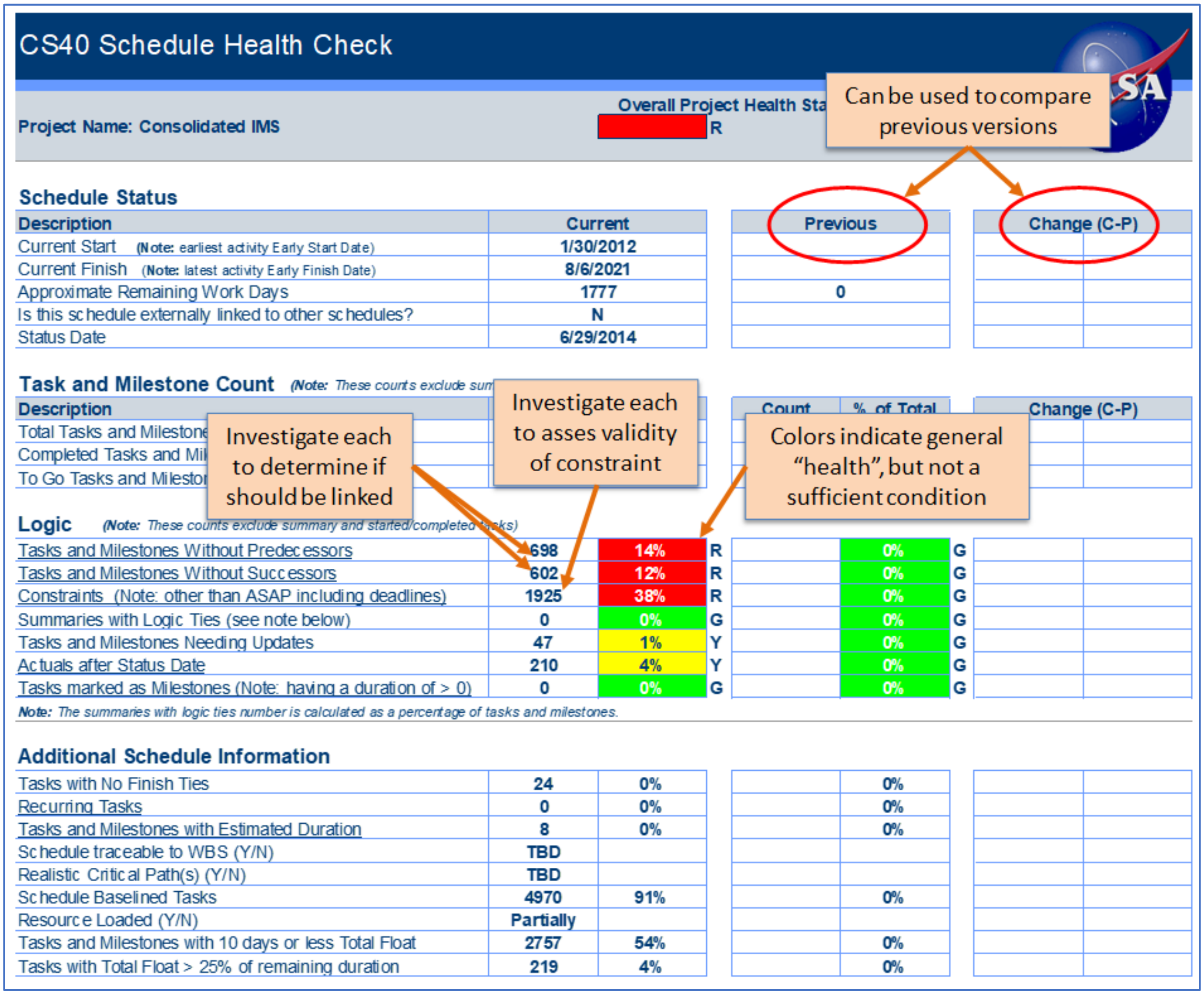
Improper use of Leads/Lags	This metric counts the number of leads and/or lags in the schedule. Leads are often used to adjust the successor start or end date relative to the logic link applied, which can result in the successor starting before the predecessor. Lags are positive durations or delays associated with logic links, which tend to hide detail in schedules and cannot be statused like normal activities. Furthermore, uncertainty distributions cannot be applied to lags for the purposes of SRAs, potentially underestimating schedule impact due to uncertainty. Lags should be replaced with activities. Further discussion of leads and lags can be found in Section 5.5.8.2.
Constraints and Float	
Hard and Soft Constraints	This metric counts the number of activities with constraints. Constraints can override assigned logic and directly affect float calculations on tasks and milestones, therefore impacting critical path calculations. Some constraints have greater impact than others. Hard constraints should be avoided. If absolutely necessary, soft constraints or deadlines may be substituted, but should be used appropriately. Minimal use of constraints is encouraged. See Section 5.5.8.3 for more information on hard constraints, soft constraints, and deadlines.
Negative Float	Number of activities with total finish float less than zero working days. Negative float is the result of an artificially accelerated or constrained schedule. Negative float indicates that a schedule is not possible based on the current planned completion dates. Compare this metric to determine which activities (with negative float) are being impacted by constraints. Ideally, there should not be any negative float in the schedule.
High Float	High total float detected anywhere in the *IMS* may indicate issues nearby and should be considered an earmark for deeper assessment. This is measure often as the sheer count or percentage of high float tasks of all schedule tasks.
Milestones	
Milestones Improperly Reflected as Activities	This metric counts coded milestones with duration greater than zero days. Milestones do not have durations because they do not reflect work being performed.
Missed Milestones	This metric counts the number of milestones that have slipped from their baseline dates. Impacts from milestone slips may include: a slip to the P/p completion date; changes in critical/driving path(s); the need for resources to be adjusted; the need for work around plans to be developed; conflicts in facility usage; issues with internal handoffs between organizations or external deliveries to P/p partners.
Resources	
Missing Resources	This metric counts the number of activities that do not have resources/costs assigned. This is useful in determining whether the schedule has been resource/cost loaded in full. Further discussion on the benefits of resource/cost loading are captured in Section 5.5.11.

Figure 6-9. Typical metrics and key indicators that are used to assess the schedule's health and mechanics.

These metrics are general guides and are not meant as exhaustive. Further, these metrics need to be carefully investigated to mitigate any potentially misleading conclusions. The P/S's understanding technical and topological understanding of the schedule, as it develops over time and data exposure, will determine which metrics matter the most.

6.2.2.1.2.2 Step 2. Interpret and Assess the Automated Health Check Report

The results of each automated *Health Checks* are tantamount to the beginning of mechanical analysis of the *IMS*. The P/S should use the *Health Check Reports* as a roadmap for investigation into root causes towards schedule improvement. An example *Health Check Report* illustrating potential avenues of investigation is shown in Figure 6-10:



CS40 Schedule Health Check

Project Name: Consolidated IMS

Overall Project Health Sta 🟥 R

Can be used to compare previous versions

Schedule Status

Description	**Current**	**Previous**	**Change (C-P)**	
Current Start **(Note:** earliest activity Early Start Date)	1/30/2012			
Current Finish **(Note:** latest activity Early Finish Date)	8/6/2021			
Approximate Remaining Work Days	1777	0		
Is this schedule externally linked to other schedules?	N			
Status Date	6/29/2014			

Task and Milestone Count ***(Note:** These counts exclude sum*

Description		**Count**	**% of Total**	**Change (C-P)**	
Total Tasks and Milestone					
Completed Tasks and Mil					
To Go Tasks and Milestor					

Investigate each to determine if should be linked

Investigate each to asses validity of constraint

Colors indicate general "health", but not a sufficient condition

Logic ***(Note:** These counts exclude summary and started/completed tasks)*

Tasks and Milestones Without Predecessors	698	14%	R		0%	G		
Tasks and Milestones Without Successors	602	12%	R		0%	G		
Constraints (Note: other than ASAP including deadlines)	1925	38%	R		0%	G		
Summaries with Logic Ties (see note below)	0	0%	G		0%	G		
Tasks and Milestones Needing Updates	47	1%	Y		0%	G		
Actuals after Status Date	210	4%	Y		0%	G		
Tasks marked as Milestones (Note: having a duration of > 0)	0	0%	G		0%	G		

***Note:** The summaries with logic ties number is calculated as a percentage of tasks and milestones.*

Additional Schedule Information

Tasks with No Finish Ties	24	0%		0%		
Recurring Tasks	0	0%		0%		
Tasks and Milestones with Estimated Duration	8	0%		0%		
Schedule traceable to WBS (Y/N)	TBD					
Realistic Critical Path(s) (Y/N)	TBD					
Schedule Baselined Tasks	4970	91%		0%		
Resource Loaded (Y/N)	Partially					
Tasks and Milestones with 10 days or less Total Float	2757	54%		0%		
Tasks with Total Float > 25% of remaining duration	219	4%		0%		

Figure 6-10. Typical output from the STAT Health Check tool.

The color-coding provides a first look at whether or not certain aspects of the schedule are "healthy". However, additional scrutiny must be exercised to understand whether "green" actually indicates "healthy" and "red" or "yellow" actually indicates "unhealthy." For example, the measurement for "Constraints other than ASAP", could be green, but it only takes a single "Must Finish On" constraint to invalidate the entire schedule. The Schedule Health Check provides a separate tab that lists every constraint that is not ASAP. Each non-ASAP constraint should be carefully investigated for validity and whether the constraint is causing an erroneous calculation of float. Likewise, the missing predecessors and successors must also be investigated individually to make sure that a critical linkage is not missing. A missing link may invalidate the critical path calculation.

For each metric, the P/S should recruit the appropriate expertise and informational resources to either justify the apparent deviation from the accepted standard or identify root causes and craft a plan for Schedule Maintenance. The P/S, who often may find that a defined, yet informal change approach is appropriate, should lead the continuous schedule health improvement effort and track its progress through completion. This will necessarily involve executing other Schedule Assessment procedures, especially those from the 2nd Tier. This strategy may identify serious non-compliances or defects that require more generalized awareness, leadership involvement, and adjudication, or a major change such as a replan or a rebaseline. It these instances, the formal change control process should be engaged as outlined in Section 7.3.1.

Regardless of the schedule health remediation strategy or formality, the P/S should record each *Health Check Report*, an explanation of each non-compliant metric's value (including justifying source data or expert opinion), and a reparation plan within the *BoE* as part of the larger narrative.

Exit Criteria. The *Health Check* procedure is satisfied when the P/S has completed the following steps:

- ✓ Execute an automated *Health Check*.
- ✓ Interpret and assess the automated *Health Check Report*, investigate root causes, and address all within a remediation plan housed in the *BoE*.
- ✓ Mark the *BoE* with each data source's date according to the current schedule and assessment iterations. Alongside this, include the next steps of schedule evolution and a corrective action recommendation when organic schedule improvement is not sufficient.

Procedure Maturation. It is incumbent upon the P/S to perform this procedure on a continuous basis due to its ease and informational value, which support the execution of other higher tier assessment procedures throughout the life cycle. It is one of the most relatable procedures to stakeholders and demands a mature *BoE* narrative that can drive status reporting on a regular cadence. The chronical within the *BoE* regarding health and structural issues should be especially cohesive, containing a narrative (with the appropriate data) prioritizing issue resolution in accordance with the plan for a progressively healthier *IMS*.

As with every Schedule Assessment procedure, it is impossible for the *Health Check* to address all issues at once, nor should that be the expectation. However, as a goal, this procedure should resolve most schedule health issues by the time advanced assessment, analysis, and reporting is due to stakeholders by P/p management necessity or Agency policy directive around the SDR timeframe. Nonetheless, the *Health Check* should be performed on a routine basis, as a completely healthy schedule is necessary for advanced assessments like schedule growth or to support cost or technical reporting, in addition to being especially critical for more sophisticated analytics, like *SRAs/ICSRAs*.

6.2.2.1.3 Procedure 3. Risk Identification & Mapping Check

It is a best practice for routine Risk Identification & Mapping Checks to be performed to ensure that the schedule risks are comprehensively identified and mapped appropriately to the IMS.

Assessment Questions Addressed:

- Reliability Dimension: Realism

- Sub-dimension: Schedule Risk (and Opportunity) Treatment
  - *Are all significant probabilistic schedule events identified?*
  - *Is their placement within the IMS's structure well-understood?*
  - *Is there a justified basis for risks' and opportunities' parameters?*

Probabilistic schedule events, including risks and opportunities, play an essential role in qualifying the P/p's programmatic posture. Without understanding these potential events, schedule reporting and analysis is incomplete and, often, irrevocably incorrect. The *Risk Identification & Mapping Check,* a successor of the *Requirements Check,* is the first of two risk-related assessment procedures (see also *Basis Check*) meant to ensure that probabilistic schedule events are properly treated as non-optional schedule components intimately linked to the *IMS*'s network of elements and, in turn, the larger programmatic story.

6.2.2.1.3.1 Step 1. Verify the P/p's Identified Set of Schedule Risks

During its early phases, a P/p creates and maintains a risk list, either in the form of a risk list housed within a Risk Management System (RMS) or a collection maintained elsewhere as approved by P/p leadership. In Step 1, the P/S undertakes a few straightforward tasks:

- ✓ Verify that the P/p-sanctioned schedule risk list exists and that it is included in the P/p's schedule *BoE* dossier. Add it in the event of its omission.
- ✓ Verify that the schedule risk list to the RMS or has been otherwise ratified as official by P/p management or the appropriate risk board.
- ✓ Verify that schedule opportunities, if any are identified by sponsoring parties (including P/p management), are included in the *BoE*. Opportunities and other discrete probabilistic schedule events that are not strictly curated within a P/p's RMS should also be included.

These tasks regard the basic bookkeeping of identified probabilistic schedule events within the P/p's management and assessment process frameworks alike. After these are completed, the P/S should turn his or her attention to those significant items *not* identified in the risk list. Since these unidentified risks, to the extent that they are at all discoverable, are uncovered primarily by executing deeper 2nd Tier assessment procedures that regard the basis and evolution of schedule and risk data, this procedure stipulates that the P/S only record within the *BoE's* risk list those uncodified risks readily identifiable via review of information on-hand, including findings previously rendered by technical experts and from insight generated by the other 1st Tier assessment procedures - the *Requirements Check* and *Health Check*. (A more in-depth round of investigation and consultation with technical experts within or independent of the P/p is entailed by the *Basis Check*.) The final Step 1 task is as follows:

- ✓ To the extent possible using freely available P/p information and documentation, augment the *BoE's* risk list with previously unidentified, discrete items representing events of significant probability and consequence to elements within the *IMS*. Mark them as candidate risks or other P/p utilized designation and include a descriptive narrative.

It is worth discussing here the other types of special probabilistic schedule events that may warrant a P/S's attention. Within the *IMS* itself, it may be appropriate for the P/S and/or Schedule Analyst to include *probabilistic branching* events tied to two or more possible downstream paths, each with associated probabilities, flowing from a common point of departure. These techniques are described in Section 6.3.2.3.5. Further, there are certain probabilistic events that, if occurring, could necessitate a P/p replan effort (not necessarily a schedule or P/p rebaselining) entailing a reconstruction of the schedule in unforeseen ways beyond what risks or probabilistic flows can encapsulate. These probabilistic events should be listed and justified within the *BoE* and receive special attention during the other assessment procedures, especially the *Basis Check*, described in Procedure 5.

6.2.2.1.3.2 Step 2. Verify that the Risk and Opportunity Placement within the IMS is Well-Understood by the P/p' Schedule Team

Continuous routine schedule risk identification provides the basis for the understanding potential threats to *IMS* elements. However, schedule risks lose most, if not all, of their informational power if they are not carefully linked to the appropriate locations within the schedule network. Mapping risks to schedule plays a crucial role in integrating the RMS and *IMS*, which are often otherwise managed completely independently. Thus, helping to protect against the lack of communication and coordination between two major PP&C domains and their respective data constructs is a major responsibility of the P/S.

The P/S assumes a special role during Step 2:

- ✓ Verify that a healthy working relationship exists between the Schedule Management and Risk Management functions and raise concern with the PM if either doesn't exist or isn't functionally optimal. After this connection is verified, take special care to verify that the Risk Manager and risk owners understand the part of the *IMS* they directly manage or to which they directly contribute. The P/S should be involved in all P/p risk discussions to understand the contextual schedule issues captured by each risk.

Schedule risks have complex effects on downstream tasks and milestones. These dynamics are not understood by risk owners unfamiliar with the *IMS* network; rather, risk owners often assume they can intuitively extrapolate the effects of schedule risk consequences that cascade beyond a localized set of tasks and logic, often erroneously citing major events (like a system CDR) as direct targets of risks' realization. Therefore, having verified collaboration between the P/s' schedule and risk domains, the P/S should:

  - ✓ Verify that the schedule risks' consequences to specific tasks within the *IMS* have been mapped in coordination with the Risk Manager and risk owners, using this information to augment the *BoE*.
  - ✓ Verify that the mapping scheme embedded within the *BoE* dossier's risk list is well-justified.
  - ✓ Verify that the set of tasks associated with each risk's mitigation plan is embedded within the IMS.

The above steps should be repeated for discrete opportunities and other probabilistic schedule events as available.

Exit Criteria. The *Risk Identification & Mapping* procedure is satisfied when the P/S has completed the following tasks:

- ✓ Identify P/p's set of risks & other discrete probabilistic schedule events.
- ✓ Verify that the risk and opportunity placement within the *IMS* is well-understood by the P/p team.
- ✓ Mark the *BoE* with each data source's date according to the current schedule and assessment iterations. Alongside this, include the next steps of schedule evolution and a corrective action recommendation when organic schedule improvement is not sufficient.

Procedure Maturation. The P/S should continuously monitor and assist, where possible, the mapping of newly uncovered risks as they are identified by the Risk Management function in close association with this procedure and the *Basis Check*. This is a considerable effort involving many responsible parties and is best facilitated in a prioritized, progressive manner over time, easing the burden on all involved. All schedule risk-related updates should be recorded in the *BoE* to enable schedule risk transparency and traceability over time.

6.2.2.2 2nd Tier Assessment Procedures

These three procedures will mature the structure and content of the schedule *BoE* beyond its origins in the schedule development process and 1st Tier assessment procedures. Though still lacking in critical analysis-driven assessment information rendered by the 3rd Tier procedures, the schedule *BoE* can be considered complete for delivery to appropriate stakeholders for formal evaluation after the 1st and 2nd Tiers have been satisfied as a result of several iterations. The key instance of such an evaluation, based necessarily on the principals set forth in this text, is that which is triggered by the delivery of the schedule *BoE* to an Independent Assessment team, (e.g., Standing Review Boards (SRBs), Independent Review Teams (IRTs), etc.) as a requirement of the LCR and KDP process.[88]

6.2.2.2.1 Procedure 4. Critical Path (and Driving Path) and Structural Check

It is a best practice for routine Critical Path and Structural Checks to be performed to affirm the integrity of the IMS's overall network logic flow, including each potential critical path.

Assessment Questions Addressed:

- Reliability Dimension: Realism
  - Sub-dimension: Critical Path Construction
    - ➢ *Is the end-to-end schedule network constructed soundly?*
    - ➢ *Are all possible critical paths (and driving paths) integrated correctly into the schedule based on schedule provider (e.g., contractor, external partner, etc.) information?*
  - Sub-dimension: Level of Detail
    - ➢ *Is the schedule adequately detailed to fully support reporting and analysis?*
    - ➢ *Is the schedule overly detailed to the detriment of usability?*

---

[88] NPR 7120.5E. NASA Space Flight Program and Project Management Requirements. Effective Date: August 14, 2012. Expiration Date: August 14, 2018. Page 50. https://nodis3.gsfc.nasa.gov/npg_img/N_PR_7120_005E_/N_PR_7120_005E_.pdf

The 1st Tier's assessment procedure results, particularly those rendered after several cycles through the *Health Check*, are prerequisites for a more penetrating assessment of the schedule's structure. While that procedure parsed schedule elements individually, the following two, logically ordered steps of the *Critical Path and Structural Check* serve as approaches to assessing the IMS as an integrated whole.

Tasks connected by logical links are the skeletal structure upon which milestones are situated. This structure should be horizontally traceable in that every task and milestone should have a link to at least one predecessor and one successor (unless located at the beginning or the end of the schedule or represents interim delivery events from or to external entities). GAO comments on the importance of coherent task and milestone sequencing:

> *Such links serve to verify that activities are arranged in the right order for achieving aggregated products or outcomes.*[89]

Horizontal traceability is a necessary but insufficient condition for holistic schedule integrity since any logical path spanning the schedule may still display defective dynamic behavior through logical insensitivity to significant schedule modifications (e.g., such as if a dramatic move in time for tasks or milestones results in no change in total float or downstream milestone dates). To test both of these conditions, given satisfactory *Schedule Health Check* results and issue remediation, the P/S should perform a *Shock Test* to identify defects in schedule logic flow, including errant constraints, by examining the change in total float associated with each path terminating at the *IMS's* end milestone (or select interim milestone) due to a change in upstream schedule elements' duration or temporal placement. In this way, the structural soundness of all possible current and potential critical paths is verified at once. A schedule that successfully passes the *Shock Test* can be characterized generally as both healthy (though some issues may remain given *Schedule Health Check* indicators) and structurally sound. Even at early stages of development, this is an achievable goal for the P/S.

6.2.2.2.1.1 Step 1. Perform a Shock Test on the IMS to Verify its Overall Structural Integrity via Horizontally Traceability and Proper Dynamic Behavior

Shock Test Process

1. ***Setup***
   - ✓ Select tool that allows easy manipulation of task durations. This could be native schedule software such as MS Project or any other user-friendly package. Since this test involves experimenting with task durations, the P/S may find it easier to work with simulation software that can easily manipulate the durations of one or more tasks.
   - ✓ Search the *IMS* for margin activities and set the durations to zero. Add the existence of these margin tasks to the *BoE* structural issues list.
   - ✓ ***Initialize Task Selection***: For the initial iteration of the test, select all tasks that share the *IMS* start date or mark the beginning of a logical string.
2. ***Perturb the Schedule Manually and Uncover Potential Issues for Investigation***

---

[89] GAO-16-89G. GAO Schedule Assessment Guide. Page 71. December 2015. http://www.gao.gov/assets/680/674404.pdf

- ✓ *Artificial Schedule Compression Step*
  - ➢ For each task within the selected set in turn, zero out its duration. Follow the flow of tasks downstream until an eventual successor doesn't move backwards in time. Note either that every downstream task in the string ending in the *IMS's* terminal milestone moved to the left or add the reason why the eventual successor did not move (due to a logical, flow confluence, constraint, or other reason) to the schedule *BoE* structural issues list.
  - ➢ Artificially correct the potential issue so that others may be progressively isolated during subsequent iterations.
  - ➢ For all such subsequent iterations, successively select the first tasks downstream from the original selected tasks that did not change position after the last iteration.
- ✓ *Artificial Schedule Slip Step*
  - ➢ For each task within the selected set in turn, increase its duration until it becomes critical, noting which downstream activities move out accordingly.
    - ▪ If the task does not eventually fall on the critical path, then there is a structural issue with the *IMS* such as missing logic, hard constraint usage, or an eventual missing successor. Add the potential issue to the *BoE* structural issues list.
    - ▪ If the task eventually falls on the critical path but *IMS's* terminal milestone date does not change, there is build-up of negative float somewhere in the network, likely caused by a hard constraint inhibiting the downstream flow. Add the potential issue to the *BoE* structural issues list.
  - ➢ Artificially correct the potential issue so that others may be progressively isolated during subsequent iterations.
  - ➢ For all such subsequent iterations of this step, successively select the first tasks downstream from the original selected tasks that did not change position after the last iteration.

3. ***Iterate Until the End of the Schedule Is Reached and All Tasks Have Been Shocked***
4. ***Investigate Each Identified Item in the BoE Structural Issues List***

- ✓ Progress through the structural issues list in the *BoE*, which will likely be well-populated the first time the *Shock Test* is performed. The P/S should, as always, investigate all uncovered issues with schedule owners and other experts, retiring those that have adequate justification recorded within the *BoE*. Those that remain will likely have appeared in *Schedule Health Checks* prior, may yet be unresolved, and likely (but not necessarily) fall within one of the following common areas of interest (organized here by investigatory question):
- ✓ **Float**
  - ➢ Do activities that have a large amount of free float have missing or incomplete logic?

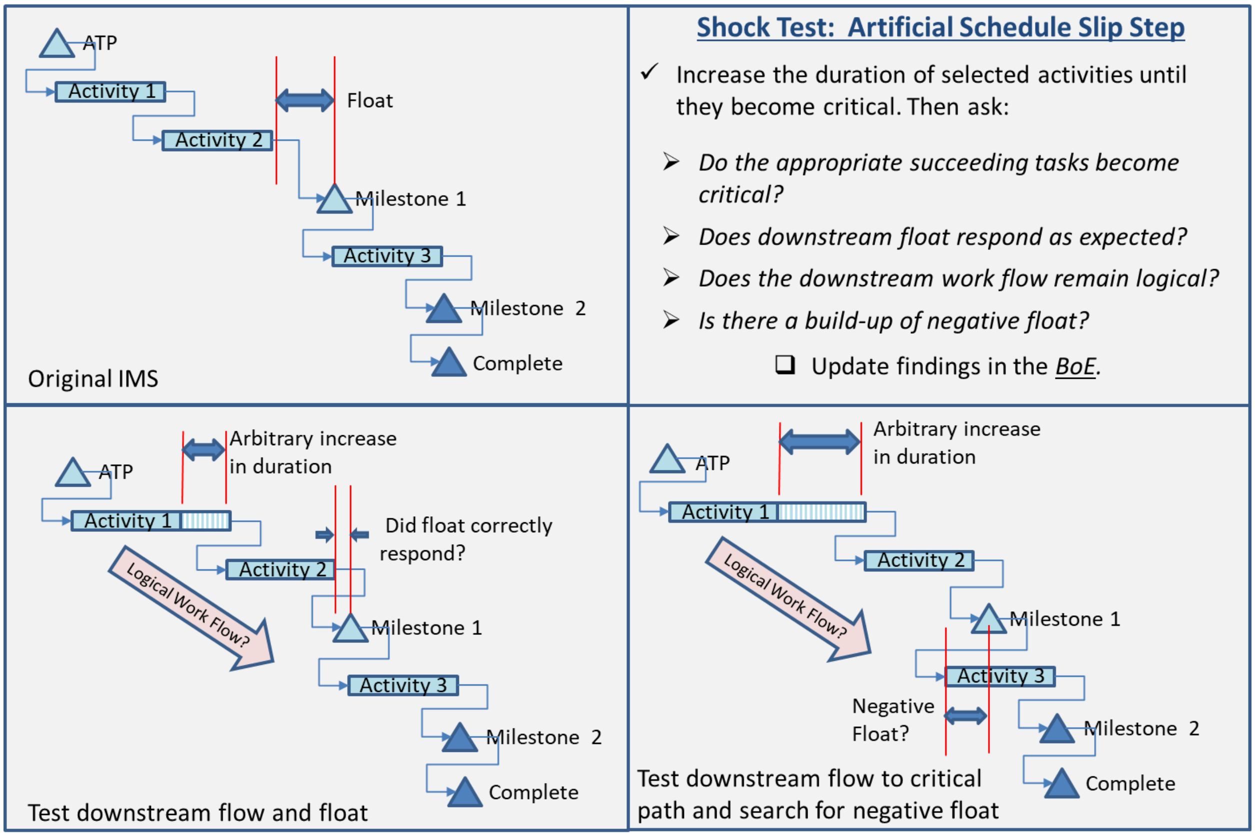
    - Does the confluence of unrelated task strings at node and its effects on float (or 'margin', in some programmatic contexts) make sense? Is the *IMS's* total float affected unexpectedly by these inflowing activities? Were the individual flows rationally derived?

- ✓ **Logic**
    - Are there any obviously incorrect activity relationships? Are all known logic interdependencies amongst segments of work represented within the *IMS*?
    - Are the schedule activities sequenced in a logical manner to complete the given work scope shaped by the P/p's set of requirements? (See *Requirements Check* assessment procedure.)
    - Are the relationship types (such as SS of FF) appropriate for the logical flow in question?
    - Are tasks missing successors? Is there a point where the downstream flow terminates unexpectedly or becomes out of phase with the tasks in that area of the *IMS*? Are hard constraints causing these issues?
- ✓ **Lags**
    - Are lags causing issues with dynamic schedule behavior? Are these lags justifiable?
    - Is their rationale for setting these lags, either positive or negative, to zero duration?
- ✓ **Constraints**
    - Are hard or soft constraints inhibiting the downstream flows? (Filtering for constraints may assist in this investigation.) Are the hard constraints justifiable? Are they causing negative float?
    - Should special exceptions be made for select soft constraints?
    - Should special exceptions be made for select *"Must Start On"* hard constraints distorting the downstream flow? Are they intentional tools that align work with the budget? Could they be expressed in another way?

5. ***Craft a Resolution Plan for All Potential Issues and Record It Within the Schedule Basis of Estimate***
    - ✓ After all investigative efforts have been completed and documented within the schedule *BoE*, the P/S should work with Technical Leads to derive a resolution plan for all remaining issues. The plan should include remediation tasks assigned to the appropriate Technical Leads, durations for remediation tasks, goal targets, a means for recording progress, and a status reporting cadence. The P/S should take great care that the plan is housed within the *BoE* and tracked over time. For major structural issues, the resolution plan should entail execution of a corrective action.
6. ***Repeat this and 1st Tier Assessment Procedures (as necessary), especially the Schedule Health Check***

- ✓ If a large quantity of schedules issues is uncovered and unresolved by dispensatory justification, rerun the *Schedule Health Check* procedure and resolve the resultant issues before reengaging the *Critical Path (and Driving Path) and Structural Check* procedure.

As shown in Figure 6-11, and as with all assessment activities, the *Shock Test* will ultimately result in an update to the issue remediation plan initially rendered by the performance of each 1^{st} Tier assessment iteration. In fact, at this juncture, as suggested above, the completion of the first *Shock Test* may necessitate immediate 1^{st} Tier procedure set revisitation if the results are well below nominal.



Shock Test: Artificial Schedule Slip Step

- ✓ Increase the duration of selected activities until they become critical. Then ask:
  - ➢ *Do the appropriate succeeding tasks become critical?*
  - ➢ *Does downstream float respond as expected?*
  - ➢ *Does the downstream work flow remain logical?*
  - ➢ *Is there a build-up of negative float?*

❑ Update findings in the *BoE*.

Figure 6-11. Illustration of the Increasing Task Durations and the Potential Effects During the Shock Test.

6.2.2.2.1.2   Step 2. Understand and Assess the Deterministic Critical Paths (and Driving Paths)

After the eventual success of the *Shock Test,* the structural integrity of the *IMS* can be mostly affirmed. This naturally enables more focused, prioritized look at the most important part of the schedule, the set of task-to-milestone logical strings comprising the critical paths (and driving paths), both deterministic and stochastic. The P/S should approach deterministic critical paths via three activities: identifying the critical paths and driving paths, understanding them within the largest P/p context, and, similar to other assessment procedures, scrutinizing them in the context of Agency and industry standards.

Understand the Critical Paths (and Driving Paths)

In addition to accurately identifying and verifying the critical path and driving path, it is also important for the P/s to understand those paths. The P/S should pursue the following sets of questions (at a minimum) and related issues when attempting to understand the critical paths:

- ➢ Given the P/p's requirements and contextual information, does the critical path, as well as near-critical paths and driving paths embedded within the *IMS* make sense? Is it misrepresented? Is there a lag between reality and what is captured in the critical path set? Is there content that P/p management is treating as schedule critical that does not appear within the critical path?
- ➢ Does the CP task sequence pass the common-sense test? Does it match the work-flow diagrams that were used to develop the *IMS*? Should the sequencing be modified to align better with P/p realities?
- ➢ Are the critical path, near-critical, paths and driving paths identified in the *IMS* the same as those profiled by P/p leadership? (*Hint:* Sometimes there are differences.) See Figure 6-12 for an example of a typical critical path report that may not actually capture the real critical path as measured within the *IMS*.
- ➢ Does status of accomplished work for activities within the critical path set indicate schedule delays? Do other analyses support this indication? (See the analysis section at the end of this chapter.)
- ➢ Is the amount of float correct and justifiable? Does it make common sense? (Section 6.3.)
- ➢ Could additional shifts accelerate any critical path on time? What is the technical justification? Can work otherwise be performed in parallel to accelerate progress on any critical path?

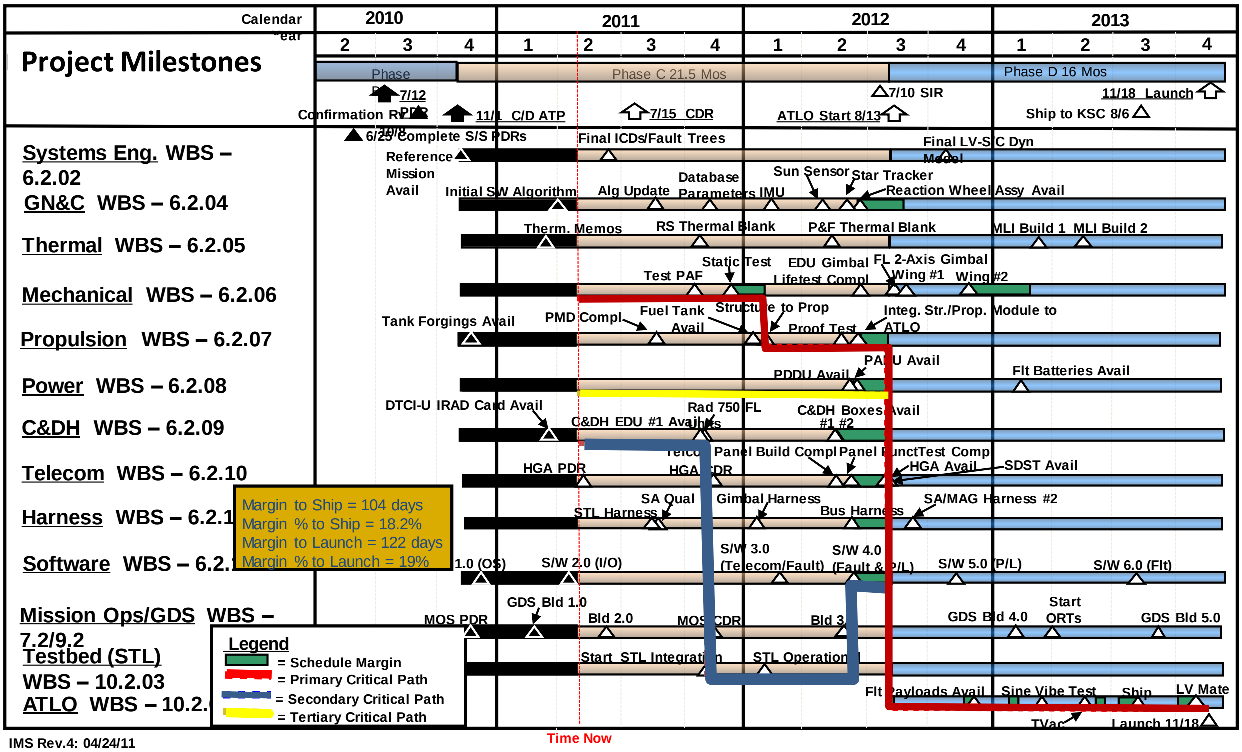


Figure 6-12. An example of the primary, secondary, and tertiary critical paths as reported on a Summary Schedule, which should be verified for accuracy.

This list of inquiry threads, though not exhaustive, should lead the diligent and informed P/S, having performed all the 1st Tier procedures and the *Shock Test* at least once, to uncover all salient aspects of the critical path set. As always, all findings associated with the critical path (and driving paths), including the answers to the above and related questions, should be documented within the schedule *BoE*.

Assess the Critical Paths (and Driving Paths)

Once the P/S understands the critical paths, as well as the near-critical or driving path set, it is appropriate to perform a more focused assessment in the continuing spirit of the *Schedule Health Check* and *Shock Test*. The aim of this pass is for the P/S to further identify potential issues and to recommend improvements to the critical paths' (and driving paths') construction, even if the *IMS* is structurally sound according to the *Shock Test;* there may be certain P/p truths, dynamics, and hard realities not yet captured.

The following sets of assessment areas and exploratory questions necessarily and by design resemble the same general classes examined by the *Schedule Health Check* and *Shock Test* (and other procedures) but relate more specifically to the critical paths, as described below.

Level of Detail and Interdependencies

The level of detail contained within the critical paths (and, by extension, other areas within the *IMS*) is bounded by two conditions: inadequate detail that omits key schedule information and precludes proper dynamic behavior; and an unreasonably heavy level of detail that prevents tractability of the critical paths and *IMS* from a basic data management and analysis standpoint. The P/S should therefore pursue these and related questions:

- Does the level of detail reflected within the critical path, near-critical paths, and driving paths help the *IMS* to achieve its full informational potential? Do these paths maintain a standard of tractability that supports insight-generation while also preserving meaningful fidelity to the rich set of schedule data that drives them?
- Is the level of detail adequate so that task interface points can be identified to support accurate interdependency assignments?
- Do the critical path, near-critical paths, and driving paths support traceability by including task durations that reasonably short, meaningful, and allow for discrete progress measurement?

    The GAO standard regarding the phenomenon of inadequate level of detail contained within the critical paths and *IMS* as a whole is simple:

    The detail should be sufficient to identify the longest path of activities through the entire program.[90]

- Is the critical path, as well as the near-critical and driving path set, sufficiently summarized to support schedule understandability and intelligibility?

---

[90] GAO-16-89G. GAO Schedule Assessment Guide. Page 11. December 2015. http://www.gao.gov/assets/680/674404.pdf

- Do the identified critical path, near critical paths, and driving paths reflect an excessive amount of low-level complexity? Does this betray the utility of the *IMS* in meeting program management and policy demands?
- Are the critical paths so heavy with detail that they require the schedule team to maintain supplementary schedules that are treated as authoritative?

  The GAO position on the phenomenon of intractable level of detail contained within the critical paths and *IMS* as a whole is clear:

  > *The schedule should not be so detailed as to interfere with its use.*[91]

Risks

- Are the critical paths constructed in a way that supports the identification and application of risks? Should its resolution increase to support proper risk placement?
- Are there risks missing from the critical paths?
- Are there risks misplaced within the *IMS's* logic network that should affect the critical paths?

Lags and Gaps

- Are there any gaps in time between critical path tasks that cannot be explained?
- Does the justification associated with the lags that remain within the critical paths' logic valid? The P/S should use special caution when scrutinizing and accepting the justification for these items.

Float and Margin

- Are margin tasks part of the critical path? What is their justification? What is the schedule owner's argument against their removal? What is driving it? Is it valid?
- Do the structure and flow of the critical paths allow for accurate calculation of float (or margin, in some programmatic contexts)? Do all critical interdependencies, constraints, and task lengths support true understanding of float?
- Is the critical path's quality sufficient to support reliable Schedule Risk Analysis and its measurement of float?

Task Types

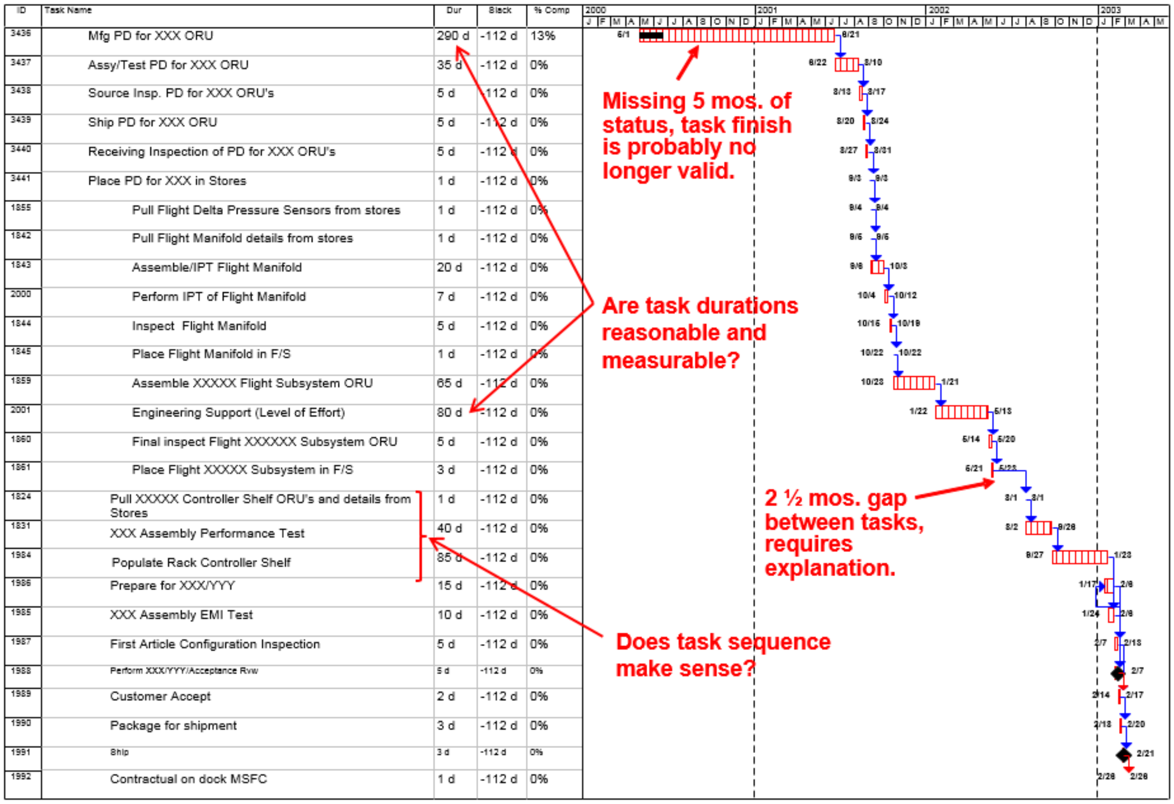
- Are there LOE tasks embedded within the critical paths? What is the justification for not removing them?

Regardless, all questions, answers, investigative notes, and related assessment information regarding the critical path set should be recorded within the schedule *BoE*. It may also help the P/S, when

---

[91] GAO-16-89G. GAO Schedule Assessment Guide. Page 16. December 2015. http://www.gao.gov/assets/680/674404.pdf

coordinating with Technical Leads, to mark the critical paths for further investigation, as shown in the Figure 6-13 and Figure 6-14. These types of markings should also be included in the schedule *BoE*.



ID	Task Name	Dur	Slack	% Comp
3436	Mfg PD for XXX ORU	290 d	-112 d	13%
3437	Assy/Test PD for XXX ORU	35 d	-112 d	0%
3438	Source Insp. PD for XXX ORU's	5 d	-112 d	0%
3439	Ship PD for XXX ORU	5 d	-112 d	0%
3440	Receiving Inspection of PD for XXX ORU's	5 d	-112 d	0%
3441	Place PD for XXX in Stores	1 d	-112 d	0%
1855	Pull Flight Delta Pressure Sensors from stores	1 d	-112 d	0%
1842	Pull Flight Manifold details from stores	1 d	-112 d	0%
1843	Assemble/IPT Flight Manifold	20 d	-112 d	0%
2000	Perform IPT of Flight Manifold	7 d	-112 d	0%
1844	Inspect Flight Manifold	5 d	-112 d	0%
1845	Place Flight Manifold in F/S	1 d	-112 d	0%
1859	Assemble XXXXX Flight Subsystem ORU	65 d	-112 d	0%
2001	Engineering Support (Level of Effort)	80 d	-112 d	0%
1860	Final inspect Flight XXXXXX Subsystem ORU	5 d	-112 d	0%
1861	Place Flight XXXXX Subsystem in F/S	3 d	-112 d	0%
1824	Pull XXXXX Controller Shelf ORU's and details from Stores	1 d	-112 d	0%
1831	XXX Assembly Performance Test	40 d	-112 d	0%
1984	Populate Rack Controller Shelf	85 d	-112 d	0%
1986	Prepare for XXX/YYY	15 d	-112 d	0%
1985	XXX Assembly EMI Test	10 d	-112 d	0%
1987	First Article Configuration Inspection	5 d	-112 d	0%
1988	Perform XXX/YYY/Acceptance Rvw	5 d	-112 d	0%
1989	Customer Accept	2 d	-112 d	0%
1990	Package for shipment	3 d	-112 d	0%
1991	Ship	3 d	-112 d	0%
1992	Contractual on dock MSFC	1 d	-112 d	0%

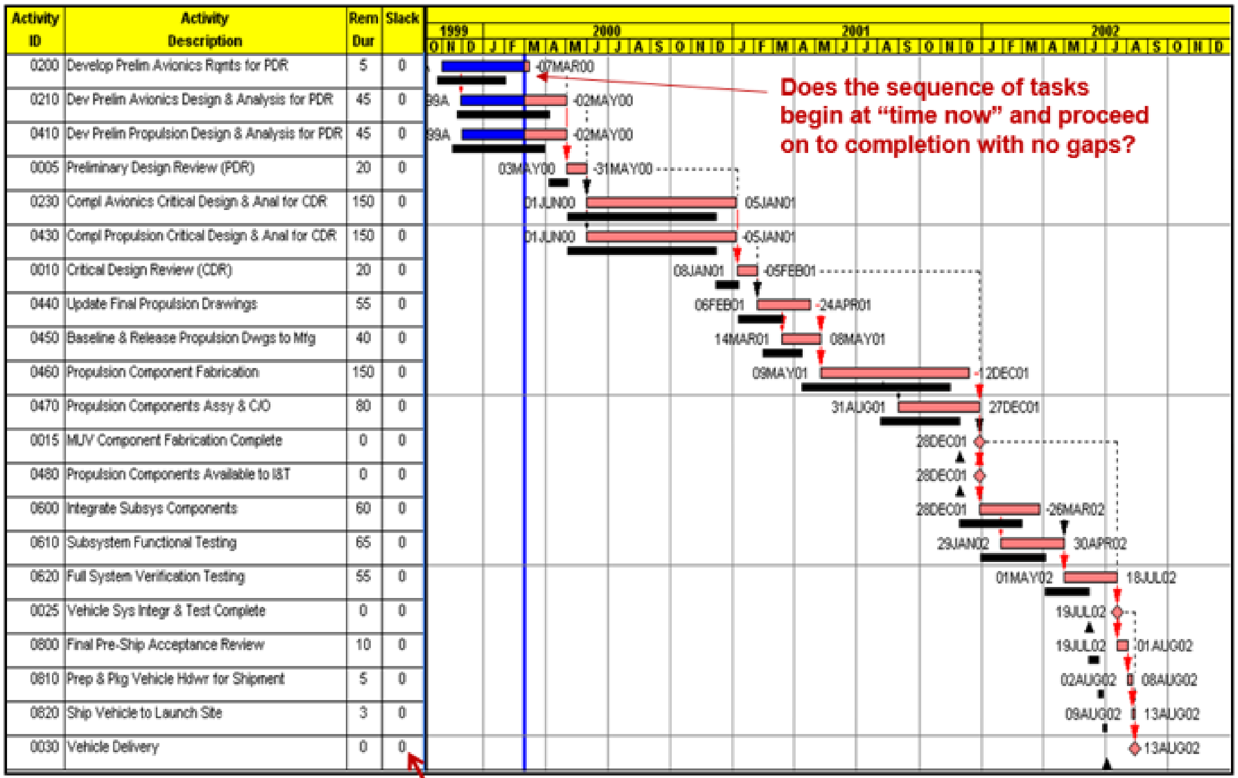
Missing 5 mos. of status, task finish is probably no longer valid.

Are task durations reasonable and measurable?

2 ½ mos. gap between tasks, requires explanation.

Does task sequence make sense?

Figure 6-13. An example of a schedule report marked up by the P/S with feedback for Technical Lead consideration.



Activity ID	Activity Description	Rem Dur	Slack
0200	Develop Prelim Avionics Rqmts for PDR	5	0
0210	Dev Prelim Avionics Design & Analysis for PDR	45	0
0410	Dev Prelim Propulsion Design & Analysis for PDR	45	0
0005	Preliminary Design Review (PDR)	20	0
0230	Compl Avionics Critical Design & Anal for CDR	150	0
0430	Compl Propulsion Critical Design & Anal for CDR	150	0
0010	Critical Design Review (CDR)	20	0
0440	Update Final Propulsion Drawings	55	0
0450	Baseline & Release Propulsion Dwgs to Mfg	40	0
0460	Propulsion Component Fabrication	150	0
0470	Propulsion Components Assy & C/O	80	0
0015	MJV Component Fabrication Complete	0	0
0480	Propulsion Components Available to I&T	0	0
0600	Integrate Subsys Components	60	0
0610	Subsystem Functional Testing	65	0
0620	Full System Verification Testing	55	0
0025	Vehicle Sys Integr & Test Complete	0	0
0800	Final Pre-Ship Acceptance Review	10	0
0810	Prep & Pkg Vehicle Hdwr for Shipment	5	0
0820	Ship Vehicle to Launch Site	3	0
0030	Vehicle Delivery	0	0

Does the sequence of tasks begin at "time now" and proceed on to completion with no gaps?

Are Slack (float) values consistent?

No LOE, Summary, or Support Tasks!

Figure 6-14. An example of a questions the P/S might consider when assessing the critical (and driving) paths.

Exit Criteria. The *Critical Path and Structural Check* procedure is satisfied when the P/S has completed the following tasks:

- ✓ Perform a *Shock Test* on the IMS to verify its overall structural integrity via horizontally traceability and proper dynamic behavior.
- ✓ Identify, understand, and assess the deterministic critical paths.
- ✓ Mark the *BoE* with each data source's date according to the current schedule and assessment iterations. Alongside this, include the next steps of schedule evolution and a corrective action recommendation when organic schedule improvement is not sufficient.

Procedure Maturation. This procedure, as suggested above, should be performed after the 1st Tier procedures begin to render favorable results. In anticipation of analytical products that support management decisions and policy requirements, the structural integrity of the *IMS* should be maximized prior to SDR, so the *Critical Path and Structural Check* should be iterated as necessary. Additionally, the check should be executed on a regular basis after SDR since the P/p's critical paths will change over time and should be measured for performance. Regardless of the moment in the life cycle during which this check is performed, the types of assessments will remain consistent, with the amount of content pursued increasing over time until late in the life cycle. As the P/p progresses, the narrative within the schedule *BoE* should be augmented such that, at P/p completion, it contains the full narrative of critical path and structural evolution of the *IMS* from inception to retirement.

6.2.2.2.2 Procedure 5. Basis Check

It is a best practice for Basis Checks to be routinely performed to affirm the quality of the estimate associated with each discrete schedule element.

Assessment Questions Addressed:

- Reliability Dimension: Realism
  - Sub-dimension: Justification of Discrete Schedule Elements
    - *Is the analogical, performance, or expert-rendered basis for every discrete structural element justified cogently?*
    - *Is schedule progress measured against the baseline?*
    - *Are changes from previous versions of the schedule adequately explained?*
  - Sub-dimension: Schedule Risk & Opportunity Treatment
    - *Are all significant probabilistic schedule events identified?*
    - *Is their placement within the IMS's structure well-understood?*

P/Ss, having made iterative attempts to affirm the scope, health, risk posture, and structural integrity of the *IMS* may now turn their attention towards understanding the DNA or basis of a schedule estimate. A schedule is simply an estimate forecast extending into the future and, as such, is nothing more than a collection of estimated elements each with a basis rationale. The basis for each of these schedule elements is extraordinarily important for measuring schedule *reliability*; the *IMS*, even having satisfactorily passed the preceding and succeeding assessment procedures, has very little meaning if strong rationale is not associated with all elements.

The role of the P/S herein is to measure the realism associated with each schedule element and, in turn, the amalgamation of the elements into an integrated whole. This approach is more nuanced than it may appear; the P/S's priority should be not to use the measure to apply a strict grade against the *IMS* but, rather to help the P/p improve the schedule's *reliability* by enhancing its realism as much as possible. This is done by providing an evolutionary path of progressive improvement over time. Best among the various strategies for assessing and evolving the collection of schedule basis rationale is to establish priorities for each procedure iteration, instead of attempting to assess all schedule element at once. In this way, focus areas such as the critical paths can take precedence and receive repeated scrutiny alongside new areas of interest with each successive assessment cycle.

The progressive development of robust schedule basis rationale through iterative performance of the *Basis Check* supports continuous Schedule Management because, to a degree deeper than the other assessment procedures, it strikes at the foundational truths of a P/p's activity at its schedule's deepest levels. Ultimately, a clear capture of realism should be the paramount goal of the P/S.

For each schedule element, the P/S should record within the schedule *BoE* the quality of source data and the method that uses that data to derive each of the element's parameters, such as duration, linkages, constraints, mapped risks, and any other element characteristic. The burden of proof is on P/p personnel, programmatic and technical, to defend the quality of their choices as manifested in the basis rationale for each element. In every case, the P/S should ensure that every element's basis rationale is fully and clearly traceable to underlying source material such as tools, techniques explanations, estimating methodology, supporting data, all of which should be included within the *BoE*.

The assessment of basis rationale is a considerably demanding effort that cannot be completed at once, especially when the P/p and its schedule are undergoing peak maturation. As such, the P/S should prioritize areas of interest (perhaps, for example, beginning with top schedule risks or the primary critical path) and progress deliberately over *Basis Check* iterations in concert with the other assessment procedures.

For any of the schedule estimating techniques, as described in Section 5.5.9.3, the P/S should judge methods and data used, marking shortcomings within the *BoE* and suggesting a plan for the incorporation of alternative estimating approaches as appropriate. In some extreme cases, a corrective action may be necessary to facilitate changes to the *IMS* if the new estimating method or data sources warrant.

As mentioned, estimating methods can be applied at different levels of a schedule simultaneously, a possibly useful but delicate technique. The P/S should always refer to the most elementary standard against which basis rationale should be measured: the *replicability* of the *IMS*. Given only the part of the *BoE* containing the aggregation of element basis rationale and reference data, a reasonably skilled P/S should be able to recreate the entire *IMS*. This criterion is most often applied to cost estimating as a measure of estimate *reliability* and has been adopted herein as an analogous standard against which P/Ss should always measure rationale quality.

Exit Criteria. The *Basis Check* procedure is satisfied when the P/S has completed the following tasks:

- ✓ Prepare the schedule basis of estimate to capture for element basis rationale.
- ✓ Assess each schedule element's basis rationale.
- ✓ Mark the *BoE* with each data source's date according to the current schedule and assessment iterations. Alongside this, include the next steps of schedule evolution and a corrective action recommendation when organic schedule improvement is not sufficient.

Procedure Maturation. Assessment of schedule elements' basis rationale as captured within the *BoE* should be performed routinely throughout the P/p's life cycle, similar to other assessment procedures. It is important for this particular assessment campaign to be launched during Schedule Development, as detailed in Section 5.5.9, since it may have the most influence on schedule element parameters as they are being derived for the first time. Once a schedule is baselined, the P/S should consider the *Basis Check* to command less but still considerable influence on schedule evolution.

Performance assessment of schedule element parameters is critical in completing the narrative of the *IMS's* evolution and supporting earnest reporting to management. This check should serve as the foundation for task duration growth and slippage assessment over time, as well as schedule risk mitigation performance assessment. Chapter 7 contains a thorough discussion of performance assessment and its role in Schedule Management.

6.2.2.2.3 Procedure 6. Resource Integration Assessment

It is a best practice for Resource Integration Check to be routinely performed to affirm that the P/p's budget, workforce, and cost estimates map to the P/p IMS.

Assessment Questions Addressed:

- Reliability Dimensions: Affordability
  - Sub-dimension: Resource & Cost Integration with Schedule
    - ➢ *Are resources and cost estimates mapped appropriately to schedule elements?*

The P/S, in support of *ICSRA* and the higher tier assessments that it fuels, should perform a simple but important assessment procedure pertaining to the meld between the P/p's financial and schedule domains. The P/p's resource suite, comprised of budget streams, workforce profiles, allocated UFE, and related elements, should reflect self-consistent time phasing. Once the P/S has verified this by inspection, he or she must affirm through deeper investigation that these elements map cleanly to the *IMS*, demonstrate clear mutual traceability, and tie to the same P/p snapshot in time.

Though both flow from P/p plans and requirements, the financial and schedule complexions may evolve independently, especially when content is added or deleted from the technical portfolio. The P/p must document within its *BoE* evidence supporting the robustness of the linkage amongst these programmatic components and that change, from, for example, a schedule performance issue, does not perturb their alignment. The P/S must evaluate and record the strength of this linkage within the *BoE*.

(The assessment of time-phased budget adequacy given the *IMS* temporal work flow is not part of this assessment procedure; refer to the *ICSRA* in Section 6.3.2.4 for more information.)

Exit Criteria. The *Resource Integration Check* procedure is satisfied when the P/S has completed the following tasks:

- ✓ Verify the robust linkage between the P/p's financial and schedule domains.
- ✓ Mark the *BoE* with each data source's date according to the current schedule and assessment iterations. Alongside this, include the next steps of schedule evolution and a corrective action recommendation when organic schedule improvement is not sufficient.

Procedure Maturation. As the P/p proceeds through formulation, it may take dedicated attention for its PP&C office to align the cost and schedule domains. Regardless, this effort should be completed prior to the initial baseline. Thereafter, the P/S should continuously check the status of the P/p's given resources, curated cost estimates, and their explicit mapping to the *IMS* by programmatic personnel.

6.2.3 Exit Criteria for the Assessment Sub-function

Having performed the 1st and 2nd Tier assessment procedures over several iterations, the P/S and the P/p's programmatic team will have amassed a considerable load of information in the *BoE*. A single iteration of the Schedule Assessment sub-function can be considered satisfied when the P/S has completed the following tasks:

- ✓ Complete all assessment procedures in tier order at least once (though it is unlikely that a linear path through these activities is possible).
- ✓ Mark the *BoE* with each data source's date according to the current schedule and assessment iterations. Alongside this, include the next steps of schedule evolution and a corrective action recommendation when organic schedule improvement is not sufficient.

The Schedule Assessment sub-function is never fully satisfied due to the interminable string of changes that will befall the P/p. These will inevitably induce changes that will ripple throughout the *IMS*. Additional perspectives that guide explorations related to Schedule Assessment can be gleaned from Schedule Analysis as described in the following section.

6.3 Analyze the Schedule

In this handbook, the Schedule Analysis sub-function denotes the process of performing a *Schedule Risk Analysis (SRA)*. *SRA* is an important process that analyzes the potential impact of schedule duration uncertainties and discrete risks on the P/p plan, reflected in the *IMS*, to evaluate the likelihood that the P/p plan is achievable within the planned finish date constraints. It is also worth noting that if EVM is required on a P/p, an *SRA* can support standard cost-based EVM metrics by providing a risk-informed, schedule-based performance indicator of the likelihood that the P/p will finish on time. *Integrated Cost and Schedule Risk Analyses (ICSRAs)* are an extension of *SRAs* that incorporate P/p costs to go a step further and help determine the adequacy of the budget, given the P/p schedule and risks. The results from these analyses provide management with insight on how to prioritize resources to address driving risks.

Specifically, Schedule Analysis addresses the questions:

- "Will it deliver the product on cost and on schedule with acceptable risk?"
- "How can we best reduce, mitigate, avoid, or accept schedule risks?"
- "How do we prioritize our risk mitigation efforts?"
- "Have we set aside sufficient margin to accommodate expected and unexpected risks?"
- "What tools/guides are available to assess schedule risk?"

6.3.1 Prerequisites

Schedule Analysis can be initiated when:

- The *SMP* sub-plan, *Schedule Assessment and Analysis Plan,* which specifies the analysis methods performed to understand the projected future performance of the planned schedule given the associated uncertainty and risk, is available
- Analysis ground-rules and assumptions are available
- Pre-planned initiating event or special request has occurred
- If *SRA*:
    - An *IMS* or an *Analysis Schedule* is available

  - Task duration uncertainties are available
  - A discrete risk list is available, current, and complete, and there is clarity regarding risk mitigation planning and funding
  - If EVM is being performed, EVM reports are available
- If *ICSRA*, all the above plus:
  - A cost estimate is available
  - Cost uncertainties are available
  - Cost risks, including liens, encumbrances, threats, and sunk costs are available

6.3.2 Perform Schedule Analysis

Schedule Analysis, whether with the intent of developing an *SRA* or an *ICSRA*, often starts with a pre-planned initiating event such as a major P/p review, a routine monthly/quarterly review, or a special request when a P/p is experiencing issues that may impact the schedule. However, P/ps may opt to perform *SRAs/ICSRAs* on a more frequent or routine basis to serve as both proactive risk management and schedule management techniques.

The *SRA* utilizes the *IMS*, or the *Analysis Schedule* if available, as its foundation and captures both uncertainties and discrete risks. The *SRA* analyzes the potential impact of uncertainties and risks on the duration of the activities in the *IMS* and calculates the probability distributions for selected activity completion dates. Thus, *SRAs* can help facilitate meeting the NPR 7120.5 and NPD 1000.5 requirements to produce Schedule Completion Ranges, also referred to as Schedule Range Estimates, and Schedule Confidence Levels or Joint Cost and Schedule Confidence Levels (*JCLs*) at the applicable P/p milestones.[92] Figure 6-15 illustrates the two types of schedule analyses that are performed: *SRA* and *ICSRA*.

---

[92] In addition to the NPR 7120.5 and NPR 1000.5 requirements, the NASA Associate Administrator issued a guidance memo on JCL Requirements Updates on May 24, 2019 for all projects and Single-project Programs with an LCC of $1 billion or more. https://www.nasa.gov/sites/default/files/atoms/files/jcl_memo_5-24-19tagged.pdf

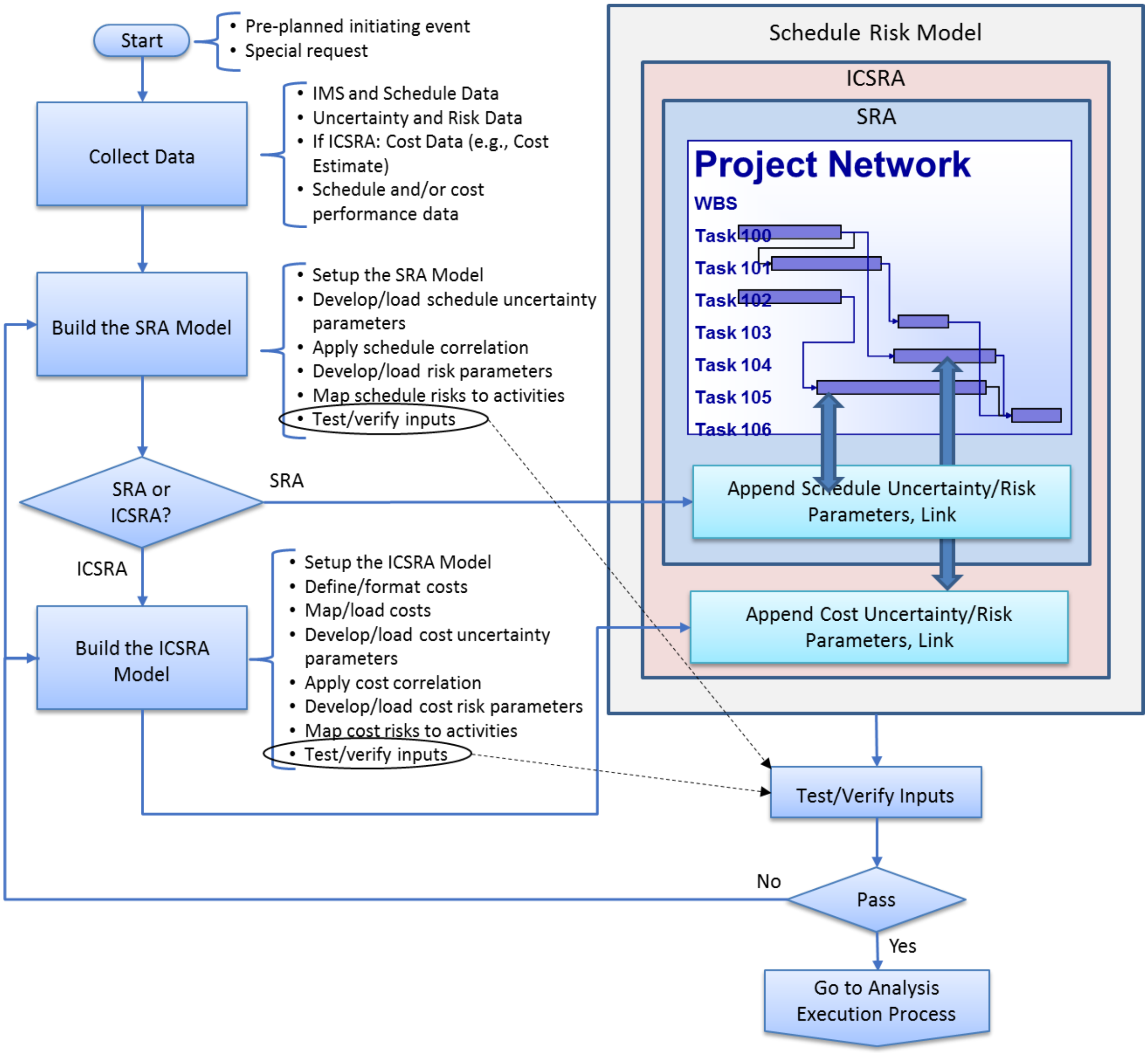


Figure 6-15. The SRA differs from the ICSRA only by the addition of costs and cost risks. In addition to the risk-informed schedule outputs from an SRA, the ICSRA will also provide risk-informed cost outputs.

As noted in the introduction to this chapter, Schedule Analysis also supports overall schedule *reliability* for Schedule Assessment according to the 3rd Tier shown in Figure 6-6.

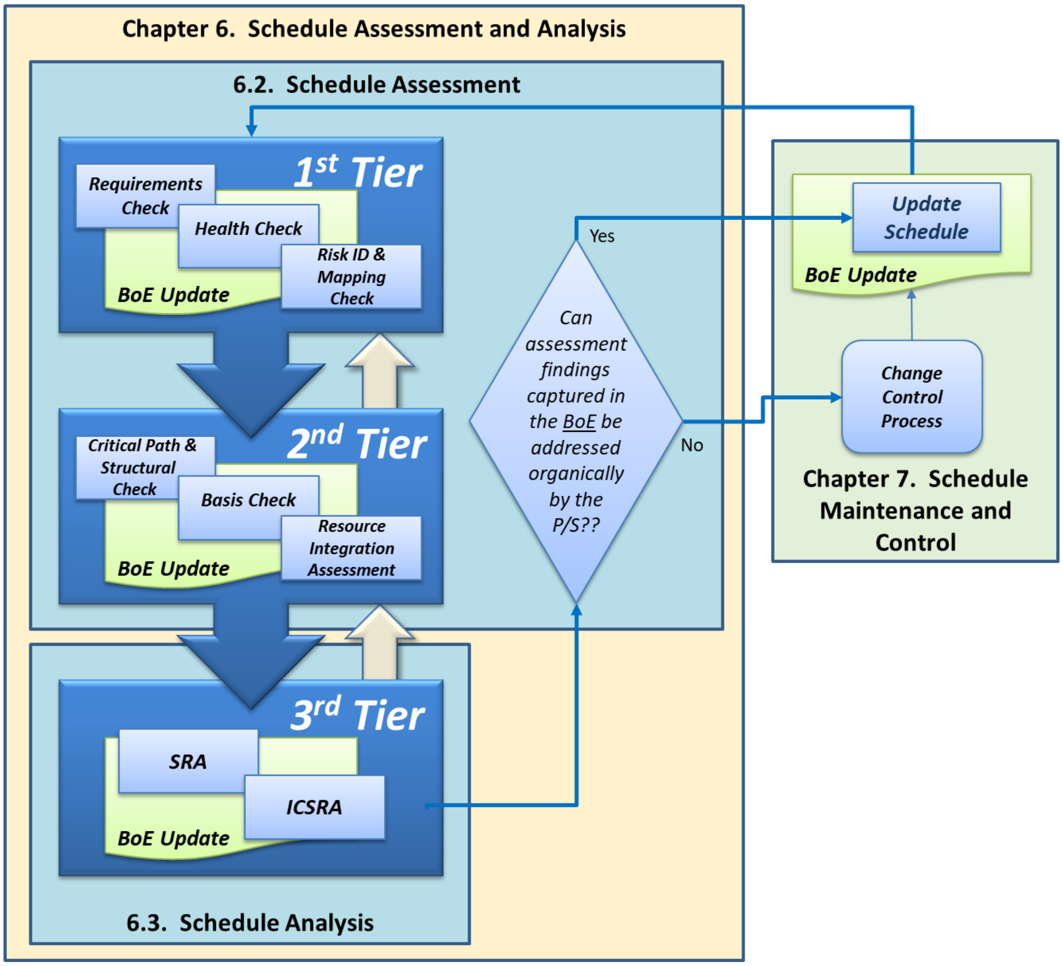


Figure 6-16. Overview of the Schedule Analysis (and Assessment) process.

SRA-based Assessment Questions Addressed:

- Reliability Dimensions: Comprehensiveness, Construction, Realism
  - Sub-dimension: Schedule Margin Sufficiency
    - ➢ *Given schedule uncertainty, risks, and potential future schedule cases, are the magnitude and allocation of schedule margin sufficient?*

SRAs are not limited to providing only confidence levels and determining margin sufficiency. For instance, *SRAs* are the basis for a variety of useful analysis when the P/p wants to understand:

- Schedule options based on alternative workflows or alternative technical options (e.g., Analysis of Alternatives)
- The probability of meeting the planned schedule or finishing the P/p on time given the associated uncertainties and discrete risks (i.e., Schedule Confidence Levels or Completion Range Estimates)

- Uncertainty and risk drivers, as well as risk prioritization for mitigation activities (e.g., Risk Sensitivity Analysis for Risk Prioritization)
- "Most likely" critical/driving path(s) given associated risks and uncertainties (e.g., Stochastic Critical Path(s))
- The potential impact of uncertainties and discrete risks on schedule margin (e.g., Allocation and Sufficiency of Margin)
- Risk-informed forecasting changes over time (e.g., Risk-based Trend Analysis)

ICSRAs involve the addition of a cost model and additional cost uncertainties and risks to the *SRA Model*. The *ICSRA* analyzes the impact of risks on the duration of the activities and the costs loaded in the *IMS* and calculates the probability distributions for selected activity completion dates as well as the probability distributions for the costs of selected activities and/or cost at completion. For space flight and information technology P/ps, NPD 1000.5 establishes the required cost and schedule *JCL* expected for P/p baseline and rebaseline plans. The *JCL* indicates the probability that P/p costs will be equal to or less than the targeted cost *and* that the schedule will be equal to or less than the targeted schedule date. PMs must establish the necessary processes that enable them to determine if their implementation plans are compliant with the cost and schedule *JCL* requirements. The *ICSRA* facilitates meeting the *JCL* requirement by combining a P/p's cost, schedule, and risk into a fully integrated management tool. This analysis, and its resulting *JCL*, helps inform management of the likelihood of a P/p's programmatic success.

ICSRA-based Assessment Questions Addressed:

- Reliability Dimension: Affordability
    - Sub-dimension: Resource & Cost Integration with Schedule
        - *Are resources and cost estimates mapped appropriately to schedule elements?*
    - *Sub-dimension: Schedule Risk Mitigation & Consequence Affordability*
    - *Sub-dimension: Phased Affordability*
        - *Does the schedule cohere with the P/p's financial reality?*

An *ICSRA* is useful when the P/p wants to understand:

- The probability of meeting both the planned cost and the planned schedule given the associated uncertainties and risks (e.g., *JCL* Analysis)
- The potential impact of uncertainties and discrete risks on funding and UFE (e.g., Funding/Reserves Analysis)

The *Analysis Execution* that details these different analyses is covered in Section 6.3.2.5.

6.3.2.1 Ensure SRA Tool Capabilities

It is a best practice for the SRA/ICSRA to be developed using appropriate tools. At a minimum, the *SRA* tool should:

1. Be compatible with common scheduling tools used by NASA.
2. Support the loading of duration uncertainty probability distributions for every activity in the schedule, excluding summary activities.
3. Support the loading of discrete risk likelihoods and duration impact probability distributions for every activity in the schedule, excluding the summary activities.
4. Support the loading of TD and TI discrete risk likelihoods and impact probability distributions for every cost parameter in the model.
5. Provide the capability to calculate cost inflation as indexed by year.
6. Support the loading of a correlation factor for every duration probability distribution loaded in the simulation model.
7. Output the following data:
    a. A data sheet that tabulates the duration inputs and outputs for every iteration.
    b. A PDF and a CDF data table and plot for every activity in the simulation model.
    c. Tornado data tables and charts that correlate risks and uncertainties with activity durations and ranks them in the tornado chart display.
    d. The calculation and display of the percentage of times that an activity was on the critical path.

If performing an *ICSRA*, the tool should also:

1. Support loading TD and TI cost values for every activity in the schedule.
2. Support the loading of TD and TI cost uncertainty probability distributions for every cost parameter in the model.
3. Provide the capability to calculate cost inflation as indexed by year.
4. Support the loading of a correlation factor for every cost probability distribution loaded in the simulation model.
5. Output the following data:
    a. A data sheet that tabulates the cost and schedule pair inputs and outputs for every iteration.
    b. A PDF and a CDF data table and plot for every activity and associated cost in the simulation model.
    c. Tornado data tables and charts that correlate risks and uncertainties with activity durations and activity costs and ranks them in the tornado chart display.
    d. The calculation and display of the percentage of times that an activity was on the critical path.
    e. A scatterplot of that shows the simulated outcomes of the *ICSRA*, where each dot in the scatterplot represents a specific result, or scenario, from the simulation calculation.

SRA/ICSRA tools often provide additional capabilities that are quite useful, although not always required. These additional capabilities should be considered when making a selection, as they may aid in P/p decision making. NASA has an Agency license agreement for two tools – JACS and Polaris – which are both available on the ONCE database.[93] It is a recommended practice that all *SRAs* and *ICSRAs* be performed on one of the NASA-provided tool platforms. The capabilities of these tools, along with other commonly-used NASA tools, are captured in the NASA Schedule Management Tools Matrix.[94]

6.3.2.2 Collect Data

It is a best practice for the programmatic products and data utilized to perform the SRA (or ICSRA) to provide an adequate representation of the P/p plan and be consistent with respect to their status dates. The programmatic products and data needed for the *SRA* are:

- *IMS* or *Analysis Schedule*
- Risk list & uncertainty data
- Schedule performance data
- If performing an *ICSRA*: Cost estimate and cost performance data

The two most important things to consider about the data collected for the analysis are:

1. Consistency. The data must be consistent. If the *IMS/Analysis Schedule*, risk list, and cost data are inconsistent with each other, then it will be difficult for the Schedule Analyst to map programmatic inputs to the model. Inconsistencies can be found when using different WBSs for cost and schedule data, if the level of detail represented in the *Analysis Schedule* does not allow for accurate representation of the risks, or if there is a lack of traceability between other cost and schedule inputs. If the EVM data is to be used to estimate uncertainties, then it must be consistent with the cost and the schedule inputs. What is meant here is that using performance data for uncertainty estimates for future performance needs to be carefully done with respect to the integrated baseline, or PMB. Sometimes the baseline will be updated to adjust for a history of low performance as reported through the EVM. When that occurs, the EVM performance data needs adjusting to account for the changes in the baseline before future uncertainty estimates are developed for the *SRA Models*. As simple as this sounds, it is common for the Schedule Analyst to be provided inconsistent data sets that must be reconciled.

2. Configuration Control. Maintaining consistency between collected data sets and the iterations of the *SRA Model* is the responsibility of the Schedule Analyst. The Monte Carlo simulation tool used for the analysis is simply a mathematical machine that operates on the inputs to produce outputs. The wisdom of the analysis comes from the thoughtful manipulation of the inputs and observance of the outputs to determine sensitivities of the P/p schedule to the inputs (e.g., uncertainties and risks). Hence, careful configuration control of the inputs and the *SRA Model* version is critical for traceability to the outputs.

---

[93] One NASA Cost Engineering (ONCE) Database. https://oncedata.hq.nasa.gov/

[94] NASA Schedule Management Tool Matrix. https://community.max.gov/display/NASA/Schedule+Management+Tools

6.3.2.2.1 Procedure 1. Collect Schedule Data and Ensure Suitability for Analysis

If the Schedule Analyst is also the P/S, then retrieving the appropriate schedule and schedule-related data should be relatively simple as the P/S typically maintains these products. If the Schedule Analyst is external to the P/p (e.g., support staff brought in to develop an *SRA*, an independent assessor, etc.), coordination will need to take place with the P/S and/or approved P/p management team staff to ensure that the "right" schedule and schedule-related data is retrievable. Ultimately, it is up to the PM to determine which version (i.e., time stamp) of the schedule to use as the basis for the analysis; however, it is a recommended practice to collect the most current schedule and schedule-related data available, keeping in mind the ability to ensure consistency with other programmatic products.

6.3.2.2.2 Procedure 2. Collect Uncertainty and Risk Data and Ensure Suitability for Analysis

NPR 8000.4 describes risk as being concerned with uncertainty about future outcomes. Risk is the potential for shortfalls with respect to achieving explicitly established and stated objectives. As applied to P/ps, these objectives are translated into performance requirements, which may be related to institutional support for mission execution or related to any one or more of the following domains:

- Safety
- Mission Success (Technical)
- Cost
- Schedule

As such, uncertainties and risks affecting the schedule can arise from several sources, including:

- Lack of a realistic schedule developed to a level of detail that accurately reflects how the work will be done, with fully developed work scopes and sequential logic. Schedules should not simply be devices intended to reassure everyone that the P/p will be completed on time.
- Inherent uncertainty of the work arising from advanced technology, design and manufacturing challenges, and external factors including labor relations, changing regulatory environment, and weather
- Complexity of P/ps, which requires coordination of many contractors, suppliers, government entities, etc.
- Estimates prepared in early stages of a P/p with inadequate definition of the work to be performed, and inaccuracies or optimistic bias in estimating activity durations
- Over-use of directed (constraint) dates, perhaps in response to competitive pressures to develop aggressive, unrealistic schedules
- P/p management strategies favoring late starts ("just-in-time") scheduling or "fast track" implementation

- Lack of adequate float or management reserve[95]

For the purposes of this handbook, and specifically for the *SRA/ICSRA* processes, the focus of all uncertainty and risk discussion will pertain to those affecting programmatics. In alignment with NASA's other PP&C guidance documents (e.g., NASA Cost Estimating Handbook, etc.), programmatic risk and uncertainty are defined as follows:

- **Uncertainty.** Uncertainty is the indefiniteness about a P/p's baseline plan. It represents the fundamental inability to perfectly predict the outcome of a future event. Uncertainty is characterized by a probability distribution, which is based on a combination of the prior experience of the assessor and historical data.[96]
- **Risk.** Risk is the combination of the likelihood and the consequence(s) of a future undesired event or scenario occurring. Uncertainties are included in evaluation of likelihood (probability of occurrence) and consequence.[97]

6.3.2.2.2.1 Step 1. Gather the Uncertainties

Schedule activity durations and costs associated with the activities should include uncertainty in reference to the current version of the P/p plan, whether an initial plan or the P/p baseline. As part of the documentation of the *BoEs*, the P/p has captured activity duration and cost uncertainties. The Schedule Analyst can incorporate the uncertainty information documented in the *BoEs* into the *SRA*, making certain to ensure that the justification for the uncertainty ranges/inputs still holds true. Other examples of inputs to such uncertainty factors can be historical data, Subject Matter Expert (SME) opinion, or past performance data. For more details see Section 6.3.2.3.2.

6.3.2.2.2.2 Step 2. Gather the Discrete Risks

The first part of this step is to verify with the Risk Manager that the risk information in the RMS is of sufficient quality to support the analyses. Section 6.2.2.1.3 provides a checklist of questions that the Schedule Analyst should review with respect to the P/p's risk management process and RMS to ensure that there is a reasonable expectation of a quality risk list. If there are any shortfalls resulting from the quality assessment, they should be corrected prior to completion of the analysis.

The risk identification step should be robust enough that it fully characterizes the risk and its impacts. At a minimum, the Schedule Analyst should be able to:

- **Include all risks.** It is common for P/ps to capture only the top *x* number of risks, or perhaps just red and yellow risks. However, for a successful and informative *SRA* (or *ICSRA*), including all identified risks provides a more holistic view and may provide insight on where clusters of risks

---

[95] Hulett, D. T. "Project Schedule Risk Assessment." PMI. Project Management Journal, 26(1). Pages 21-31. https://www.pmi.org/learning/library/project-schedule-risk-assessment-2034

[96] NPR 8000.4 defines uncertainty as, "An imperfect state of knowledge or a variability resulting from a variety of factors including, but not limited to, lack of knowledge, applicability of information, physical variation, randomness or stochastic behavior, indeterminacy, judgment, and approximation."

[97] NPR 8000.4 defines risk as, "Risk is the potential for shortfalls with respect to achieving explicitly established and stated objectives. As applied to P/ps, these objectives are translated into performance requirements, which may be related to mission execution domains (safety, mission success, cost, and schedule) or institutional support for mission execution."

may impact the schedule. In addition, Agency resources such as historical CADRe data capture historical P/p risks that may be helpful in ensuring a more complete risk list.

- **Qualify all risks.** All risks, including green risks, should be individually qualified (i.e., LxC categorical ratings that produce the 5x5 risk matrix).

Not only should the risk entries include an assessment against the P/p rating criteria, but P/p should identify the mapping between the risks and the tasks within the *IMS/Analysis Schedule*, describing how each will impact the P/p's plan. It is important to note that the P/p is accountable for risks that impact the schedule but may be outside P/p control (e.g., the risk of an international contribution not coming in on the scheduled date). Depending on the robustness of the P/p's Risk Management process, the Schedule Analyst may also be able to:

- **Quantify all risks.** All risks, including green risks, should be individually quantified (likelihood of occurrence, schedule impact, and cost impact).
- **Map all risks.** All risks should be mapped to activities within the schedule.

If the P/p has not already quantified or mapped the risks to the *IMS*, these steps will be addressed in Section 6.3.2.3.4. Once the Schedule Analyst is assured that the risks are of a quality suitable for the analysis, the risk data, usually in the form of an MS Excel spreadsheet, is exported from the database. Typical data exported includes the fields as shown in Figure 6-17.

Risk ID	Title	Risk Statement	Context	Owner	Likelihood	Consequence	Risk Mitigation Plan	Schedule UID
1	Widget Delay	Given that the widget is a complex new design, there is a possibility that unplanned development issues may cause re-design and lead to late delivery into I&T	The framis pin for the widget is a new technology development and may have perrformance problems when completed, requiring redesign.	Sam	3	4	Alternate Framis Pin design in parallel development	2074
2								
3								
4								
5								

Figure 6-17. This image illustrates the typical risk data exported to an Excel file.

6.3.2.2.3 Procedure 3. Collect Cost Data and Ensure Suitability for Analysis

The general approach to estimating costs should be consistent with the processes defined in the Cost Estimating Handbook[98]. It is important to note that the costs will need to be mapped to the schedule, requiring consistency in the WBS used for Schedule Development and cost estimating. An important characteristic of the *ICSRA Model* is that it will "stretch and/or shrink" the durations of activities in the schedule that are exposed to risk impacts. Using this principle to guide how the *ICSRA* is built, means that more fidelity is required for areas of the schedule exposed to risk and less in other areas. It is also important to separate TD costs (e.g. labor, facility utilization time) from TI costs (e.g., travel, supplies, component purchases, firm-fixed-price subcontracts, etc.).

---

[98] NASA Cost Estimating Handbook, Version 4.0. February 27, 2015. https://www.nasa.gov/sites/default/files/files/01_CEH_Main_Body_02_27_15.pdf

The basic principles of cost loading do not change whether the Schedule Analyst is loading the *IMS* or the *Analysis Schedule* because the *Analysis Schedule* should accurately reflect the intent of the P/p's *IMS*. Some key characteristics of the schedule used for an *ICSRA* are as follows:

- The cost estimate will need to be linked to the schedule (i.e., cost-loaded). As a note, by loading the cost estimate to the schedule, a phasing profile will be a resulting output.
- Costs allocated to the activities or summary activities in the schedule will need to be characterized as TD or TI.
- Careful consideration needs to be made on what level of risk and uncertainty is inherent in the cost estimate.

Greater detail is provided in Section 6.3.2.4.

In addition, when producing an *ICSRA*, there generally exists some ambiguity about the differences between cost loading, resource loading, and budget loading a schedule. These terms are defined in Section 5.5.12. Understanding the nuances between these methods is a necessary step in collecting the right "cost" data to properly develop the *ICSRA*. The Schedule Analyst will need to work closely with the Cost Analyst to understand which "costs" are to be applied to the *ICSRA Model*. Although the terminology "resource-loaded schedule" is used in the NASA policy, traditional resource loading of the schedule is not the only option to support the *ICSRA* requirement. Appendix J of the Cost Estimating Handbook helps to clarify the policy:

> "The policy clearly states that the projects are required to generate a resource-loaded schedule. This terminology can be confusing and deserves some attention. NASA's definition of resource loading is the process of recording resource requirements for a schedule task/activity or a group of tasks/activities. To many people, the use of 'resource loading' implies that the tasks need to be loaded with specific work or material unit resources. This is NOT the intent of the policy. In general, the terminology of 'resource-loaded schedule' can be used interchangeably with 'cost-loaded schedule.' The intent of the *JCL* policy is not to recreate the lower level management responsibilities of understanding and managing specific resources (labor, material, and facilities), but to instead model the macro tendencies and characteristics of the project. To do this, *cost loading a schedule is sufficient* and a resource-loaded schedule is not required."[99]

6.3.2.2.4 Procedure 4. Collect Schedule and Cost Performance Data

Schedule performance data is captured during the Schedule Maintenance and Control sub-function. The Schedule Analyst should work with the P/p management team to ensure that the most current schedule and cost performance data is available for incorporation into the *SRA/ICSRA Model*. The schedule and cost performance data utilized should be consistent with the other programmatic products used in the *SRA*.

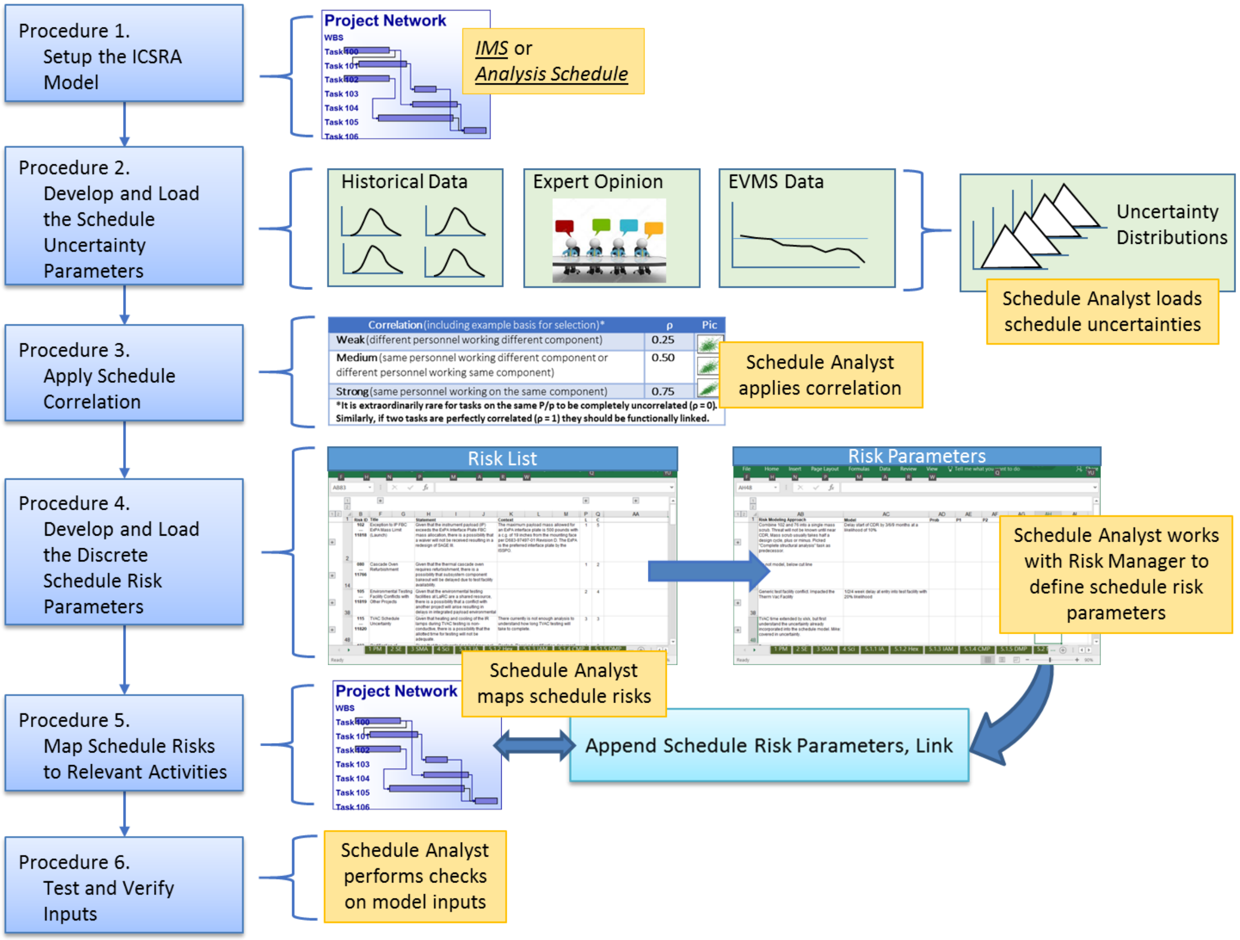
---

[99] NASA Cost Estimating Handbook, V4.0. February 2015. Appendix B. Page J-6. https://www.nasa.gov/sites/default/files/files/01_CEH_Main_Body_02_27_15.pdf

In addition to schedule-based performance metrics, captured in Section 7.3.3, the EVMS is an excellent source of performance data. EVM data can be used to adjust the uncertainties used in the risk parameters used in the *SRA Model*. For example, if the Schedule Performance Index (SPI) is .95 and not improving, the future activity durations should have uncertainty adjustments that increase durations by 5% or more depending on trends and effectiveness of corrective action plans. Other schedule-based performance metrics and indicators that provide useful information for estimating uncertainty include BEI, CEI, and HMI. These metrics are detailed in Section 7.3.3.1.3.

6.3.2.3 Build the SRA Model

After ensuring *SRA* tool capabilities and collecting the necessary data, there are six procedures required for *SRA Model* construction as shown in Figure 6-18. Procedure 1 sets up either the complete *IMS* or an *Analysis Schedule* to be able to incorporate the uncertainties and risks and execute the risk analysis. Procedure 2 develops and loads the schedule duration uncertainty parameters from the *BoE*. Procedure 3 applies any necessary correlation factors to the activities. Procedure 4 develops and loads the discrete risk parameters impacting the schedule based on input from the RMS. Procedure 5 maps the discrete risks to relevant activities, and Procedure 6 tests and verifies that the model is calculating as expected.



Correlation (including example basis for selection)*	ρ
Weak (different personnel working different component)	0.25
Medium (same personnel working different component or different personnel working same component)	0.50
Strong (same personnel working on the same component)	0.75

***It is extraordinarily rare for tasks on the same P/p to be completely uncorrelated (ρ = 0). Similarly, if two tasks are perfectly correlated (ρ = 1) they should be functionally linked.**

Figure 6-18. The figure illustrates the six procedures for construction of the SRA.

The schedule network shown in the figure is either the *IMS* or an *Analysis Schedule* as determined in the *Collect Schedule Data* procedure in Section 6.3.2.2.1. Then, the uncertainties, illustrated in the upper right of the above figure, are inserted directly into the schedule attached to the relevant activities that have uncertain durations. The uncertainties are not usually subject to trade studies and mitigation options analysis and therefore relatively static. Also, their parameters are generally simple. For these reasons, experience has shown that they are more easily loaded and managed if they are placed directly in the schedule. The risk data file is then exported from the P/p's risk management database. Therein, quantified risk parameters are appended to the relevant risks in the database. The form and format of the risk parameters must comply with the input needed by the *SRA* software selected per the Schedule Management Planning sub-function. The *SRA Model*, all input documentation, and all results documentation should be maintained in the same archive location such that they can be revisited at any time for additional risk sensitivity studies or data extract for trend analyses. The following sections discuss each procedure.

6.3.2.3.1 Procedure 1. Setup the SRA Model

The *SRA Model* should be sufficiently detailed to allow for an accurate understanding of the entire scope of the P/p and complete traceability of any elements with uncertainty or risk. Although the *IMS* and *Analysis Schedule* are both acceptable options to be used as the framework for the *SRA Model*, ***it is a best practice to use the IMS as the framework for the SRA, when feasible***. The *IMS* provides the most complete depiction of P/p's plan and allows for greater traceability for uncertainties and risks during analysis. Using the *IMS* also helps to avoid the creation and maintenance of multiple artifacts.

Nonetheless, there are times when it may be difficult to utilize a P/p *IMS* as constructed for the *SRA Model*. These reasons include but are not limited to: *IMS* results in undesirable assessment checks or does not adhere to NASA best practices, *IMS* is not structurally sound to support risk analysis, *IMS* has multiple schedules mapped in a server environment, *IMS* size/magnitude and level of detail does not support risk analysis. Thus, when utilizing the *IMS* is not feasible, it is a recommended practice that an *Analysis Schedule* be used to perform the *SRA*, as needed. Whether using the full *IMS* or an *Analysis Schedule*, it is important to ensure that the schedule has gone through the Assessment checks detailed in Section 6.2.

Before choosing between the *IMS* and *Analysis Schedule*, it is important to be aware of not only the benefits, but the limitations and consequences of using an *Analysis Schedule* for *SRA*. Figure 6-19 summarizes the differences between using either the *IMS* or *Analysis Schedule* as the foundation of the *SRA Model*. The P/p must carefully balance fidelity, currency, relevance, etc. when making the decision to use an *Analysis Schedule* in lieu of the *IMS* for the *SRA*.

Characteristic	*Integrated Master Schedule*	*Analysis Schedule*
Fidelity	▪ High fidelity; an accurate description of the work actually being performed.	▪ Low fidelity; float available to absorb risk impacts is often lost, important detail may be masked. ▪ Summarizing multiple parallel activities at a higher level may diminish merge bias.[100]
Currency	▪ Maintenance requirements will instill a lag in the information ▪ Pending changes will lag due to approval process, funding changes and often contract negotiations.	▪ Can accommodate latest information and changes. ▪ Changes don't require the rigor of the CM/DM controls.
Visualization	▪ May be too complex to easily visualize the overall perspective of the P/p. ▪ Includes all content from start including completed activities.	▪ Can be tailored to highlight current P/p issues and ignore irrelevant activities ▪ Can be truncated to current time to improve visualization.
Risk Modeling	▪ May be more difficult due to complexity; but likely higher fidelity. ▪ Validates all risk drivers with more granular traceability to discrete risk impacts to activities and specific float values.	▪ Simpler and much easier to visualize. ▪ Verification of risk parameters is easier.
Relevance	▪ Represents the baseline and is configuration controlled, routinely maintained, with continuous quality assessments performed. ▪ It is an accurate representation of all work to be performed.	▪ Onus on Schedule Analyst to verify it will fully emulate the IMS and is traceable to the IMS.
Validation of SRA	▪ May be difficult due to complexity but will eliminate the need to validate the model.	▪ Typically excludes non-risk-impacted path items, which reduces validation time. ▪ However, without modeling *all* scope, may miss potentially important logic ties.
Maintenance	▪ The IMS is maintained on a routine basis by the P/p and should not require any additional effort to reflect the current P/p status.	▪ Additional maintenance required to keep Analysis Schedule current and relevant.

---

[100] GAO-16-89G. GAO Schedule Assessment Guide. Page 1. December 2015. http://www.gao.gov/assets/680/674404.pdf

Logic	▪ The IMS contains all activities and their logical relationships down to the lowest level. ▪ Logic is routinely assured through the Assessment Process.	▪ Important activity relationships may be lost as the schedule is rolled-up to a higher level.
Cost/Resource Loading	▪ Can be very complex, and not easily mapped due to potential differences between the cost baseline structure and the IMS structure.	▪ Developed primarily to facilitate the loading of cost/resource data as well as risks and uncertainties.
Model Validation	▪ Can be very difficult due to size, complexity, use of constraints other than ASAP, large number of LOE tasks, large number of milestones used for visibility, etc.	▪ Much easier because activities that do not contribute value to the analysis can be deleted or rolled up into a single summary activity. ▪ Completed activities can be deleted and replaced by a single sunk cost Activity.
Critical Paths	▪ All critical and near critical paths are modeled at the lowest level.	▪ Summarizing a collection of tasks at a higher level may mask potential stochastic critical paths or may even introduce false critical paths that would not be critical in the complete IMS.
Computer Run-Time	▪ The large size of the IMS can significantly increase the runtime for some of the risk analysis tools.	▪ Smaller size and specific tailoring can keep the run-times manageable.

Figure 6-19. Comparison of the IMS and the Analysis Schedule for use in the SRA.

The appropriate level for the *Analysis Schedule* is determined based on a balance between the *IMS*, cost estimate, and risk list. It is important when creating the *Analysis Schedule* to avoid making changes that lose traceability and transparency to the *IMS*. The *Analysis Schedule* should be demonstrated to be an accurate emulator of the *IMS* in areas important to the risk analysis. The *IMS* and the *Analysis Schedule* should be consistent, showing the same dates for major milestones and showing the same critical paths.[101] The process of translating a P/p *IMS* into an *Analysis Schedule* involves the formulation of a summary or simplified schedule comprised of tasks that mimic and replicate as closely as possible how the P/p is planned and managed. This formulation process enables a Schedule Analyst to easily construe a holistic portrait of how uncertainty and risk can impact a P/p's schedule and cost. Activities in the *IMS* that are not risk-prone may be rolled-up to higher-level summary activities in the *Analysis Schedule*. Completed activities may be rolled-up as well or captured at a milestone on which costs can be loaded. Where there are potential risk impacts, the *Analysis Schedule* should follow the *IMS* to a low enough level to capture the activity or activities impacted by the risk.

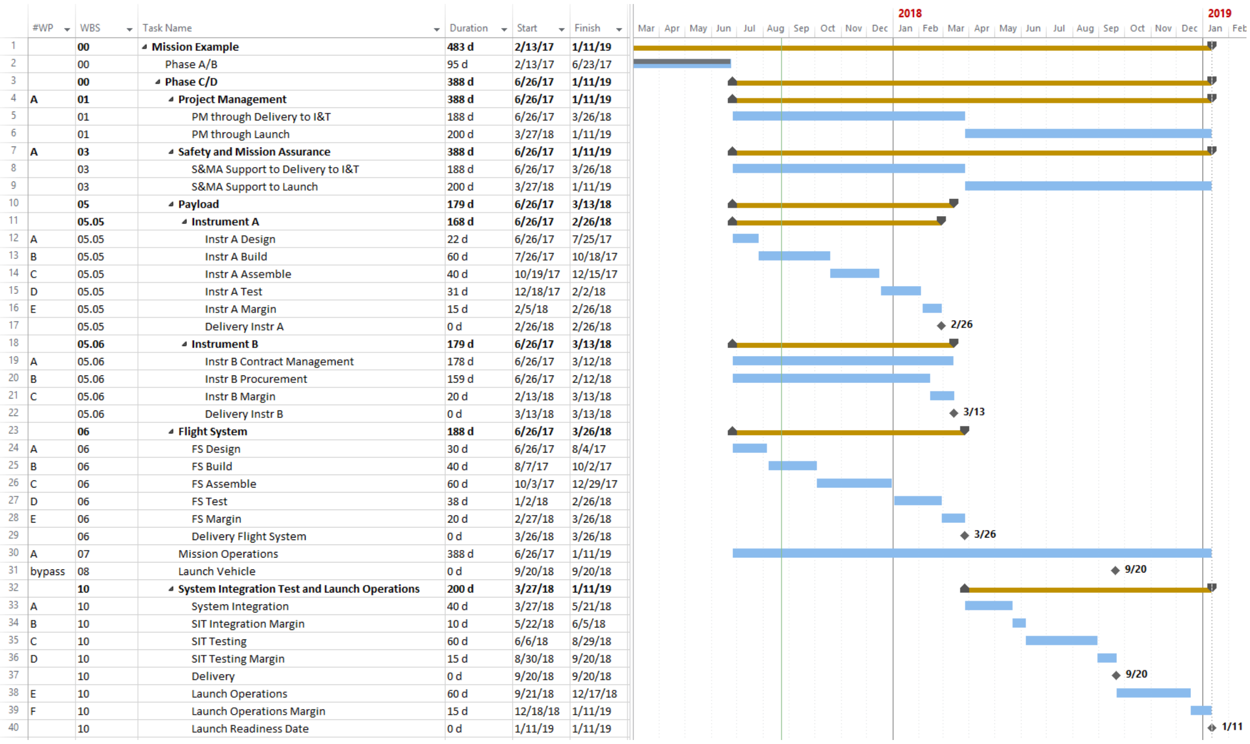
Some key characteristics when building an *Analysis Schedule* include[102]:

---

[101] Best Practices for Analysis Schedule Development. Reed Integration. Page 3. October 31, 2015.
[102] Best Practices for Analysis Schedule Development. Reed Integration. Page 5-6. October 31, 2015.

- Keep it manageable (e.g., ~100 – 3000 tasks) with working durations (excluding roll ups/hammocks/LOE) but be comfortable with the level of the *Analysis Schedule* as compared to the original *IMS.*
    - Ensure a clear representation of major work flows.
    - Pay close attention to the original complexity of the schedule, including serial and parallel nature of tasks.
    - Be careful of the level of detail and resulting merge bias. Rolling up sets of activities on parallel paths to a summary level may hide or underestimate the potential impacts of underlying merge bias.
    - Reduce redundancy while maintaining traceability of work required that flows into milestone deliverables and all significant milestones are captured:
        - Ensure all the P/p milestones are captured.
        - Do not capture the same milestone multiple times at the subsystem level. The intent is to capture milestones and work flow once. Many *IMSs* will have P/p level milestones captured in each subsystem element to maintain visibility of that milestone, but for an *Analysis Schedule* it just creates redundancy. Make sure the work flow from the subsystem element to the P/p milestone is properly captured.
- Maintain the same working calendar(s) (working time) as the *IMS*.
- Maintain natural float while avoiding the use of lag to represent float and/or schedule margin.
- Match the level of detail to the tasks impacted by risks. For example, if there are no risks in the C&DH, roll-up to the summary level; if there are risks in a star tracker, breakdown the GN&C to the component level.
- There is no need to model the *IMS* from the beginning of the P/p to the "time now". The *Analysis Schedule* can be modeled without including completed work, as long as the completed portion of the schedule is clearly associated with sunk costs. Using fiscal year cutoff points tend to work well due to the requirement to capture cost and schedule data at that time for the PPBE process.

Figure 6-20 illustrates an example of a high-level, generic *Analysis Schedule*:



	#WP	WBS	Task Name	Duration	Start	Finish
1		**00**	**◢ Mission Example**	**483 d**	**2/13/17**	**1/11/19**
2		00	Phase A/B	95 d	2/13/17	6/23/17
3		**00**	**◢ Phase C/D**	**388 d**	**6/26/17**	**1/11/19**
4	**A**	**01**	**◢ Project Management**	**388 d**	**6/26/17**	**1/11/19**
5		01	PM through Delivery to I&T	188 d	6/26/17	3/26/18
6		01	PM through Launch	200 d	3/27/18	1/11/19
7	**A**	**03**	**◢ Safety and Mission Assurance**	**388 d**	**6/26/17**	**1/11/19**
8		03	S&MA Support to Delivery to I&T	188 d	6/26/17	3/26/18
9		03	S&MA Support to Launch	200 d	3/27/18	1/11/19
10		**05**	**◢ Payload**	**179 d**	**6/26/17**	**3/13/18**
11		**05.05**	**◢ Instrument A**	**168 d**	**6/26/17**	**2/26/18**
12	A	05.05	Instr A Design	22 d	6/26/17	7/25/17
13	B	05.05	Instr A Build	60 d	7/26/17	10/18/17
14	C	05.05	Instr A Assemble	40 d	10/19/17	12/15/17
15	D	05.05	Instr A Test	31 d	12/18/17	2/2/18
16	E	05.05	Instr A Margin	15 d	2/5/18	2/26/18
17		05.05	Delivery Instr A	0 d	2/26/18	2/26/18
18		**05.06**	**◢ Instrument B**	**179 d**	**6/26/17**	**3/13/18**
19	A	05.06	Instr B Contract Management	178 d	6/26/17	3/12/18
20	B	05.06	Instr B Procurement	159 d	6/26/17	2/12/18
21	C	05.06	Instr B Margin	20 d	2/13/18	3/13/18
22		05.06	Delivery Instr B	0 d	3/13/18	3/13/18
23		**06**	**◢ Flight System**	**188 d**	**6/26/17**	**3/26/18**
24	A	06	FS Design	30 d	6/26/17	8/4/17
25	B	06	FS Build	40 d	8/7/17	10/2/17
26	C	06	FS Assemble	60 d	10/3/17	12/29/17
27	D	06	FS Test	38 d	1/2/18	2/26/18
28	E	06	FS Margin	20 d	2/27/18	3/26/18
29		06	Delivery Flight System	0 d	3/26/18	3/26/18
30	A	07	Mission Operations	388 d	6/26/17	1/11/19
31	bypass	08	Launch Vehicle	0 d	9/20/18	9/20/18
32		**10**	**◢ System Integration Test and Launch Operations**	**200 d**	**3/27/18**	**1/11/19**
33	A	10	System Integration	40 d	3/27/18	5/21/18
34	B	10	SIT Integration Margin	10 d	5/22/18	6/5/18
35	C	10	SIT Testing	60 d	6/6/18	8/29/18
36	D	10	SIT Testing Margin	15 d	8/30/18	9/20/18
37		10	Delivery	0 d	9/20/18	9/20/18
38	E	10	Launch Operations	60 d	9/21/18	12/17/18
39	F	10	Launch Operations Margin	15 d	12/18/18	1/11/19
40		10	Launch Readiness Date	0 d	1/11/19	1/11/19

Figure 6-20. Example of an Analysis Schedule.

Cautions When Setting Up the SRA Model

Other important considerations regarding setting up the *SRA Model* include:

- **Margin.** Margin activity durations will impact the results of the SRA. Any margin tasks in the schedule should be set to zero. If the margin tasks are not set to zero, the uncertainty and risk impacts are essentially doubled since they are accounted for in both the margin activity durations and the probabilistic risk analysis simulation of task duration uncertainties and discrete risk impacts. Thus, setting the margin activities to zero will allow a proper comparison of the schedule slip resulting from the uncertainty- and risk-impacted activities to the allocated schedule margin. For traceability reasons, it is a recommended practice to model the margin activities as having zero duration by applying an uncertainty distribution set to “0”.

- **Point of Reference.** For any programmatic analysis, the P/p must establish a Point of Reference. It is critically important that the P/p can provide a complete and consistent set of data inputs for the analysis; technical, cost, schedule and risks must all be to the same reference point. For example, the schedule cannot contain progress for a risk mitigation activity that has not been approved and incorporated into the baseline *IMS* with the required funding. It is acceptable to use post-processing or perform sensitivity analyses to show the impacts of proposed changes. However, the model must have a firm and consistent *BoE* that is formally documented.

- **Date of Analysis.** It is important to have the Point of Reference as close as possible to the analysis date to minimize the impacts of changes from the Point of Reference date to the analysis date.

- **Model Detail.** A potential risk of creating an *Analysis Schedule* is the increased likelihood of losing lower-level schedule P/p details like dependencies and constraints crucial to modeling P/p workflow and replicating reality. The risk of losing schedule detail and workflow attributes when creating an *Analysis Schedule* can result in a reduction of programmatic insight and ultimately impact NASA Agency decision-making. This potential loss of detail can be mitigated or reduced if proper due diligence is taken to construct a robust *Analysis Schedule*.
- **Merge Bias.** Merge bias indicates the complexity of the start of an activity due to having a large number of predecessor activities. Activities with a large number of predecessors have a higher probability of being delayed due to the cumulative effect of all links having to complete on time in order for the activity to start on time. In other words, "merge bias is the impact of having two or more parallel paths of activities, each with its own variability or uncertainty, merge into one milestone or other activity. Under most circumstances, the inclusion of parallel tasks in the schedule will cause the deterministic schedule to be at a low confidence level."[103] In general, more parallel tasks increases the mean duration (shift right) and reduces the variance of the statistical distribution.[104] In other instances, merge bias may be underestimated when rolling up multiple parallel paths into a single summary activity, such as when using an *Analysis Schedule*. Careful consideration should be exercised when rolling parallel activities into summary activities. Understanding where merge bias exists is especially important when performing the *SRA*. These affected activities should be analyzed for uncertainty/risk impacts since they may become critical as a result of the large number of merge points.
- **Logic and Constraints.** Regardless of the approach, the goal of the schedule that provides the framework for the *SRA Model* is to understand how a schedule will react to uncertainty and risk impacts. Logic and constraints can have significant, adverse effects on an *SRA*. Any constraints impacting the ability of the activities to move freely based on the logic between activities should be removed. The goal is not to change schedule logic or constraints to garner desired or positive results, but to ensure that the *SRA Model* will accurately capture positive and negative changes in the schedule due to schedule logic and flow, whether using the *IMS* or an *Analysis Schedule*.
- **Import Issues.** If the *SRA* tool being utilized requires an import of the schedule file and is not an add-in to the native scheduling software, it is possible to run into issues. The Schedule Analyst should perform spot checks of activity logic and finish dates. If the *SRA* tool has a built-in import check or health check capability, it should be run, and any inconsistencies resolved before moving on to the next procedure.

6.3.2.3.2 Procedure 2. Develop and Load the Schedule Duration Uncertainty Parameters

It is a best practice for schedule duration uncertainties to be quantified with respect to appropriate activities for inclusion in the SRA. This section discusses various methods for selecting and applying

---

[103] Majerowicz, W. and S. Shinn. "Schedule Matters: Understanding the Relationship between Schedule Delays and Costs on Overruns." Page 6. 2016. https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20160003386.pdf

[104] Kuo, Fred. "Everything You Want to Know about Correlation but Were Afraid to Ask." NASA PM Challenge. 2011. https://www.nasa.gov/sites/default/files/atoms/files/04_correlation_2016_cost_symposium_fkuo_tagged.pdf

schedule uncertainty distributions to the activity durations, including the advantages and disadvantages of these methods. Figure 6-21 illustrates the concept of schedule and cost uncertainty parameters.

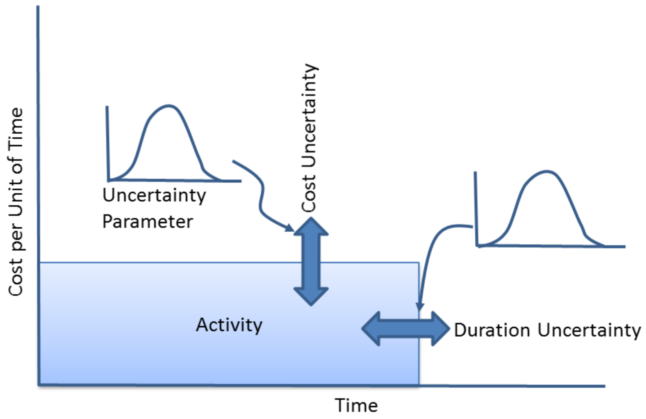


Figure 6-21. This figure illustrates the cost and schedule uncertainties concept.

6.3.2.3.2.1   Step 1. Develop the Schedule Duration Uncertainty Parameters

It is critical that the Schedule Analyst invests time and thought in developing credible and appropriate schedule duration uncertainty distributions. Developing informed duration uncertainties requires that the P/p have a clear understanding of whether its task duration estimates are accurate, inflated, or overly optimistic. Factors that influence the process for determining uncertainty distributions include:

- **Complexity of Work.** The complexity of the work can affect uncertainty. In general, the higher the complexity, the more uncertain the outcome.[105]
- **Built-in Margin.** Underlying margin assumptions can drive uncertainty ratings. For example, if a P/p's activity durations have "built in" margin, then more opportunity is associated with task than risk.
- **Maturity.** The maturity of the activities can affect uncertainty values. For example, a process fully in production mode would tend to have less "uncertainty" than a truly developmental process. It has also been observed that as a P/p moves from early formulation through development to production, the inherent uncertainty decreases.
- **Level of Uncertainty Modeling.** The level of detail in a P/p's *SRA Model* will influence the uncertainty bounds. For example, the uncertainty bounds at the system level will not be the same as the uncertainty modeled several levels lower.[106]
- **Baseline Plan Biases.** Any inherent biases when developing the P/p plan should be considered. Uncertainty would be counteracting any preconceived optimistic or pessimistic bias.

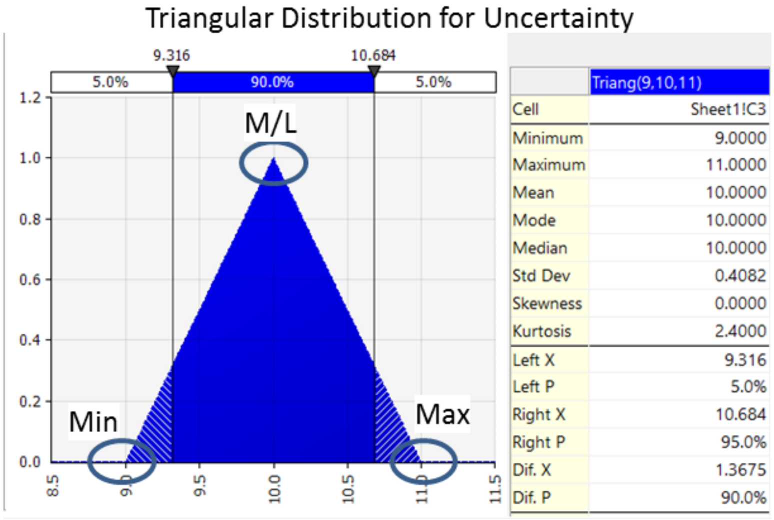
---

[105] Elliott, D. and C. Hunt. "Cost and Schedule Uncertainty: Analysis of Growth in Support of JCL." NASA Cost Symposium. 2014.

[106] Whitley, Sally. "Schedule Uncertainty Quantification for JCL Analysis." NASA Cost Symposium. 2014.

- **Risk Management System.** Although uncertainty is independent of risk, how complete and thorough the risk management system is will affect uncertainty values. From a modeling perspective, an *SRA* can be calculated with a cadre of methodologies incorporating discrete risks and uncertainties. In general, P/ps lean on using their risk management system (which is not omniscient) to capture discrete risks that are currently being watched and managed, while using uncertainty to capture both unidentified risks and activity duration uncertainty in the plan.

One distinguishing aspect of uncertainty versus risk is the absence of a likelihood of occurrence for uncertainty. Thus, some value of uncertainty from the uncertainty distribution will always be applied to the *SRA/ICSRA*. Uncertainty can be modeled with a number of probability distributions, such as normal, lognormal, Weibull, Rayleigh, PERT, or uniform, information on which can be found on the SCoPe website.[107] However, in actual use, uncertainty is typically modeled using a three-point estimate as shown in Figure 6-22. The low value represents the minimum (Min) extreme of uncertainty around the duration (or cost), the middle value represents the "most likely" (M/L) value of uncertainty, and the high value represents the maximum (Max) extreme of uncertainty. It is important to note that the baseline plan may not be any one of these numbers – Min, M/L, Max – but should be within the range of Min and Max. In most Monte Carlo simulation tools, uncertainty can be modeled by actual values as shown in the figure or may be percentage-based such as plus (+) or minus (-) some percentage (%) of the estimated value.



	Triang(9,10,11)
Cell	Sheet1!C3
Minimum	9.0000
Maximum	11.0000
Mean	10.0000
Mode	10.0000
Median	10.0000
Std Dev	0.4082
Skewness	0.0000
Kurtosis	2.4000
Left X	9.316
Left P	5.0%
Right X	10.684
Right P	95.0%
Dif. X	1.3675
Dif. P	90.0%

Figure 6-22. The figure illustrates an example triangular distribution for uncertainty.

At a macro level, there are three methods for selecting cost and schedule uncertainty distributions: data-driven, performance-based, and SME-based approaches.

---

[107] SCoPe website, https://community.max.gov/x/9rjRYg

Option 1: Analogous Data-Driven Methods

Early in the P/p life cycle, the most defensible method for selecting uncertainty distributions is through the analysis of historical data. This analysis can be accomplished by utilizing historical analogy (either by direct comparison or by bounding possible outputs with analogies) or though utilizing parametric (cost/schedule as a function of some driving factor, such as mass or complexity[108]) data. Either approach is highly defendable but often is hard to use due to a lack of data at the appropriate level. High level cost and schedule data (both raw and normalized datasets) can be accessed in ONCE.[109]

Things to consider when utilizing parametric or historical data:

- **Were the data normalized? How?** Collected data need to be normalized. Normalization involves analyzing the raw data and making adjustments for consistency. The inconsistencies that may be found in a dataset include changes in dollar values over time (e.g., inflation); learning or cost improvements for organizational efficiency; and, if more than one unit is being produced, the effects of production rates on the dataset being analyzed. When analyzing a dataset, normalization considerations should include adjustments for the cost (currency, Base Year), size and weight, complexity or mission, frequency, and mission platform (crewed, robotic).
- **At what level are the data, and are the data compatible with my SRA Model?** As discussed, above, uncertainty metrics (whether done in absolute or relative terms) are not easily transferable from one level of fidelity to another.
- **Are the data relevant to what is being estimated?** As with all statistically-driven analysis, special care must be taken so that the data are relevant to the system or subsystem being estimated. The less the relevance, the greater the uncertainty. Uncertainty distributions applied to the *SRA Model* should not be truncated by the analogous data; instead, the tails of the distribution should be allowed to expand beyond the analogous data.
- **Are there enough data to support the analysis?** Sample size matters. Small samples introduce statistical bias in the estimate. This bias should be considered when deriving uncertainties.[110]

SERs. Schedule Estimating Relationships (SERs) can be used to estimate durations of schedule events much like CERs are used to estimate a particular price or cost. An SER is a mathematical relationship that defines schedule as a function of one or more parameters or factors, which may include technical parameters as well as parameters for cost. SERs can be used to estimate schedule duration by connecting an established relationship with one or more independent variables to the duration time of an event. Existing NASA tools, such as SMART and NICM, contain schedule data and SERs that can be

---

[108] Elliott, D. and C. Hunt. "Cost and Schedule Uncertainty: Analysis of Growth in Support of JCL." NASA Cost Symposium. 2014.
[109] Johnson, J., E. Plumer, M. Blandford, J. McAfee. "One NASA Cost Engineering (ONCE) Database." NASA Cost Symposium. 2014.
[110] Jarvis, W. and P. Oleson. "KDP B Range Estimates: Unbiased Range Estimation." NASA Cost Symposium. 2014.

used effectively, if the purpose and utility of the results are understood by the Schedule Analyst.[111] These tools are available on the ONCE Database.[112]

Option 2: Performance-Based Methods

In some cases, it is possible to use performance data to extrapolate uncertainty distributions for use in the analysis models. Performance-based methods are really an offshoot of Data-Driven Methods. There are countless methods by which this can be done based on the type of performance data available and the level at which the data have been captured. For example, it is sometimes easy to compare a P/p's most up-to-date *IMS* to earlier versions. This comparison provides the Schedule Analyst with a view for how the P/p's duration estimates have compared to their actuals. In this case, the distribution that best fits the growth patterns of completed tasks can be used to model uncertainty of to-go tasks. Performance-based (e.g., EVM) methods allow the Schedule Analyst to develop low-level uncertainty distributions with the rigor of data-based approaches. This method is one of the best ways that data can be used to justify uncertainty factors for *JCL* analyses. Additional references on how to use performance data for uncertainty analysis can be found on the NASA Cost and Schedule Symposium website.[113]

Things to consider when utilizing performance-based inputs:

- **Past Performance:** Just like in mutual funds, past performance may not be a good indicator of the future. This is especially the case when moving from one "type" of activities to another. For example, transiting from design and development to assembly and test.
- **Level of Data:** As stated previously, one needs to make sure that the level of performance-based metrics collected is the same general fidelity as the analysis model.

Duration Ratio Method. One method of using past performance for determining useful duration uncertainty bounds is the Duration Ratio method. This method calculates the "duration ratio" from the baseline and actual durations extracted directly from the *IMS*.

$$Duration\ Ratio\ = \frac{Actual\ Activity\ Duration}{Baseline\ Activity\ Duration}$$

Duration Ratios derived from *IMS* actual and baseline plan activity durations offer an objective approach to estimating schedule durations and associated uncertainty based on the P/p's own historic data. The benefits of this method include:

- Planned and actual durations are factual, objective and performance-based
- Uncertainty correlates to the P/p's own performing organizations
- Focus is on discrete activities – milestones, summary activities and level of effort-type activities are not included

---

[111] NASA Cost Estimating Handbook, Version 4.0. February 27, 2015. Appendix K. Pages K-1 and K-2. https://www.nasa.gov/sites/default/files/files/CEH_AppK.pdf

[112] SMART and NICM can be found on ONCE, https://oncedata.hq.nasa.gov/

[113] https://www.nasa.gov/offices/ocfo/cost_symposium

Additional precision can be achieved with a data segmentation strategy and examining the removal of outliers and anomalies which can skew the results.[114,115]

Option 3: SME-Based Methods

Unfortunately, it is rarely the case that data exist to justify all the uncertainty distributions required for the analysis model. This is particularly true when a bottom-up analysis is performed on either an *Analysis Schedule* or the P/p's *IMS*, as even the highest-level *Analysis Schedules* tend to have tasks at a lower level (component or below) than schedule data that are available. Under these circumstances, it is necessary to obtain SME judgment to develop schedule uncertainty metrics. This section outlines the most common method for obtaining SME inputs and converting them into triangular uncertainty distributions for use in risk simulations. Following a discussion of several issues associated with this methodology, other approaches for using SME guidance to develop uncertainty distributions will be discussed.

Although SME guidance is sometimes subjective, there are actions that can be taken to ensure that the analysis is as accurate as possible. The first step in developing SME-based distributions is identifying the experts who will provide input to the analysis. Experts should be chosen based on their familiarity with the tasks for which they are providing input. Things to consider when utilizing SME inputs:

- **Right Expertise:** It's important to get the right expert solicitation for cost and schedule uncertainties. For example, a person may be quite the expert in a technical field but may not have a good understanding of the cost and schedule uncertainties of that field; whereas, a recent PM, or Center cost estimator, may not be as competent in the technical area but have a better feel for cost and schedule impacts. SMEs should be able to provide time estimates based on personal knowledge and/or experience with the same personnel, or from similar P/p work or specialized training.
- **Confirmation Bias:** Tendency to search for, or interpret information, in a way that confirms one's beliefs or hypotheses. For example, an SME on a given P/p may underestimate the negative uncertainty because they "want" the P/p to succeed.
- **Framing Bias:** Using a too-narrow approach and description of the situation or issue.
- **Hindsight Bias:** Inclination to see past events as being predictable.

One final approach for making SME-driven uncertainty estimates as accurate as possible is through obtaining multiple inputs from which a distribution can be developed.[116] [117]

Once an expert or group of experts has been identified, the Schedule Analyst should take care to document the name, position, and contact information for each SME. This approach ensures that the

---

[114] Kou, F., K. Cyr, and W. Majerowicz. "Duration Uncertainty Based on Actual Performance Lessons Learned." NASA Cost Symposium. 2012.

[115] Drexler, J., T. Parkey and C. Blake. "Techniques for Assessing a Project's Cost and Schedule Performance." NASA Cost and Schedule Symposium. 2017.

[116] Butts, G. "Psychology & It's Effects on Estimating." NASA Cost Symposium. 2012.

[117] Greenberg, M. "Expert Elicitation of a Maximum Duration using Risk Scenarios." NASA Cost Symposium. 2014.

analysis is traceable should any questions arise later. The next step is to extract their inputs for the uncertainty distributions. This identification is traditionally done through the evocation of three potential durations for the task in question: the minimum duration required to complete the task, the most likely duration required to complete the task, and the maximum duration required to complete the task. Each of the suggested durations, (Min, M/L, Max), should have associated rationale. These durations are then incorporated into the risk parameter as a triangular distribution.

Cautions When Developing Schedule Duration Uncertainty Parameters

There are two issues with the SME-based method that must be considered in the selection of distributions: (1) double counting, which is due to the unique nature of risk analysis, and (2) underestimating the risk, which is an intrinsic characteristic of all SME-based judgments.

- **Double Counting.** Double counting is a situation that occurs in *SRAs*, whereby the potential impact of uncertainties and/or risks are incorrectly accounted for more than once in an *SRA/ICSRA*. Double counting usually occurs when: (1) uncertainties or risks are applied to activity durations (or costs) whose estimates were based on past P/p data that already accounted for similar uncertainties/risks; (2) wide uncertainty distributions are applied to activity durations (or costs) that account for risk events, which are also applied separately as discrete risk impacts; and (3) schedule duration uncertainty drives cost impacts that are also applied separately as cost uncertainties or risks. The first two cases are further described below, and the third case is described in Section 6.3.2.4.4.
    - **Inherent Risk.** When evoking uncertainty distributions, the Schedule Analyst should walk through the risk register with the SMEs. The SMEs should be asked if, in the other P/ps they have worked, these risks have ever been experienced. If they have, it is likely that the uncertainty distribution proposed by the SMEs include these risks. For example, high risk WBS elements or subsystems can have low uncertainties. If this is the case, the Schedule Analyst and the SMEs must strive to disambiguate the uncertainty and the risk impact. The uncertainty must be reduced or even removed, and the risk properly defined and carried forward. The Schedule Analyst should document in the *SRA Model* the rationale for any risks that are removed or uncertainty that is lowered to avoid double counting.
    - **Overlapping Risks and Uncertainties.** Since the *SRA Models* a P/p's risk register, if proper care is not taken in the selection of uncertainty distributions, risk can be double-counted. The SME's judgment regarding the events likely to increase or decrease the time required to complete a task may inherently include risk impacts that are already included in the risk register as modeled in the risk parameter. Although there is no fool-proof way to be 100% sure that double counting is not taking place, the Schedule Analyst can attempt to minimize this situation.
- **Underestimating the Uncertainty.** The second issue is that whenever SME judgment is used to develop uncertainty distributions, there is a tendency for SMEs to underestimate the range of uncertainty (i.e., framing bias). It has been demonstrated that SMEs tend to only capture a portion of the true uncertainty in their estimate of the range of potential outcomes of an

event.[118] Whereas, it is important to watch out for double counting high risk WBS elements or subsystems that may have low uncertainties, the reverse may also be true – low risk WBS elements or subsystems may have high uncertainties. Thus, it is important that the Schedule Analyst compensate for this underestimation through the expansion of the parameters used in the uncertainty probability distribution to allow for a wider range of potential outcomes.

6.3.2.3.2.2 Step 2. Load the Schedule Duration Uncertainty Parameters

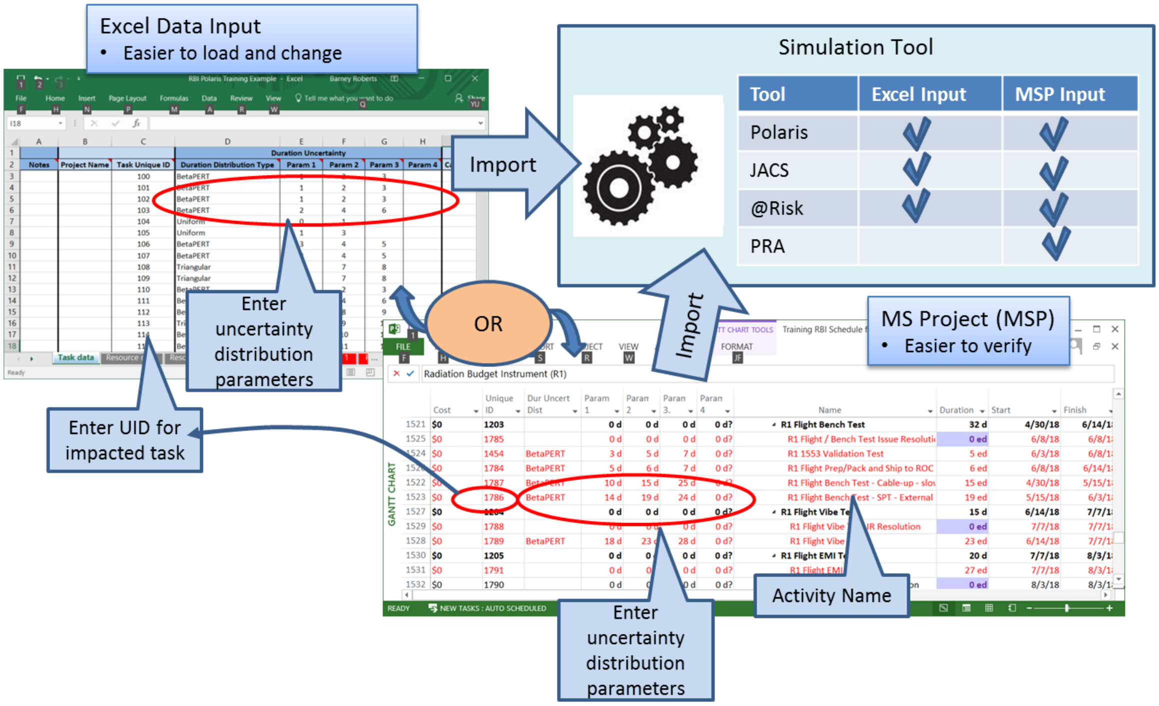
Once the uncertainties are determined, they may be loaded into the *SRA Model*. The different *SRA* tools allow uncertainties to be loaded in several ways: (1) into activity fields in the *IMS* or the *Analysis Schedule* that are then loaded into the *SRA Model*; (2) through an uncertainty register within the *SRA Model*; or 3) into a separate input sheet that is imported into the *SRA Model*. Each approach is acceptable; however, there are pros and cons to each.

- **Loading uncertainty directly into the *IMS* or *Analysis Schedule*.** Directly loading uncertainty into the *IMS* or the *Analysis Schedule* ensures correct mapping to the appropriate activity and allows a quick check of the distribution parameters (i.e., Min, M/L, Max), since they can be loaded into columns adjacent to the activity name. Manual entry of uncertainty parameters directly in the *IMS* or *Analysis Schedule* facilitates a more granular approach to applying uncertainty.
- **Loading uncertainty into the uncertainty register in the *SRA* tool**. When directly loading the *SRA Model*, the values are entered in an uncertainty register that applies uncertainty values to the schedule using assigned field codes (e.g., CAM, subsystem, etc.). Using an uncertainty register allows for quicker changing of inputs and may be useful when running scenarios. It is also helpful when using blanket uncertainty for large numbers of activities.
- **Loading uncertainty through an imported input sheet.** Use of the *SRA* tool's input sheet, which are generally MS Excel-based spreadsheets, may be a better solution for uncertainties due to the ability to categorize the uncertainties and load quicker. Often the Excel-based input sheet can facilitate entry of broad, blanket uncertainty distributions. Also, the use of the Excel-based input sheet can facilitate the entry of correlation. On the downside, using the Excel-based input sheet requires loading the UID of the impacted activity and introduces a potential error source having no easy method for validation and correction.

Figure 6-23 illustrates typical loading options for activity uncertainties for the more popular tools used within NASA. Other *SRA* tools or scheduling tools may not support the options discussed herein.

---

[118] Hubbard, D. W. "How to Measure Anything." John Wiley & Sons, Inc. 2012.



Tool	Excel Input	MSP Input
Polaris	✓	✓
JACS	✓	✓
@Risk	✓	✓
PRA		✓

Figure 6-23. The figure shows typical options for loading activity uncertainties.

6.3.2.3.3 Procedure 3. Apply Schedule Correlation

Per the Joint Agency Cost Schedule Risk and Uncertainty guide, "the uncertainty analysis is not complete until correlation is assessed."[119] Thus, ***it is a best practice for schedule correlation to be accounted for in the SRA.*** "Correlation is the term used to describe the degree to which variables 'move together'."[120] More specifically, correlation is a statistical technique used to determine the degree to which variables are related or associated.

- **Correlation.** Correlation is a statistical technique used to determine the degree to which variables are related or associated. Correlation does not prove or disapprove a cause-and-effect relationship.

Correlation between activities may be positive or negative. For instance, if the same contractor is responsible for completing a number of related activities that share the same resources, the tasks may be positively correlated if the contractor is uniformly efficient or inefficient across all the activities. Task durations may also be positively correlated if they are related to external factors, such as funding delays, design changes, bad weather, etc. Task durations may be negatively correlated if the contractor has limited resources and the efficient accomplishment of some activities hinders the efficient completion of

---

[119] Joint Cost, Schedule, Risk, and Uncertainty Handbook (CSRUH). Naval Center for Cost Analysis. 2014. Page 46.
[120] Joint Cost, Schedule, Risk, and Uncertainty Handbook (CSRUH). Naval Center for Cost Analysis. 2014. Page 45.

others. Because difficulties (or successes) in overcoming the P/p risks or schedule underestimations are likely to be systemic to a P/p, modeling correlation is an important aspect of an *SRA*.[121]

Correlation is an input parameter in most statistical simulation tools. Correlation values range from zero to one and indicate whether the relationship between activities is weak (0.0) or strong (1.0). When possible, data driven approaches to assign correlation between activities (e.g., historical schedule growth between satellite subsystems) are preferred. Other methods for applying correlation between tasks include modeling correlation that is found between activity durations when activities are influenced by a common risk factor. If a data driven approach is not feasible, general industry guidance suggests that values (ρ) between 0.25 and 0.75 be assigned between activities, as shown in Figure 6-24.[122] In keeping with general industry guidance, it is a recommended practice that 0.3 be the default correlation value.

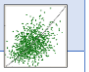
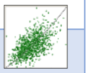
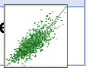
Correlation (including example basis for selection)*	ρ	Pic
Weak (different personnel working different component)	0.25	
Medium (same personnel working different component or different personnel working same component)	0.50	
Strong (same personnel working on the same component)	0.75	
***It is extraordinarily rare for tasks on the same P/p to be completely uncorrelated (ρ = 0). Similarly, if two tasks are perfectly corre (ρ = 1) they should be functionally linked.**		

Figure 6-24. Examples of the differences between weak, medium, and strong correlation values.

Correlation alters both the mean and standard deviation of the probability distribution outputs, as shown in Figure 6-25. Correlation also has a different effect whether the activities being modeled are rolled up at a summary level, and whether they are serial or parallel. Rolling up subtasks implicitly assumes 100% correlation of the subtasks, when the same uncertainty factors are used. For serial tasks, higher correlation tends to create a wider spread distribution, often with little to no effect on the mean. For parallel tasks, increasing correlation reduces the mean duration (shift left) but increases the variance of the curve.[123] Less correlation and more parallel tasks means more schedule risk.

---

[121] Druker, E. "JCL in a Nutshell: Exploring the Math of Joint Cost & Schedule Risk Analysis through Illustrative Examples. 2010. NASA Cost Symposium.

[122] Druker, E. "JCL in a Nutshell: Exploring the Math of Joint Cost & Schedule Risk Analysis through Illustrative Examples. 2010. NASA Cost Symposium.

[123] Kuo, Fred. "Everything You Want to Know about Correlation but Were Afraid to Ask." NASA PM Challenge. 2011. https://www.nasa.gov/sites/default/files/atoms/files/04_correlation_2016_cost_symposium_fkuo_tagged.pdf

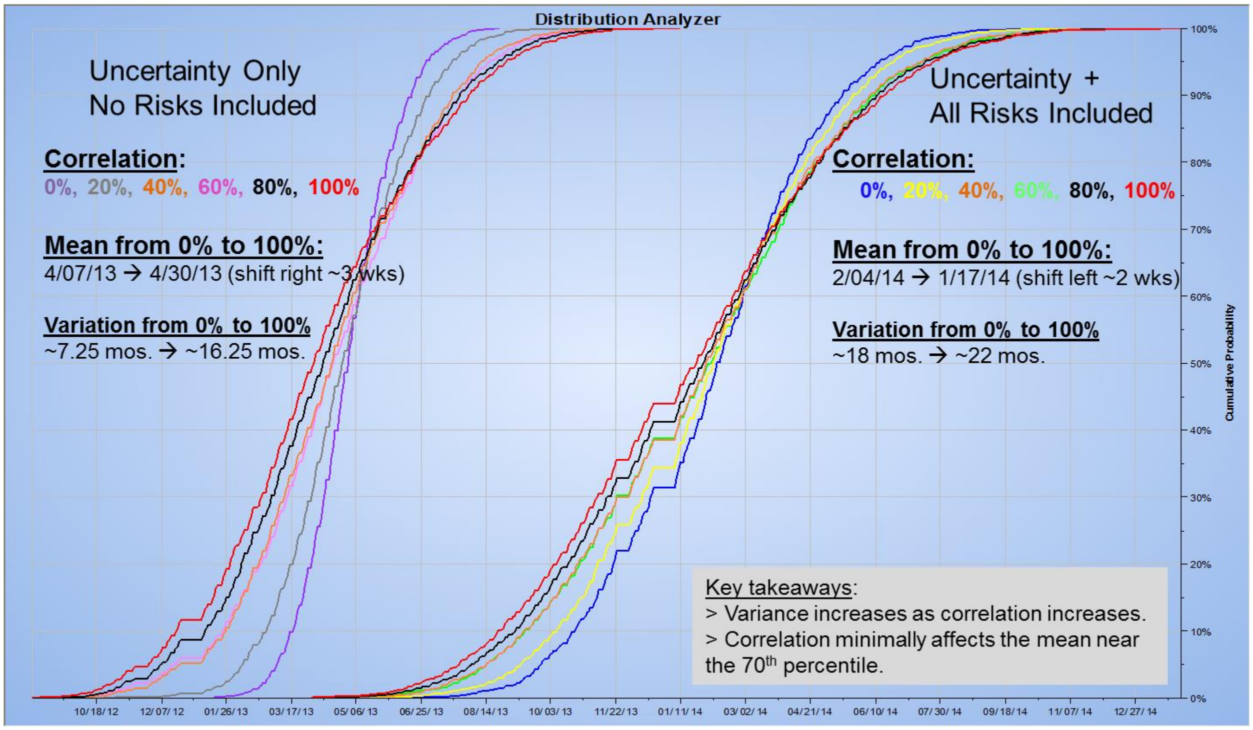


Figure 6-25. Illustration of how correlation values impact analysis results.

It is important to note that functional correlation between elements may already be accounted for in the schedule. Functional correlation exists when SER factors are used to estimate schedule durations in multiple WBS elements. For example, if the results of a weight-based SER are used to generate a thermal control subsystem and a structure subsystem, then both elements will be functionally correlated. If activities are not functionally correlated, not applying correlation in the *SRA Model* is the same as assuming a correlation value of zero. Ignoring correlation produces the most pessimistic results and can lead to an overstatement of both schedule risk and the effects of merge bias.[124] "If correlation is ignored, the variance at the total levels in the (schedule or cost) estimate will be understated, in many cases dramatically."[125]

It is also possible to not only correlate activity durations with other activity durations, but also activity durations with costs, activity durations with risks, costs with costs, costs with risks, and risks with risks. These are generally input options in the statistical simulation tools. For example, the Risk Driver method discussed in Section 6.3.2.3.4 assigns risks to multiple activities causing the activities to be correlated since the risk will occur on all activities if turned "on" during the simulation.

Cautions When Applying Correlation

Another important consideration regarding the modeling of correlation is as follows:

---

[124] Druker, E. "JCL in a Nutshell: Exploring the Math of Joint Cost & Schedule Risk Analysis through Illustrative Examples. 2010. NASA Cost Symposium.

[125] Joint Cost, Schedule Risk, and Uncertainty Handbook (CSRUH). Naval Center for Cost Analysis. 2014.

- **Merge Bias.** As noted in Section 6.3.2.2.1, merge bias indicates the complexity of the start of an activity due to having a large number of predecessor activities. Activities with a large number of predecessors have a higher probability of being delayed due to the cumulative effect of all links having to complete on time in order for the activity to start on time. "The number of merging parallel paths and the level of overlap and degree of correlation between them (lower correlation between uncertain durations produces greater merge bias) produce an increasing merge bias impact to the schedule."[126]

6.3.2.3.4 Procedure 4. Develop and Load the Discrete Risk Parameters Impacting Schedule

It is a best practice for discrete risks to be assessed and quantified with respect to schedule impacts for inclusion in the SRA. Each individual discrete risk will be assigned a probability distribution (e.g., normal, triangular, lognormal, beta, etc.) that simulates the risk impact. The Schedule Analyst should be able to trace the risk parameters directly to the RMS and defend the modeling approach to the risk owner and the P/p management team. If the discrete risks are not already quantified by the P/p, it is a recommended practice to build the risk parameters directly within the P/p's formal RMS. Experience has shown that traceability, defensibility and repeatability are critical in this type of analysis. Working with the Risk Manager and risk owner to quantify the risks directly in the P/p's official RMS facilitates risk discussions, allows for easy changes and updates, and enables configuration control of the modeling approach by facilitating control of the inputs and the associated outputs of the *SRA Model*.

6.3.2.3.4.1 Step 1. Select Pre- or Post-Mitigated Schedule Risk Values

Pre-mitigated risk is the current, or "time now", risk assessment. It is the likelihood and impact of any active risk prior to future mitigations being implemented. Post-mitigated risk is the expected value of the risk exposure after the completion of all future risk mitigation activities. It is important for the P/p management team to understand the potential impacts of risks in both their pre- and post-mitigated states. For instance, understanding the potential impact of the risk at various time throughout the P/p life cycle allows the P/p management team to monitor trends over time. This often requires comparing past analyses to examine how completion dates are trending as risks and uncertainties are updated. (Details of trend analyses are in Section 6.3.2.5.3.8.) The *SRA Model* also offers the P/p management team the opportunity to examine risk mitigation scenarios, which requires adjusting the risk quantification through the risk parameters to perform risk sensitivity analysis. Figure 6-26 is an example of a risk mitigation burn-down plan (i.e., risk waterfall chart).

---

[126] Joint Cost, Schedule, Risk, and Uncertainty Handbook (CSRUH). Naval Center for Cost Analysis. 2014. Page B-2.

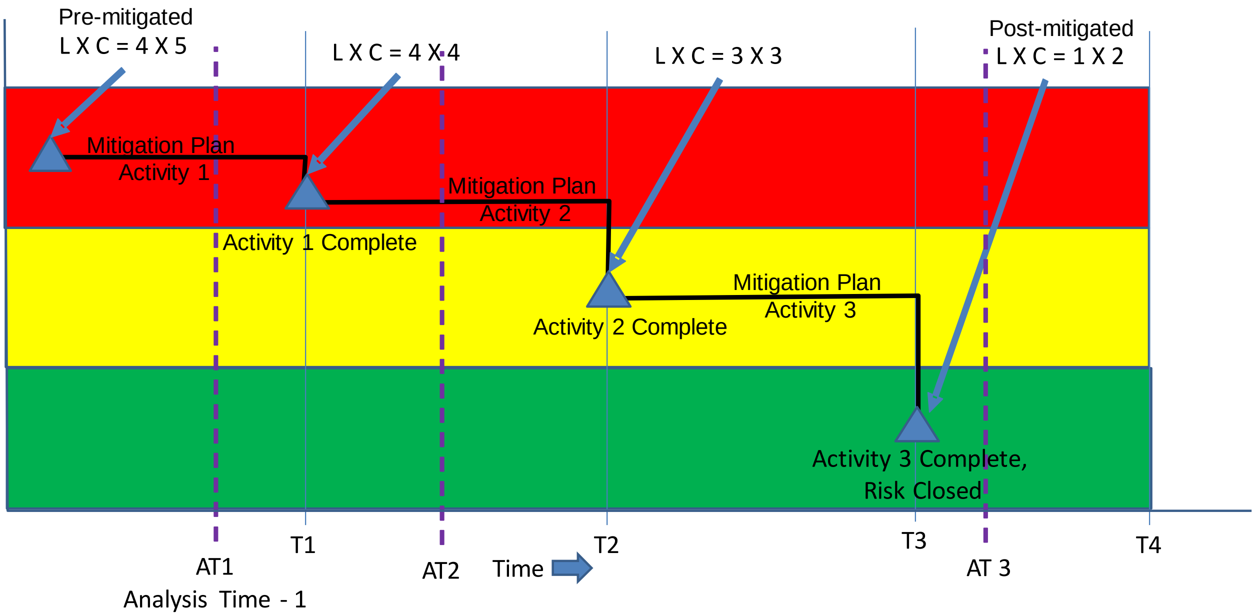


Figure 6-26. Risk Mitigation burn-down plan and values to be used at different analysis times.

Utilizing pre-mitigated risk details. From the *Collect Data* process described in Section 6.3.2.2, the P/p's current risk list should be exported from the RMS and provided to the Schedule Analyst. The risk list should include all risks, which are, at a minimum, qualified according to the P/p's risk management process (e.g., assigned categorical values based on a "Likelihood x Consequence" (LxC) risk matrix). Developing the risk parameters is captured in Step 2.

Utilizing post-mitigated risk details. As with pre-mitigated risks, capturing the likelihood of occurrence and the consequence impact for post-mitigated risks follows the same process. The only nuance is that the parameter values for post-mitigated risk are based on successful mitigation efforts taken to reduce either the likelihood or the consequence, or both, of the risks, whereas parameter values for pre-mitigated risks are on the likelihood and consequence of risks in their current state. In order to utilize post-mitigated risk details, the Schedule Analyst should first ensure that the risk mitigations have been thoroughly planned and their activities and costs have been loaded into the cost estimate and *IMS*, if they have been approved for inclusion and funding is available. If not already incorporated into the schedule by the P/p, it is a recommended practice to capture each step of the approved P/p-identified risk mitigation effort as an individual "activity" in the *SRA Model* and properly map them to the appropriate, existing schedule activity. Both the TD and TI costs associated with the mitigation effort should be captured within the mitigation activities. Mitigation activities will have uncertainty around their estimates. Thus, a range estimate in terms of minimum, most likely, and maximum (Min, M/L, Max) values should be established for both cost and duration of a mitigation activity. It is reasonable to expect that a higher level of uncertainty would be applied to mitigation activities than other activities within the same WBS element, as mitigation of risk contains high degrees of uncertainty of success. Furthermore, risk mitigation may not completely eliminate the risk. More than likely, risk mitigation will serve to lower the risk event's probability or impact to a level acceptable by the PM. Residual risk represents the likelihood and impact of a risk after mitigation activities are enacted. Assessment of residual risks provides detail on the effectiveness of risk mitigation.

The following tips are provided to assist in which values to use in the risk parameters.

1. The risk management process requires the P/p to take action on EVERY risk, but that action is not always “Mitigation”. It may be “Accept”, “Research”, “Watch”, “Retire/Close”, “Residual.” It is not unusual for the P/p to remove “Accept”, “Watch” and “Residual” risks from the active risk register. Regardless of whether or not a risk is on the active list, it is important to note that all categories of risk actions may have risk exposures and must be considered for inclusion in the risk parameters.
2. Risk mitigation is ignored unless there is clear traceability to funding and activities in the **BASELINE** plan. If there is no traceability, use pre-mitigated values.
3. The mitigation activities must be rational. Too often a P/p will show a milestone as a risk mitigation activity, for example an LCR or the completion of a test. Simply holding an LCR does nothing to reduce a risk. Conducting an LCR may actually confirm the existence of the risk. Often a test is used as a mitigation activity. Testing does nothing to change the likelihood nor consequence of a risk; although, testing may reveal to the P/p that the risk has occurred. “Watching” does not mitigate a risk. Assigning a “tiger team” does not mitigate a risk. Should any of the risk mitigation activities seem irrational, use the pre-mitigated values.
4. As mentioned in Part 1, there is inherent risk in the mitigation plan itself and it should be considered just as any other task in the schedule. Both cost risks and schedule risks should be considered for every mitigation activity.
5. In the diagram in Figure 6-27, the mitigation plan has three activities that reduce the risk from a 4X5 to a 1X2. There is no guarantee that any of the mitigation activities will result in the LxC increments shown. After each activity, the risk must be reassessed; the P/p cannot blindly accept the resulting likelihood and consequence values assigned to the mitigation plan. This is because the mitigation activity may not yield the expected result.
6. Consider the analysis time AT1, where Mitigation Activity 1 has been incorporated into the baseline plan. The analyst should not use the post-mitigated, residual risk LxC values just because a mitigation plan exists; it may fail. At AT1 the analyst needs to consider the effectiveness of the mitigation activity. For example, if the activity is to purchase alternative widgets with known performance to replace widgets that have some likelihood of not meeting a performance requirement, then use the post-mitigated value. If the activity is to test the current widget to see if it meets the performance requirement, then use the pre-mitigated value.
7. Consider analysis time AT2. The analyst should use the current risk value of 4X4 ONLY and ONLY IF the P/p has actually reassessed the risk. Otherwise the analyst should use the last value formally reassessed by the P/p, which in this case, is the initial pre-mitigated value.
8. Consider the analysis time AT3. Often a P/p will “Close” the risk and remove it from consideration for the analyst by removing the risk from the active risk list. This too, is likely incorrect because the risk may still have a residual value (i.e., residual risk). The analyst should use the residual value, again, IF and ONLY IF the P/p has reassessed the risk value to confirm

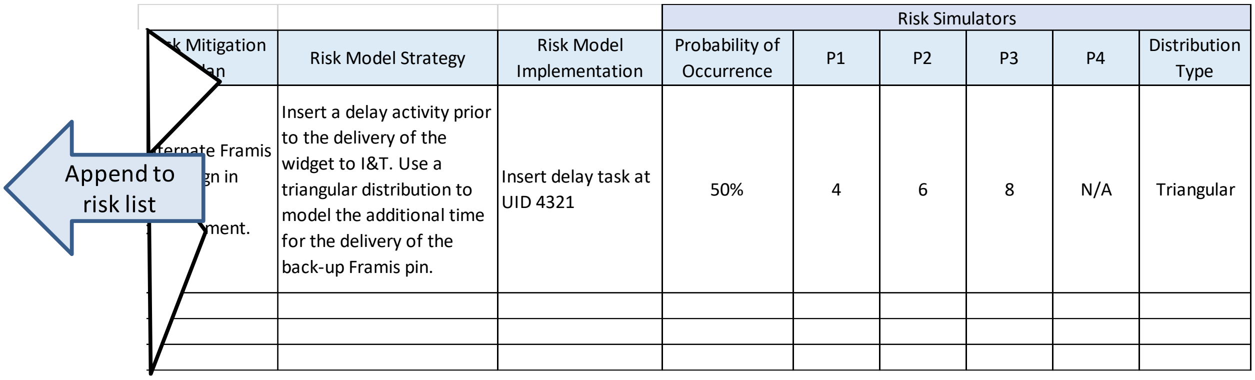
that the likelihood and/or consequence have been reduced. Otherwise revert to the last value reassessed.

Ultimately, the P/p's *SRA Model* may include some risks in pre-mitigated states and some risks in post-mitigated states, based on whether some risk mitigations have been approved and funded to be included as part of the P/p plan. It is important to document such assumptions in the *BoE*.

6.3.2.3.4.2 Step 2. Develop Schedule Risk Parameters

The Schedule Analyst appends the risk parameters with information from the risk file exported from the RMS. If the P/p has not yet quantified the likelihood of occurrence or consequence impact values of any of the risks in the RMS, the Schedule Analyst will need to work with the risk owner (e.g., Technical Lead responsible for the risk) to determine the likelihood of occurrence, along with the impact should the risk occur. Depending how much information is known about the risks, the same methods used for constructing the uncertainty parameters – data driven, performance-based, and SME-based – may be helpful in establishing a basis for the quantified risk values. Finally, the Schedule Analyst verifies the parameters with the PM. The quantified risk values that are determined for use in the *SRA Model* should be communicated to the Risk Manager and documented as part of the *BoE*.

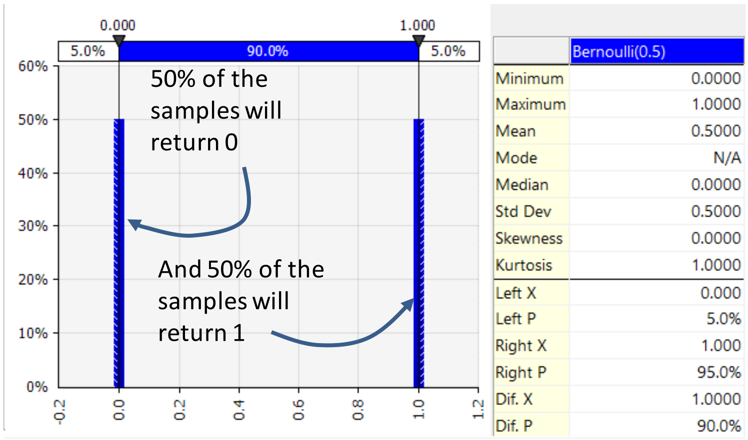
The risk parameters show exactly how the Schedule Analyst will simulate the risks in the schedule network. A typical set of risk parameters appended to the risk file exported from the RMS is shown in Figure 6-27. The last few columns of the appended risk data fields contain the inputs for the stochastic model and the type of distribution model used. A risk parameter consists of two parts, the likelihood of occurrence and the impact should the risk occur. The likelihood is captured as a probability (%), while the quantified impacts are usually captured as three-point estimates (i.e., Min, M/L, Max).



			Risk Simulators					
k Mitigation lan	Risk Model Strategy	Risk Model Implementation	Probability of Occurrence	P1	P2	P3	P4	Distribution Type
ternate Framis gn in ment.	Insert a delay activity prior to the delivery of the widget to I&T. Use a triangular distribution to model the additional time for the delivery of the back-up Framis pin.	Insert delay task at UID 4321	50%	4	6	8	N/A	Triangular

Figure 6-27. Example risk parameters appended to the risk file exported from the RMS.

The likelihood of occurrence is simply a random draw that reflects the likelihood quoted by the risk owner. The most commonly-used probability distribution used for the likelihood of occurrence is a Bernoulli distribution. For a likelihood of X% the Bernoulli distribution will return a value of 1.0 X% of the time and a value of zero otherwise. Figure 6-28 shows a Bernoulli distribution for a probability of 50%, where half the time the risk occurs in the simulation (1.0) and half the time the risk does not occur in the simulation (0.0).



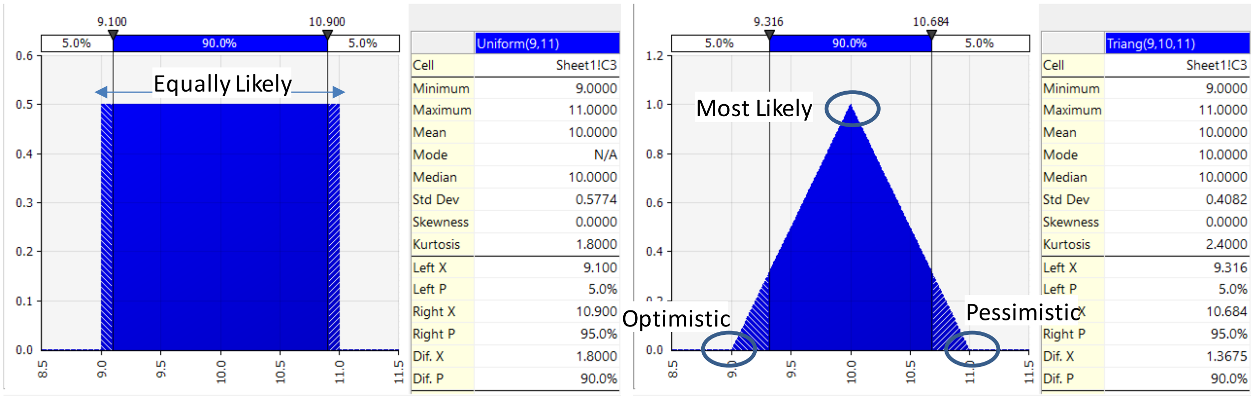
	Bernoulli(0.5)
Minimum	0.0000
Maximum	1.0000
Mean	0.5000
Mode	N/A
Median	0.0000
Std Dev	0.5000
Skewness	0.0000
Kurtosis	1.0000
Left X	0.000
Left P	5.0%
Right X	1.000
Right P	95.0%
Dif. X	1.0000
Dif. P	90.0%

Bernoulli Distribution

Figure 6-28. The Bernoulli distribution is often used for the likelihood of a risk occurring. Shown here, 50% of the time the distribution will return zero otherwise it will return 1.

The impact, should the risk occur, is uncertain and is also modeled by a probability distribution function. Up to four parameters, P1 through P4, are inputs to the probability distribution function used to describe the impact should the risk occur. The fields needed for the risk and uncertainty parameters were identified in the *Activity Attributes* table. Some probability distribution functions use only use two parameters, some three, and a few use four. There are many other probability distributions available for modeling. Most are supported by any of the Monte Carlo simulation tools available. Two of the most commonly-used probability distribution functions are discussed below and shown in Figure 6-29.

- **Uniform Distribution.** The uniform distribution models the case of "I know it is equally likely to be anywhere between this and that." A uniform distribution model is a two-parameter model with a lower limit and an upper limit. Any value within that range is equally likely to result when sampled. Uniform distributions are appropriate when minimal information is known, such as early in a P/p's life cycle or when a new technology is being developed.



	Uniform(9,11)
Cell	Sheet1!C3
Minimum	9.0000
Maximum	11.0000
Mean	10.0000
Mode	N/A
Median	10.0000
Std Dev	0.5774
Skewness	0.0000
Kurtosis	1.8000
Left X	9.100
Left P	5.0%
Right X	10.900
Right P	95.0%
Dif. X	1.8000
Dif. P	90.0%

	Triang(9,10,11)
Cell	Sheet1!C3
Minimum	9.0000
Maximum	11.0000
Mean	10.0000
Mode	10.0000
Median	10.0000
Std Dev	0.4082
Skewness	0.0000
Kurtosis	2.4000
Left X	9.316
Left P	5.0%
X	10.684
Right P	95.0%
Dif. X	1.3675
Dif. P	90.0%

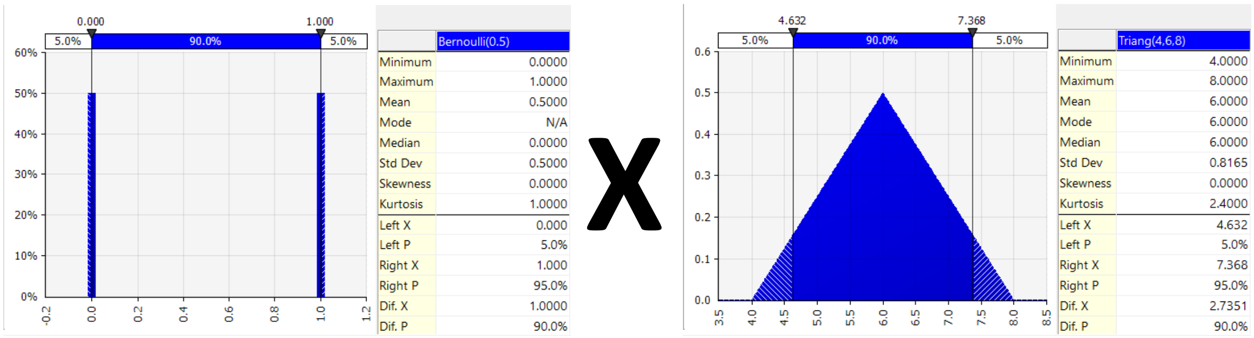
Uniform Distribution

Triangular Distribution

Figure 6-29. The triangular and the uniform distribution are the most commonly used.

- **Triangular Distribution.** A triangular distribution is a three-parameter model with the lower end being the most optimistic or minimum outcome of the risk impact, the middle point is the most likely outcome, and the upper end being the pessimistic or maximum outcome of the risk impact (i.e., Min, M/L, Max). Triangular distributions are most commonly used because of the ease of facilitating data from the SMEs. For example, "I know it will be at least this, but won't exceed that, and is most likely this." Triangular distributions are useful when more information is known about the risk, such as when data is available about a risk or when SMEs can provide rationale for each risk parameter.

A risk parameter that is typically used for the risk as linked to the P/p network as shown in Figure 6-27 and Figure 6-32 would be a Bernoulli distribution with parameters set for the risk likelihood of 50% multiplied by the triangular distribution with parameters set that define the risk impact of Min = 4, M/L = 6, and Max = 8. The Bernoulli distribution will return the value of 1.0, 50% of the time, and the value of 0.0 otherwise; thus, the triangular distribution has an effective random output from its distribution for half the samples.



	Bernoulli(0.5)
Minimum	0.0000
Maximum	1.0000
Mean	0.5000
Mode	N/A
Median	0.0000
Std Dev	0.5000
Skewness	0.0000
Kurtosis	1.0000
Left X	0.000
Left P	5.0%
Right X	1.000
Right P	95.0%
Dif. X	1.0000
Dif. P	90.0%

	Triang(4,6,8)
Minimum	4.0000
Maximum	8.0000
Mean	6.0000
Mode	6.0000
Median	6.0000
Std Dev	0.8165
Skewness	0.0000
Kurtosis	2.4000
Left X	4.632
Left P	5.0%
Right X	7.368
Right P	95.0%
Dif. X	2.7351
Dif. P	90.0%

Figure 6-30. This figure illustrates the use of the Bernoulli and triangular distribution to model a risk with a likelihood of 50% and an impact with a triangular distribution of 4 for the Min value, 6 for the M/L value and 8 for the Max value.

Risk Driver Method. An alternate technique for applying uncertainties and risks to the *SRA/ICSRA Model* is the Risk Driver method. The Risk Driver method uses the statistical simulation tool's uncertainty/risk register to model uncertainties and risks as "risk factors". With this approach, the risk factors are estimated as a probability distribution of the optimistic, most likely, and pessimistic (i.e., Min, M/L, Max) parameters, expressed as a multiplicative factors (i.e., percentage) of the remaining activity durations instead of specified risk impact durations. The risk factors are then assigned to specific activities in the schedule. The discrete risks are modeled using the probabilities as assigned by the P/p or adjusted by the Schedule Analyst with appropriate rationale, whereas the uncertainties are modeled at probabilities of 100%. If more than one risk is acting on an activity, the resulting ranges are the multiplication of the percentages tied to the individual risks. The Risk Driver method is useful when the discrete risks are higher-level strategic risks rather than tactical or technical risks. These risk factors can be thought of global risk, or uncertainties, that may apply to a large subset of the tasks. This method can be utilized if the P/p feels that there are common risks, or uncertainties that affect multiple tasks. For example, performance risk or uncertainties could be applied to multiple tasks' durations and cost due to known past performance issues. Risk factors can be applied utilizing historical data, performance data, or SME interviews. It may be appropriate to apply both three-point estimate method and the Risk Driver method within the *SRA/ICSRA Model*, as long as the Schedule Analyst provides justification for the modeling technique for each risk. The rationale for using the Risk Driver method for these types of risks is the differentiation of the identified strategic risk beyond typical uncertainty. Using this method also automatically correlates the activities that are mapped to the same risks, so no additional correlation factors need to be applied.[127]

Cautions When Developing Schedule Risk Parameters

Other important considerations regarding the modeling of schedule risk parameters are as follows:

- **Not Including All Risks.** It is common for P/ps to capture only the top *x* number of risks, or perhaps just red and yellow risks. However, for a successful and informative *SRA*, including all identified risks, even the green ones, provides a more holistic picture and may provide insight on where clusters of risks may impact the schedule. Sometimes a P/p will only include risks on the deterministic critical path. Doing this assumes that the P/p knows with complete certainty what the critical path is and limits the insights available through probabilistic analysis. If the P/p loads all the risks, it may find that a different path is more likely to be critical given the combined uncertainty and risk impacts affecting the schedule network. At the very least, applying all the risks will give better insight into the stochastic secondary, tertiary, etc. critical or driving paths. In addition, Agency resources such as historical CADRe data capture historical P/p risks that may be helpful in ensuring a more complete risk list.
- **Double Counting.** To avoid double counting, the Schedule Analyst must take special care to segregate uncertainty caused by risks being modeled in the simulation from the underlying uncertainty of the P/p plan. This is of particular concern early in the formulation phase when parametric models and/or SERs are being used for schedule development and cost estimating. Parametric models and SERs are based on the data from a large number of previous P/ps which were exposed to typical risks that P/ps normally face. Once the input risk is ready to be loaded into the model, it is a recommended practice that the Schedule Analyst perform an "in/out" determination for each risk that is being considered for inclusion in the *SRA*. This is done by reviewing each risk and determining whether it is truly a discrete risk, "in", or covered by the uncertainty in the parametric cost analysis or schedule estimate, "out". It is important that the "out" risks be retained and deactivated, but not deleted from the risk analysis model. This is because the determination is somewhat arbitrary and may need to be revisited. Since the determination is arbitrary and sensitivity analyses should be run to ensure the P/p plan is robust enough to absorb the uncertainty in the "in/out" decision.
    - **Inherent Risk.** SERs include some inherent schedule risk and uncertainty. The Schedule Analyst needs to work with the Technical Leads to ensure that the discrete risks reported by the P/p are not already included in the P/p schedule estimate. An example would be mass growth or design life. As long as the risk-reported mass growth or design life are within the range considered in the P/p schedule estimate, it should not be included in the analysis. If there is any doubt regarding whether or not the estimate includes the possible risk impact, it is better to include the risk. (See similar rationale in Section 6.3.2.3.1 for Uncertainty Definitions.)

---

[127] Hulett, D. T. "Integrated Cost-Schedule Risk Analysis using Risk Drivers and Prioritizing Risks." NASA Cost Symposium. 2009.

- **Operational/Flight/Mission Risks.** It is common to categorize a specific risk as an operational, flight, or "mission" risk. The P/p will usually exclude this category of risks from an *SRA*, since they reflect impacts that are likely to happen beyond the launch date. It is important to examine risks in this category, because under the principle of "Test As You Fly," the P/p may have some exposure to these risks during AI&T that have not been captured in other discrete risk entries in the risk list.

6.3.2.3.4.3 Step 3. Append Discrete Schedule Risks to the SRA Model

It is a recommended practice to append the risk list at the bottom of the P/p's *IMS* or *Analysis Schedule*, *regardless* of whether the software supports the use of a separate Excel input file for the risks. This allows for easier traceability of the risks and associated risk parameters when running the *SRA Model*, and especially when performing risk sensitivity studies.

Cautions When Appending Schedule Risk Parameters to the SRA Model

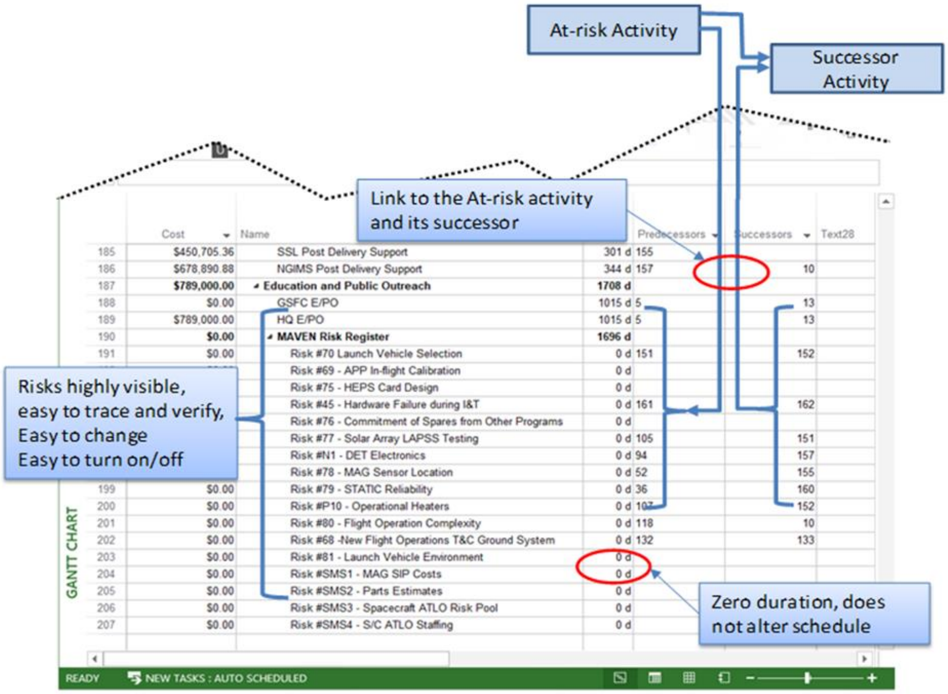
The most difficult part of this type of analysis is verification of the modeling. It has been found that loading the risk parameters within the body of the *IMS* or *Analysis Schedule*, which is typically how a risk register applies the risks, incurs the following problems.

1. It is difficult to verify that the incorporation of the risks has not altered the *IMS* or *Analysis Schedule*. Line item numbers within the *IMS* or *Analysis Schedule* have changed and that will compromise traceability. If discrepancies are found in the verification process, it is difficult to find which risk parameter is causing the problem. (Referencing Unique ID's is one workaround for this situation but is typically more cumbersome.)
2. Risks will continue to evolve, or new risks may be defined, during the course of the analysis. If the risks are distributed through the schedule, it makes it difficult to find the risk needing updating.
3. It is extremely difficult to verify that the risk parameters are compliant with the P/p's risk list when they are distributed throughout the schedule. **Note:** *If* loading the risks within the body of the *IMS* or *Analysis Schedule* instead of appending the risks at the bottom of the *SRA* model, be sure to flag the risks or label the risks with the term "Risk" at the beginning so that they are easily filterable.
4. This process also facilitates updates to the schedule. The entire updated schedule can be cut and paste in the *SRA Model* over the prior version of the schedule and the risk links can be remapped using the UIDs.

These problems may not be as significant when using an *IMS* or *Analysis Schedule* that is several hundred lines or less. Some Monte Carlo simulation software packages support loading risks in a separate Excel file or risk register, which will resolve most of the problems mentioned above. However, doing so will compromise the ability to test the model as discussed in Section 6.3.2.3.6.

6.3.2.3.5 Procedure 5. Map Schedule Risks to Relevant Activities

It is a best practice for discrete risks with schedule impacts to be mapped to appropriate activities in the SRA. Once the risk parameter is appended to the *IMS* or *Analysis Schedule*, the individual risks need to be linked to the tasks impacted by the risk. Figure 6-31 illustrates this procedure. This approach maintains the integrity of the *IMS* or *Analysis Schedule* and facilitates the test procedure.



At-risk Activity

Successor Activity

Link to the At-risk activity and its successor

Risks highly visible, easy to trace and verify, Easy to change Easy to turn on/off

Zero duration, does not alter schedule

	Cost	Name		Predecessors	Successors	Text28
185	$450,705.36	SSL Post Delivery Support	301 d	155		
186	$678,890.88	NGIMS Post Delivery Support	344 d	157	10	
187	**$789,000.00**	**◢ Education and Public Outreach**	**1708 d**			
188	$0.00	GSFC E/PO	1015 d	5	13	
189	$789,000.00	HQ E/PO	1015 d	5	13	
190	**$0.00**	**◢ MAVEN Risk Register**	**1696 d**			
191	$0.00	Risk #70 Launch Vehicle Selection	0 d	151	152	
		Risk #69 - APP In-flight Calibration	0 d			
		Risk #75 - HEPS Card Design	0 d			
		Risk #45 - Hardware Failure during I&T	0 d	161	162	
		Risk #76 - Commitment of Spares from Other Programs	0 d			
		Risk #77 - Solar Array LAPSS Testing	0 d	105	151	
		Risk #N1 - DET Electronics	0 d	94	157	
		Risk #78 - MAG Sensor Location	0 d	52	155	
199	$0.00	Risk #79 - STATIC Reliability	0 d	36	160	
200	$0.00	Risk #P10 - Operational Heaters	0 d	107	152	
201	$0.00	Risk #80 - Flight Operation Complexity	0 d	118	10	
202	$0.00	Risk #68 -New Flight Operations T&C Ground System	0 d	132	133	
203	$0.00	Risk #81 - Launch Vehicle Environment	0 d			
204	$0.00	Risk #SMS1 - MAG SIP Costs	0 d			
205	$0.00	Risk #SMS2 - Parts Estimates	0 d			
206	$0.00	Risk #SMS3 - Spacecraft ATLO Risk Pool	0 d			
207	$0.00	Risk #SMS4 - S/C ATLO Staffing	0 d			

Figure 6-31. This illustration is an excerpt from an MS Project file showing the technique for appending the risk file and linking the risks in the schedule.

Other Considerations When Mapping Risks

The strategies for mapping a risk depends on the nature of the risk. The risk strategy field describes the approach used to model the way in which the risk will impact the schedule. The important thing about the strategy used is that it properly models the P/p's response to the risk should it occur. A few examples are discussed below.

- **Activity Duration Impact.** This is the most commonly-used risk modeling approach. As shown in Figure 6-32, activity duration impact is modeled as a delay task, for example a zero-duration activity (a milestone) inserted between the risk-impacted activity and its successor. A likelihood of occurrence and an impact probability distribution are assigned to the zero-duration activity. When the Monte Carlo simulation tool randomly selects "True" for the likelihood of occurrence, a random sample is drawn from the impact probability distribution and assigned to the duration field.

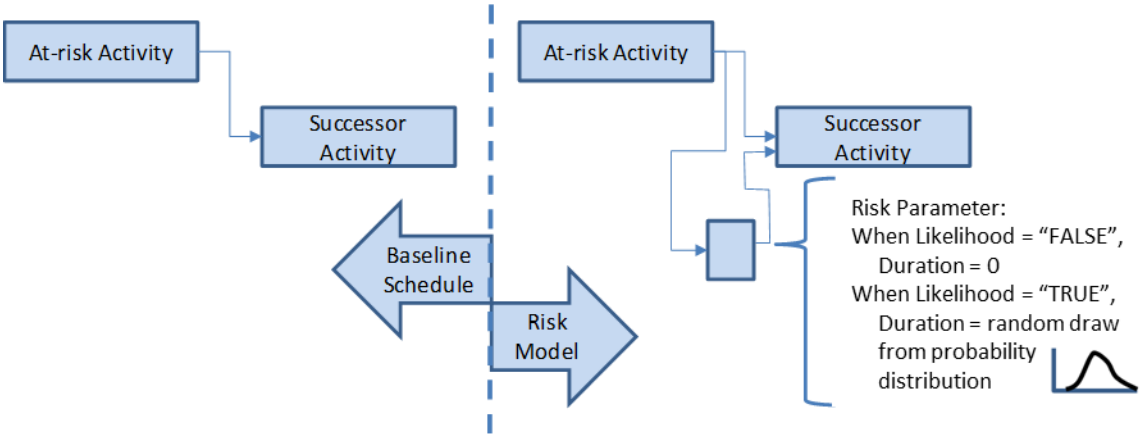


Figure 6-32. On the left side of this figure is how the at-risk activity appears in the P/p schedule network and on the right side is how the Delay-Activity risk parameter is applied.

- **Delayed Start.** This approach is similar to the Activity Duration Impact above except that the risk is attached to the start of the At-risk Activity.
- **Delayed Completion.** Likewise, for a delayed completion, the At-risk Activity's duration is not impacted, but the delivery of the product to the next activity is delayed by the risk.
- **Probabilistic Branching.** "Branching" occurs when there is more than one possible path. As shown in Figure 6-33, the Monte Carlo simulation tool randomly selects a "TRUE" for the likelihood of occurrence, a set of branch activities are executed. The branched activities may also have at-risk activities within the branch. A typical example is when the P/p is pursuing two or more alternative solutions and Activity 1 is a test or other selection process with associated likelihoods of success for either solution used for the switch. In this case both solutions pass through Activity 2 and 3 but one alternative solution requires additional activities such as additional software or additional secondary structure.

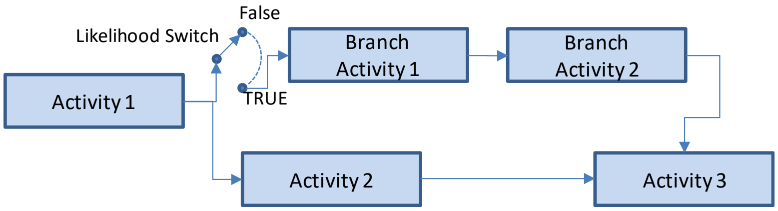


Figure 6-33. The figure illustrates how probabilistic branching models are used.

- **Conditional Branching.** This risk modeling approach is very similar to the probabilistic branch modeling approach above; however, the path taken depends on the completion of a predecessor path. Rather than the switch being activated by a random draw, the switch actuator is replaced with a conditional statement that actuates the switch. IF [Condition] = TRUE, THEN execute branch activities. An example often experienced is during Integration and Test (I&T). The "IF" test is for the delivery of the Flight Module X into integration and test activity. If not delivered, then the branch is to use an Engineering Development Unit for Flight

Module X, complete the testing, then when the flight unit is ready, swap out then perform regression testing.

- **Parallel and Serial Risks.** Parallel risks are separate, independent risks whose impacts can be resolved separately. For example, Integration and Test has two risks (1) Module X can fail during vibration testing and (2) Module Y may fail during vibration testing. Should either or both fail, they can be redesigned/repaired and re-integrated separately and the one taking the longest time is the driver. Serial risks are risks whose impacts are cumulative. An example is Module X has the following two risks during acceptance testing: (1) Module X may not meet a performance requirement, and (2) Module X may not meet a power consumption requirement. Risk 1 must be resolved before exposure to risk 2 can occur. These risks will be cumulative. These two types are illustrated in Figure 6-34.

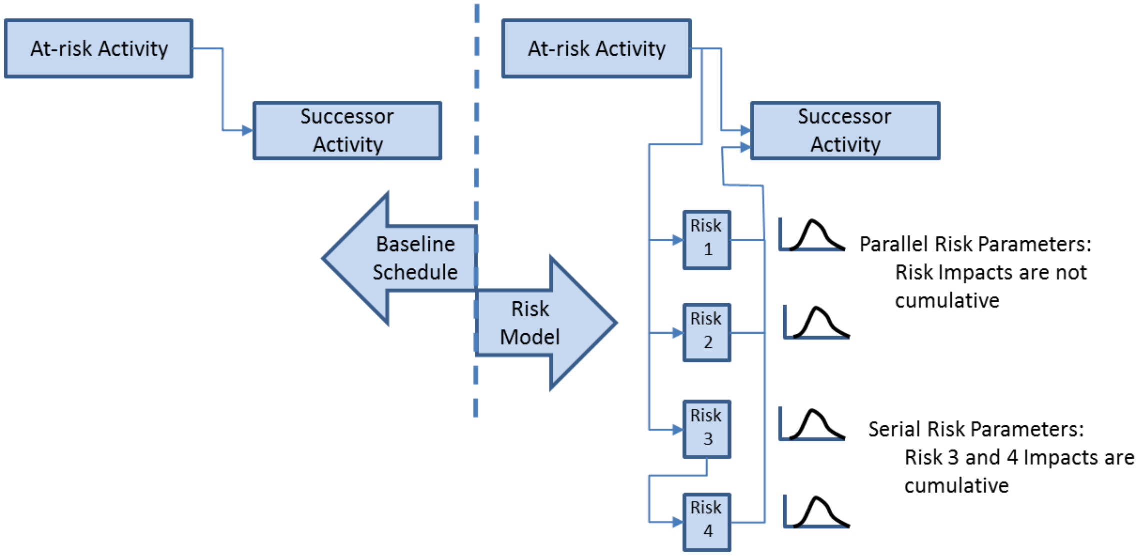


Figure 6-34. The figure illustrates parallel and serial risks.

Cautions When Mapping Risks

Another important consideration regarding the mapping of discrete is as follows:

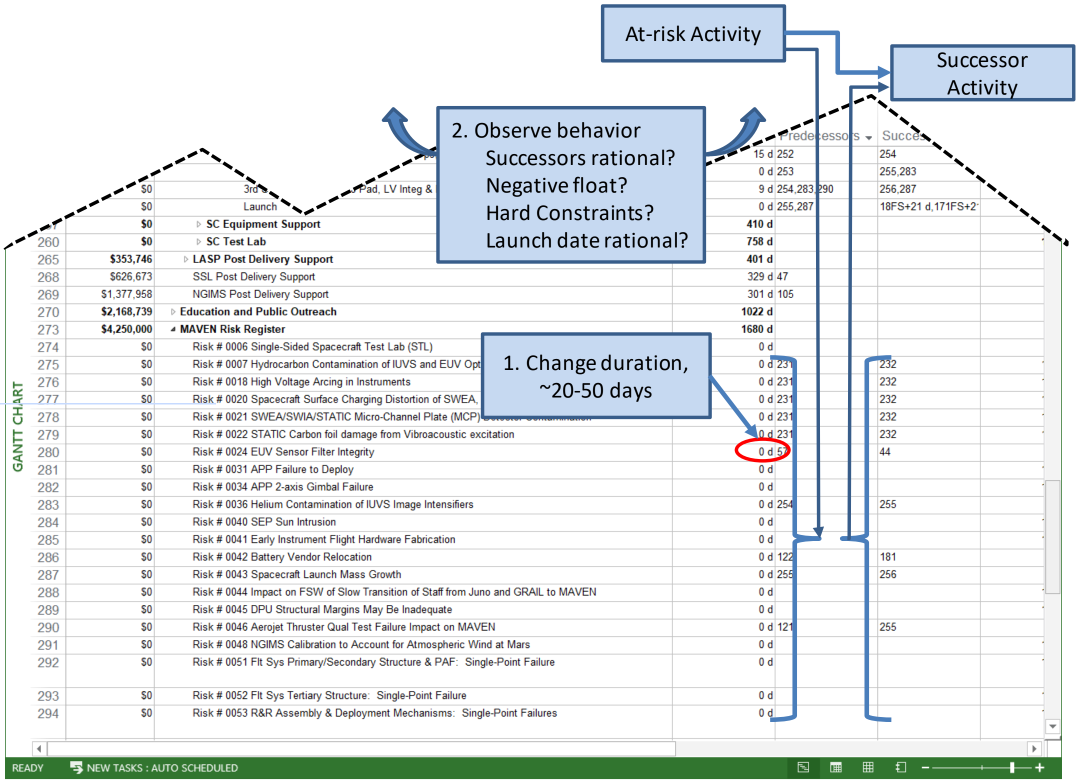
- **Double Counting by Over-Mapping.** It is important to ensure that risks are appropriately linked to the activities that they directly affect. While it may be assumed that a risk affects a string of activities, mapping the risk to multiple activities along the same logic path, may result in the risk being double- (or triple-, etc.) counted. It is a recommended practice that a discrete risk be mapped to the first activity in the string of activities that it affects, as the risk impact will ripple through the logic, potentially pushing the string of activities to the right (assuming little to no float is on the activities in the path). If there are similar risks affecting multiple activities along the same path, it is a recommended practice to capture and map these risks as discrete risks with individual identifiers. Depending on the nature of the risk, it *may* be appropriate to map to additional activities that are on different logic paths, (e.g., if a late delivery impacts multiple schedule paths).

6.3.2.3.6 Procedure 6. Test and Verify the Discrete Schedule Risk Inputs

It is a best practice for the discrete schedule risk inputs to the SRA Model to be reviewed to ensure that they are captured and calculating correctly in the SRA Model prior to running the simulation, and that they represent the intended model of the schedule risk. Specifically, the discrete risks inputs should be tested to make sure that the schedule network responds appropriately. The Schedule Analyst can check to see how the risks are calculating by arbitrarily changing the duration of the risk, assuming the risk is on the critical path. The risk is initially loaded as a milestone with a duration of zero days. The Monte Carlo simulation tool draws samples from the risk parameters that are loaded for that risk and then changes the duration appropriately.

To test the calculation, arbitrarily change the duration of the risk and observe the dynamics of the schedule. For example, if the At-risk Activity has 10 days of total float, then changing the risk to have a 10-day duration should not change the completion date, but it would make the activity become critical. Every increment added to the risk beyond that point should also move the completion date by an equal amount of days.

Should this not be the case and negative float is incurred for the At-risk Activity, then there is a "hard" constraint downstream of the activity that must be removed. This constraint can usually be found by searching the constraint field for the following constraints: Must Finish On, Finish No Later Than, Must Start On, or Start No Later Than. When found, change the constraint to the appropriate constraint, such as "ASAP" or "Start No Earlier Than". Figure 6-35 illustrates the test.



				Predecessors	Succe
			15 d	252	254
			0 d	253	255,283
	$0	3rd	9 d	254,283,290	256,287
	$0	Launch	0 d	255,287	18FS+21 d,171FS+2
	$0	▷ **SC Equipment Support**	**410 d**		
260	**$0**	▷ **SC Test Lab**	**758 d**		
265	**$353,746**	▷ **LASP Post Delivery Support**	**401 d**		
268	$626,673	SSL Post Delivery Support	329 d	47	
269	$1,377,958	NGIMS Post Delivery Support	301 d	105	
270	**$2,168,739**	▷ **Education and Public Outreach**	**1022 d**		
273	**$4,250,000**	◢ **MAVEN Risk Register**	**1680 d**		
274	$0	Risk # 0006 Single-Sided Spacecraft Test Lab (STL)	0 d		
275	$0	Risk # 0007 Hydrocarbon Contamination of IUVS and EUV Opt	0 d	231	232
276	$0	Risk # 0018 High Voltage Arcing in Instruments	0 d	231	232
277	$0	Risk # 0020 Spacecraft Surface Charging Distortion of SWEA,	0 d	231	232
278	$0	Risk # 0021 SWEA/SWIA/STATIC Micro-Channel Plate (MCP) Detector Contamination	0 d	231	232
279	$0	Risk # 0022 STATIC Carbon foil damage from Vibroacoustic excitation	0 d	231	232
280	$0	Risk # 0024 EUV Sensor Filter Integrity	0 d	57	44
281	$0	Risk # 0031 APP Failure to Deploy	0 d		
282	$0	Risk # 0034 APP 2-axis Gimbal Failure	0 d		
283	$0	Risk # 0036 Helium Contamination of IUVS Image Intensifiers	0 d	254	255
284	$0	Risk # 0040 SEP Sun Intrusion	0 d		
285	$0	Risk # 0041 Early Instrument Flight Hardware Fabrication	0 d		
286	$0	Risk # 0042 Battery Vendor Relocation	0 d	122	181
287	$0	Risk # 0043 Spacecraft Launch Mass Growth	0 d	255	256
288	$0	Risk # 0044 Impact on FSW of Slow Transition of Staff from Juno and GRAIL to MAVEN	0 d		
289	$0	Risk # 0045 DPU Structural Margins May Be Inadequate	0 d		
290	$0	Risk # 0046 Aerojet Thruster Qual Test Failure Impact on MAVEN	0 d	121	255
291	$0	Risk # 0048 NGIMS Calibration to Account for Atmospheric Wind at Mars	0 d		
292	$0	Risk # 0051 Flt Sys Primary/Secondary Structure & PAF: Single-Point Failure	0 d		
293	$0	Risk # 0052 Flt Sys Tertiary Structure: Single-Point Failure	0 d		
294	$0	Risk # 0053 R&R Assembly & Deployment Mechanisms: Single-Point Failures	0 d		

Figure 6-35. Test the risk parameters by simulating risk impact with the change of a risk duration. Observe schedule response.

Once the risk inputs have been tested and the *SRA Model* is in working order, the Schedule Analyst can either integrate costs to create an *ICSRA Model* or begin executing the analysis. The following Section 6.3.2.4 describes the *Build the ICSRA Model* process. Section 6.3.2.5 describes the *Analysis Execution Process*.

6.3.2.4 Build the ICSRA Model

Per the NASA Cost Estimating Handbook, NASA employs cost-risk assessments on its space flight missions in order to understand uncertainties and risks and help ensure that resources and plans are adequate to deliver P/ps on time and within budget. Cost uncertainties and risks must be carefully and quantitatively assessed in developing and presenting any cost estimate for several reasons. First, when trade studies are conducted, a single cost estimate, such as an expected cost, may mislead the trade team by not revealing the potential for overruns. Second, at Confirmation Reviews and Authority to Proceed (ATP) decision points, the cost estimate must include an appropriately chosen level of unallocated future expense (UFE) to achieve a desired confidence level. The objective of a cost-risk analysis is to produce a credible P/p cost cumulative distribution function (CDF, or “S-curve”) for the range of costs of the P/p. The objective of the integrated cost and schedule risk analysis, or *ICSRA*, is to identify the probability that the given P/p’s cost will be equal or less than the targeted cost *and* the schedule will be equal or less than the targeted schedule date.

This handbook assumes that the *SRA Model* exists as an entrance criterion for building the *ICSRA Model*. Therefore, this process is discussed hereinafter as an appendage to the *SRA*. Figure 6-36 below, illustrates the *Build the ICSRA Model* process. It consists of eight procedures. Procedure 1 sets up the *ICSRA Model* to be able to incorporate the costs, as well as the cost uncertainties and cost risks and execute the risk analysis. Procedure 2 defines and formats the costs to be loaded into the *ICSRA Model*. Procedure 3 maps and loads the costs. Procedure 4 loads the cost uncertainty parameters from the *BoE*. Procedure 5 applies any necessary correlation factors to the costs. Procedure 6 defines and loads the discrete cost risk parameters based on input from the RMS. Procedure 7 maps the discrete cost risks to relevant activities, and Procedure 8 tests and verifies that the model is calculating as expected. **Note:** The examples discussed in this process and all its procedures are specific to MS Project.

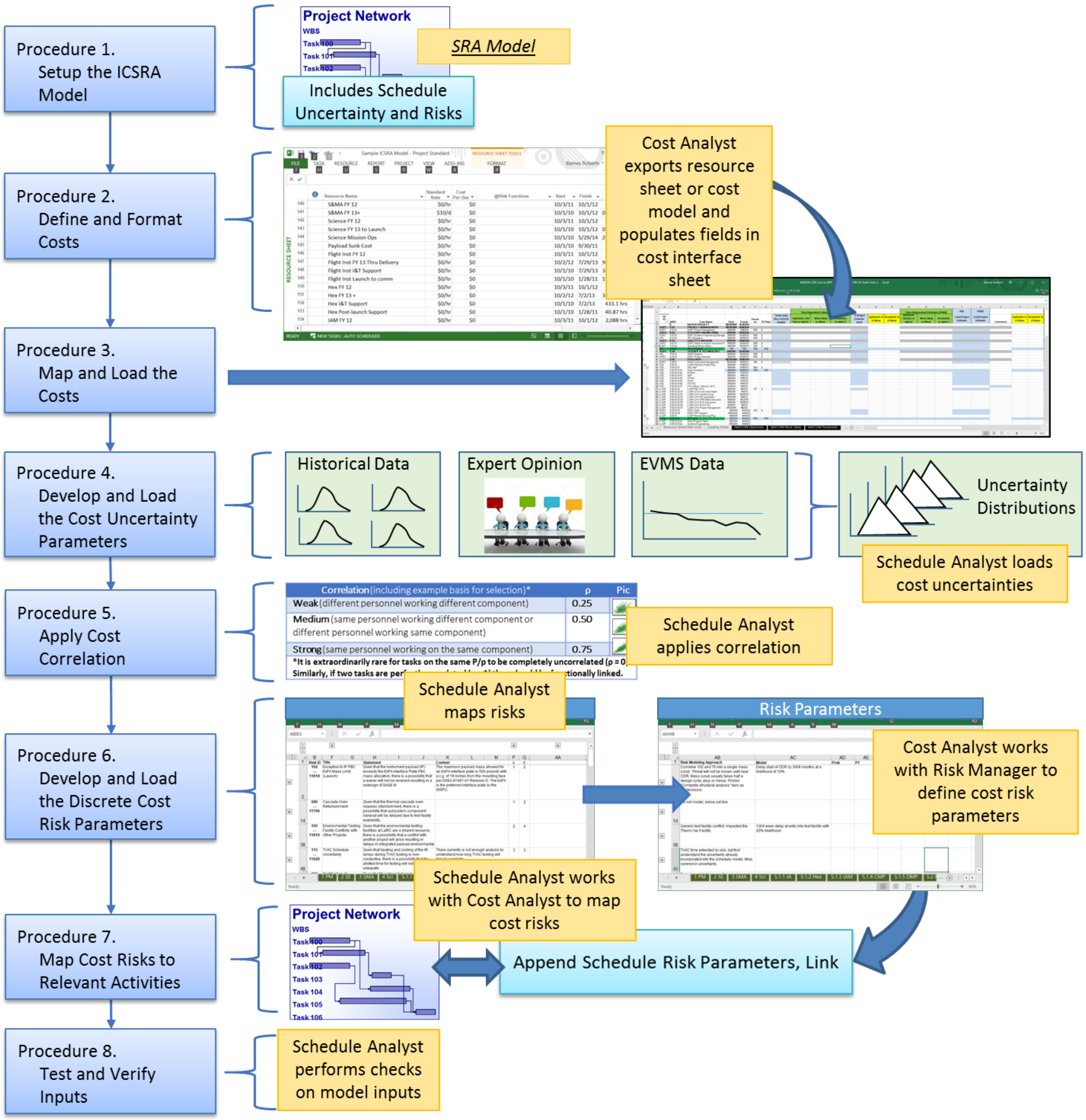


Figure 6-36. The figure illustrates the six procedures for construction of the ICSRA.

The schedule network shown in the figure is the fully loaded *SRA Model* as described in Section 6.3.2.3. Hammock tasks may need to be appended to the schedule to enable the mapping of costs, thus beginning the transition of the *SRA Model* to the *ICSRA Model*. The hammocks are linked into the appropriate driver activities in the *ICSRA Model*. Cost estimates are acquired for each of the hammock tasks. This is done by exporting the assigned resources from the Resource Sheet (MS Project) into an MS Excel workbook and providing to the Cost Analyst to fill in the cost data for the resources as listed. Costs are then mapped to appropriate activities or hammocks in the schedule. Additional cost data and formulas to calculate the uncertainty parameters for any relevant costs are included. The uncertainties are not usually subject to trade studies and mitigation options analysis and therefore relatively static. Also, their parameters are generally simple. For these reasons, experience has shown that they are more easily loaded and managed if they are placed directly into the schedule versus through an interface sheet. The fields needed for the risk and uncertainty parameters were identified in the *Activity Attributes Table*. Correlation is applied to costs, as appropriate. The risk data file is then exported from the P/p's risk management database. Therein, quantified risk parameters are appended to the relevant risks in the database. The form and format of the risk parameters must comply with the input needed by the *ICSRA* software selected per the Schedule Management Planning sub-function. Then, the cost risks are loaded into the *ICSRA Model* and mapped to relevant activities. The *ICSRA Model*, all input documentation, and all results documentation should be maintained in the same archive location such that they can be revisited at any time for additional risk sensitivity studies or data extract for trend analyses. The following sections discuss each procedure.

6.3.2.4.1 Procedure 1. Setup the ICSRA Model

Similar to setting up the *SRA Model*, ***it is a best practice for the IMS to be used as the framework for the ICSRA, when feasible***. As previously mentioned, when building the *ICSRA*, the *SRA* is constructed first, then tested and verified, and finally the cost model and associated cost uncertainty and cost risk parameters are added. This document assumes that this practice is followed and the *SRA* is complete and tested prior to construction of the cost parameters. Most Monte Carlo simulation tools support cost and risk data entry in MS Excel or in the scheduling tool. However, using that capability complicates the test and verification of the *ICSRA*. Therefore, it is a recommended practice to append the cost model directly to the *IMS* or the *Analysis Schedule*.

Since traditional resource-loaded schedules are a rarity within NASA, the handbook focuses on the development of cost hammocks and cost loading the schedule to produce the *ICSRA Model*. Thus, modeling techniques are needed that will allocate cost input, as well as cost uncertainty and cost risk parameters to the work activities in the schedule. Furthermore, a typical cost estimate WBS may not map one-for-one to a schedule WBS. Even if the WBSs were the same, levels of detail may vary between the cost estimate data and the schedule. "Hammock" tasks can be added to the *ICSRA Model* when costs are to be mapped to the schedule, but the schedule is significantly more detailed than the available cost data or the required fidelity of the cost modeling.

The hammock modeling approach aims to focus on a logical section of the schedule that contains a series of activities that are all sequentially linked via finish-to-start relationships. An example would be for a set of many activities that are not exposed to schedule risks and may therefore be summarized at a very high level. As illustrated in Figure 6-37, the hammock activity is an activity that is linked to the start date of the first activity in this sequence and to the end date of the last activity—the name comes from this anchoring to the first and last activities, which is analogous to two trees that anchor a hammock. The cost hammock is linked start-to-start (SS) to Activity 1 and Activity 2 is linked finish-to-finish (FF) to the cost hammock. Consequently, when the simulation runs, the cost hammock dynamically expands, or contracts allowing the costs to increase or decrease depending on the behavior of the tasks under it.

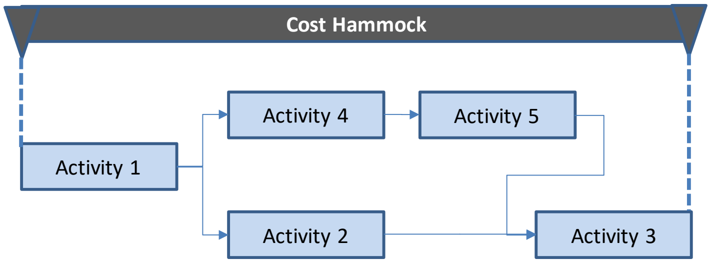
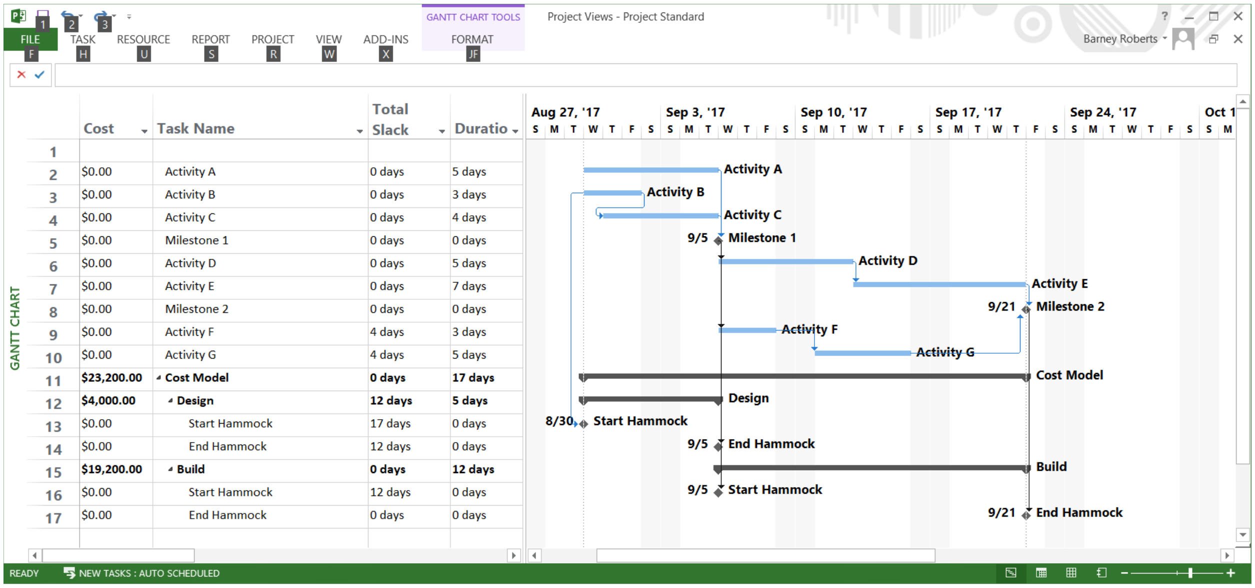


Figure 6-37. The general concept of a hammock task is illustrated in this figure.

Tips on Building the Cost Hammocks

In Figure 6-38, the cost estimate provides values for the Design Activity and the Build Activity. Design costs $100/hour and the Build costs $200/hour. The Design activity hammock summarizes activities A, B, and C, and stretches from the start of Activity B to Milestone 1. The Build cost hammock summarizes the Activities D, E, F and G, and stretches from Milestone 1 to Milestone 2. Below the figure, two cases are discussed that describe when the hammocks are valid and when they are not valid and what one must do to correct for those invalid cases.



	Cost	Task Name	Total Slack	Duratio
1				
2	$0.00	Activity A	0 days	5 days
3	$0.00	Activity B	0 days	3 days
4	$0.00	Activity C	0 days	4 days
5	$0.00	Milestone 1	0 days	0 days
6	$0.00	Activity D	0 days	5 days
7	$0.00	Activity E	0 days	7 days
8	$0.00	Milestone 2	0 days	0 days
9	$0.00	Activity F	4 days	3 days
10	$0.00	Activity G	4 days	5 days
11	**$23,200.00**	**Cost Model**	**0 days**	**17 days**
12	**$4,000.00**	**Design**	**12 days**	**5 days**
13	$0.00	Start Hammock	17 days	0 days
14	$0.00	End Hammock	12 days	0 days
15	**$19,200.00**	**Build**	**0 days**	**12 days**
16	$0.00	Start Hammock	12 days	0 days
17	$0.00	End Hammock	0 days	0 days

Figure 6-38. The figure illustrates two cost hammocks appended to a schedule foe a design and build activity.

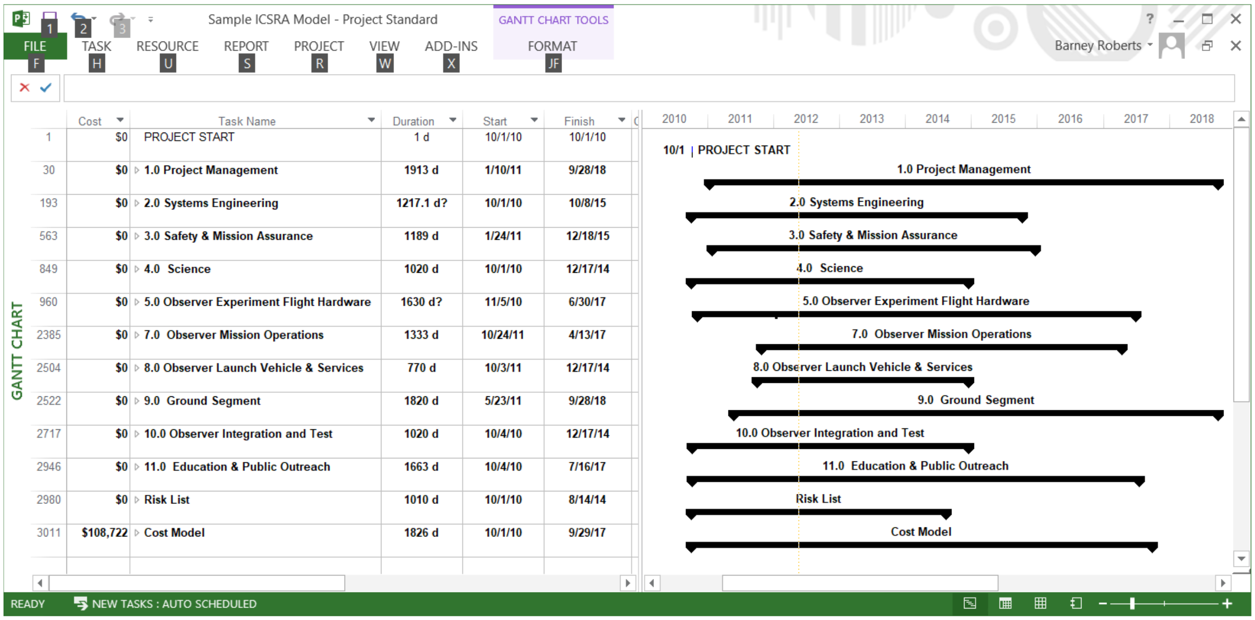
- **Case 1: Design Hammock.** The hammock is valid if A, B, and C do not finish early due to risk or uncertainty. Early finishes for those activities will not shrink the design hammock activity and therefore the cost savings due to early finish cannot be captured. If A finishes early, C will still drive the end date of the hammock, and vice versa. Exception: activity A and C finish the same number of days early and the hammock will make the correct calculation. Should there be no risks applied to activities A, B, or C and the uncertainties are similar, the hammock activity, with a composite uncertainty, is a good approximation. Also, just because A, B, or C have the potential to finish early and the savings are not accrued does not necessarily mean that the Schedule Analyst needs to further refine the model. The error may be so small that the additional fidelity is not worth the effort to further decompose the model.

- **Case 2: Build Hammock.** Early finishes, as discussed in Case 1, invalidate the hammock. In addition, for Case 2, activity G has 4 days of total float. Should activity G run long due to risk or uncertainty, the additional costs incurred are not captured by the hammock until the 4 days of float are used up. This case may or may not be a negligible impact.

The Schedule Analyst will always be challenged with making decisions of fidelity versus model complexity. Should either of these cases produce an undesirable error, the hammock must be abandoned and subdivided into two or more hammocks. Should the cost estimate not be available at that lower level, the Schedule Analyst must either ratio the costs based on assumed complexity ratio or simply ignore the error. When such decisions are made, the Schedule Analyst must document the decision rationale/assumptions in the *BoE*.

Cautions When Setting Up the ICSRA Model

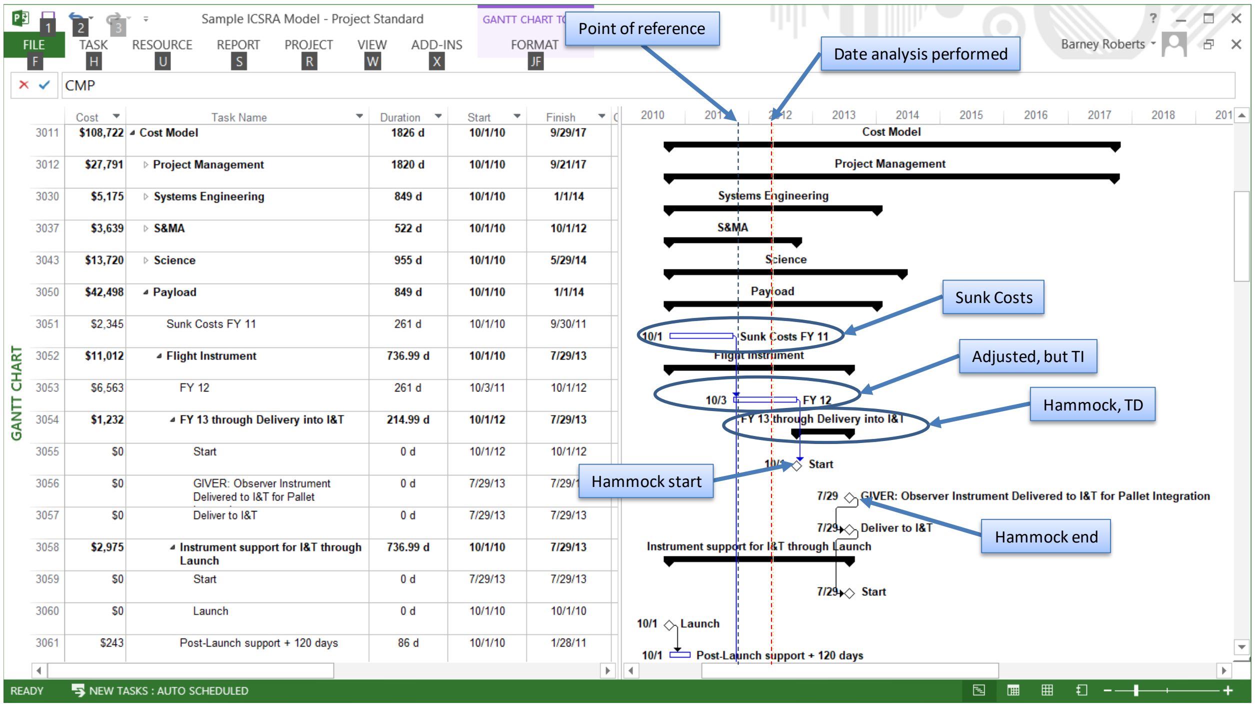
Figure 6-39 is the *ICSRA* from a NASA project (activity names changed to comply with data restrictions). For traceability purposes, the cost model is added to the *SRA* just below the risk list at the bottom of the MS Project file. The cost parameters have been assigned simulated resources and the costs are calculated to be $109M. This specific *ICSRA* will be used in this section to further describe the cost parameter development procedures.



	Cost	Task Name	Duration	Start	Finish
1	$0	PROJECT START	1 d	10/1/10	10/1/10
30	$0	1.0 Project Management	1913 d	1/10/11	9/28/18
193	$0	2.0 Systems Engineering	1217.1 d?	10/1/10	10/8/15
563	$0	3.0 Safety & Mission Assurance	1189 d	1/24/11	12/18/15
849	$0	4.0 Science	1020 d	10/1/10	12/17/14
960	$0	5.0 Observer Experiment Flight Hardware	1630 d?	11/5/10	6/30/17
2385	$0	7.0 Observer Mission Operations	1333 d	10/24/11	4/13/17
2504	$0	8.0 Observer Launch Vehicle & Services	770 d	10/3/11	12/17/14
2522	$0	9.0 Ground Segment	1820 d	5/23/11	9/28/18
2717	$0	10.0 Observer Integration and Test	1020 d	10/4/10	12/17/14
2946	$0	11.0 Education & Public Outreach	1663 d	10/4/10	7/16/17
2980	$0	Risk List	1010 d	10/1/10	8/14/14
3011	$108,722	Cost Model	1826 d	10/1/10	9/29/17

Figure 6-39. Sample ICSRA showing the risk list and the cost model appended at the bottom of the IMS.

Example: Flight Instrument Cost-loading Model. Figure 6-40 shows an expanded view of the cost modeling from the project example shown in Figure 6-39 and includes several important considerations (i.e., cautions) regarding the simulation approach. The analysis took place in spring of 2012 and it was a straight forward forecast of how the next five months would go for FY12. Thus, the FY12 cost model was simply the FY12 estimate adjusted by the cost performance index and was loaded as a TI cost that was evenly spread over FY12. This FY12 approach was repeated for all other components except for those exposed to a risk that may occur in those next 5 months. Those cases were modeled as time dependent with a risk assigned. The Flight Instrument activity after FY12, was exposed to several risks and a hammock was built to accommodate the cost model variability due to risks and uncertainties. The hammock start date is the beginning of FY13 via a link from the FY12 fixed model and ends where the instrument is completely integrated and delivered to System Integration and Test (I&T), modeled by a link back up into the *IMS* where that event occurs. Thus, in the body of the *IMS*, as the Flight Instrument experiences delays due to risk and uncertainty and is late for delivery into I&T, the cost hammock is "stretched" via that link and will accumulate the additional costs for the delay.



	Cost	Task Name	Duration	Start	Finish
3011	**$108,722**	**Cost Model**	**1826 d**	**10/1/10**	**9/29/17**
3012	**$27,791**	**Project Management**	**1820 d**	**10/1/10**	**9/21/17**
3030	**$5,175**	**Systems Engineering**	**849 d**	**10/1/10**	**1/1/14**
3037	**$3,639**	**S&MA**	**522 d**	**10/1/10**	**10/1/12**
3043	**$13,720**	**Science**	**955 d**	**10/1/10**	**5/29/14**
3050	**$42,498**	**Payload**	**849 d**	**10/1/10**	**1/1/14**
3051	$2,345	Sunk Costs FY 11	261 d	10/1/10	9/30/11
3052	**$11,012**	**Flight Instrument**	**736.99 d**	**10/1/10**	**7/29/13**
3053	$6,563	FY 12	261 d	10/3/11	10/1/12
3054	**$1,232**	**FY 13 through Delivery into I&T**	**214.99 d**	**10/1/12**	**7/29/13**
3055	$0	Start	0 d	10/1/12	10/1/12
3056	$0	GIVER: Observer Instrument Delivered to I&T for Pallet	0 d	7/29/13	7/29/1
3057	$0	Deliver to I&T	0 d	7/29/13	7/29/13
3058	**$2,975**	**Instrument support for I&T through Launch**	**736.99 d**	**10/1/10**	**7/29/13**
3059	$0	Start	0 d	7/29/13	7/29/13
3060	$0	Launch	0 d	10/1/10	10/1/10
3061	$243	Post-Launch support + 120 days	86 d	10/1/10	1/28/11

Figure 6-40. This figure shows the cost model for the Flight Instrument activity along with other important notes.

- **Point of Reference**. For any programmatic analysis, the P/p must establish a Point of Reference. In Figure 6-40, the schedule Point of Reference is the beginning of fiscal year 2012 (see the left-most dashed vertical line on the schedule) and corresponds to "point estimate" for cost. It is critically important that the P/p can provide a complete and consistent set of data inputs for the analysis; technical, cost, schedule and risks must all be to the same reference point. For example, the cost data cannot contain the cost for a contract change order whose schedule impact is not contained within the *IMS*, or *Analysis Schedule*, if used. This consistency is absolutely necessary to be able to confirm the cost inputs and verify their performance. It is acceptable to use post-processing or perform sensitivity analyses to show the impacts of proposed changes. However, the cost model must have a firm and consistent *BoE* that is formally documented. This specific project chose the beginning of fiscal year 2012 (FY12) as the Point of Reference because the financial system supported an accurate accounting of all costs and a calculation of the sunk costs to that point. Therefore, all costs to FY12 are considered fixed and the variable cost models are from that point on.

- **Date of Analysis.** For this project, the analysis was conducted in the spring of 2012. It is important to have the Point of Reference as close as possible to the analysis date to minimize the impacts of changes from the Point of Reference date to the analysis date.
- **Sunk Costs.** For the Payload subsystem, all sunk costs are modeled as a TI cost spread over FY11. Likewise, but not shown in the figure, each subsystem of the project had a similar sunk cost model. Sunk costs were distributed to the subsystems to facilitate the verification by being able to check that the component cost models would sum to the subsystem level.
- **Cost Loading.** A risk-informed, "resource-loaded" *SRA* model forms the *ICSRA*. Care should be taken when considering the approach necessary to assign and allocate resources that will be integrated with uncertainties and risks in the *ICSRA model*. To build a reliable *ICSRA Model* and satisfy Agency requirements, the schedule should at a minimum be cost loaded. As discussed in Section 5.5.12, budget loading the schedule should be avoided as it may not account for inherent cost uncertainties and risks and would therefore not give an accurate projection of the P/p's cost. However, it is possible that cost loading may ultimately double count uncertainties and risks if the uncertainties and risks are not traceable to the cost estimate. This can be avoided with proper documentation of both the cost estimate and the planned schedule in the *BoE*. More fidelity could be achieved by resource loading the schedule; although, the time required to do so may create inefficiencies for the purposes of creating an ICRSA if resource loading is not already part of the P/p's day-to-day work.

6.3.2.4.2 Procedure 2. Define and Format Costs to be Loaded into the ICSRA Model

It is a best practice for a cost model that replicates the P/p cost estimate to be defined and formatted for the purposes of performing an ICSRA. It should be noted that a "cost model" is not a "cost estimate." Developing a cost estimate is a formal analysis process that generates the actual expected costs for each WBS item in the P/p plan per the cost estimating techniques defined in the NASA Cost Estimating Handbook. The cost model as defined herein, is a mathematical model attached to the schedule that replicates the cost estimate. For example, a cost estimate may go to a very low-level of detail that is not needed for the *ICSRA*. Therefore, the cost model in the *ICSRA* will replicate the cost estimate at a much higher level. In addition, the cost model is developed in such a way that will allow for cost growth due to schedule growth caused by schedule risks and uncertainties, as well as cost growth due to cost risks and uncertainties. The cost uncertainties and cost risks, which are captured by parameters similar to those for schedule duration uncertainties and schedule risks, are covered in the following procedures.

The P/p's Cost Analyst provides the cost estimates to the Schedule Analyst in the *Collect Data* process detailed in Section 6.3.2.2 for inclusion in the *ICSRA Model*. This is best accomplished through the use of a spreadsheet. Most scheduling software tools can export an MS Excel sheet with the assigned resources. The Schedule Analyst can export the resource spreadsheet and add extra columns where the Cost Analyst can capture cost inputs, including parameters to reflect the uncertainty and risk related to the costs.

Figure 6-41 shows an example from a NASA project to demonstrate the procedure. Step 1 is to export the resource sheet into an MS Excel worksheet. The upper part of the figure is the Resource Sheet from MS Project and it is shown being mapped into MS Excel via the downward pointing blue arrow on the left. Step 2 is to modify that worksheet to be able to capture all of the needed cost, risk, and uncertainty data. This is the worksheet image across the lower part of the figure. Once completed the sheet becomes the “Cost Interface” sheet and is used as the standard interface between the Cost Analyst and the Schedule Analyst and supports the _ICSRA_ throughout the P/p life cycle.

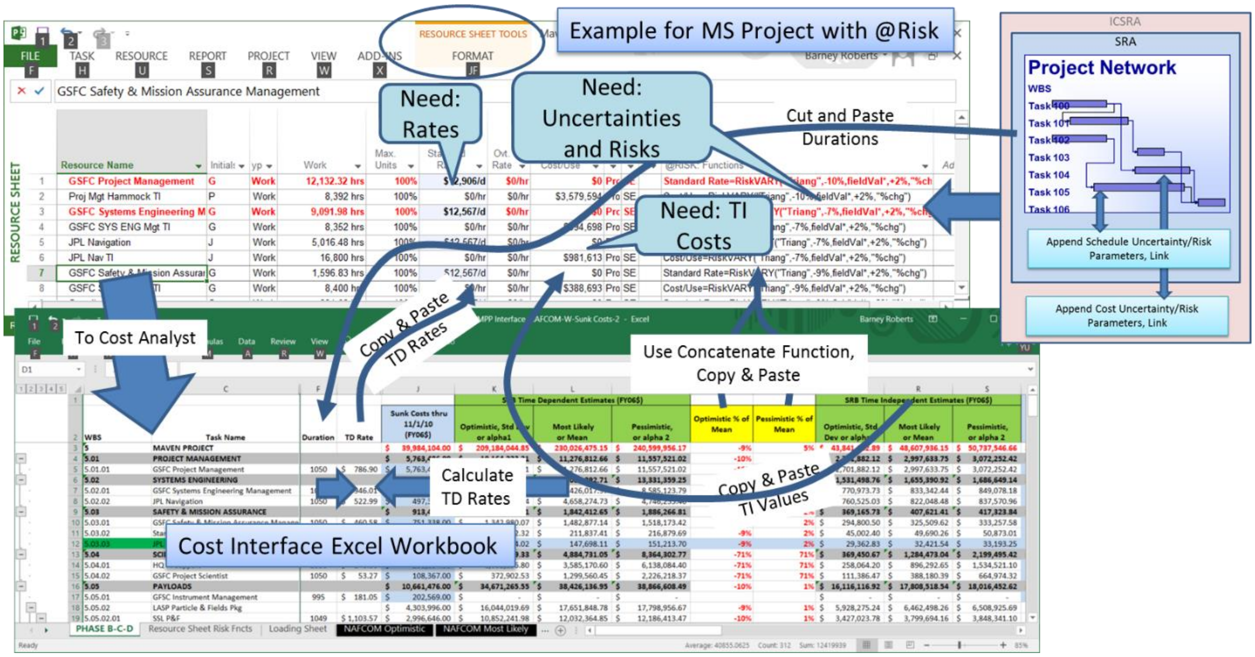
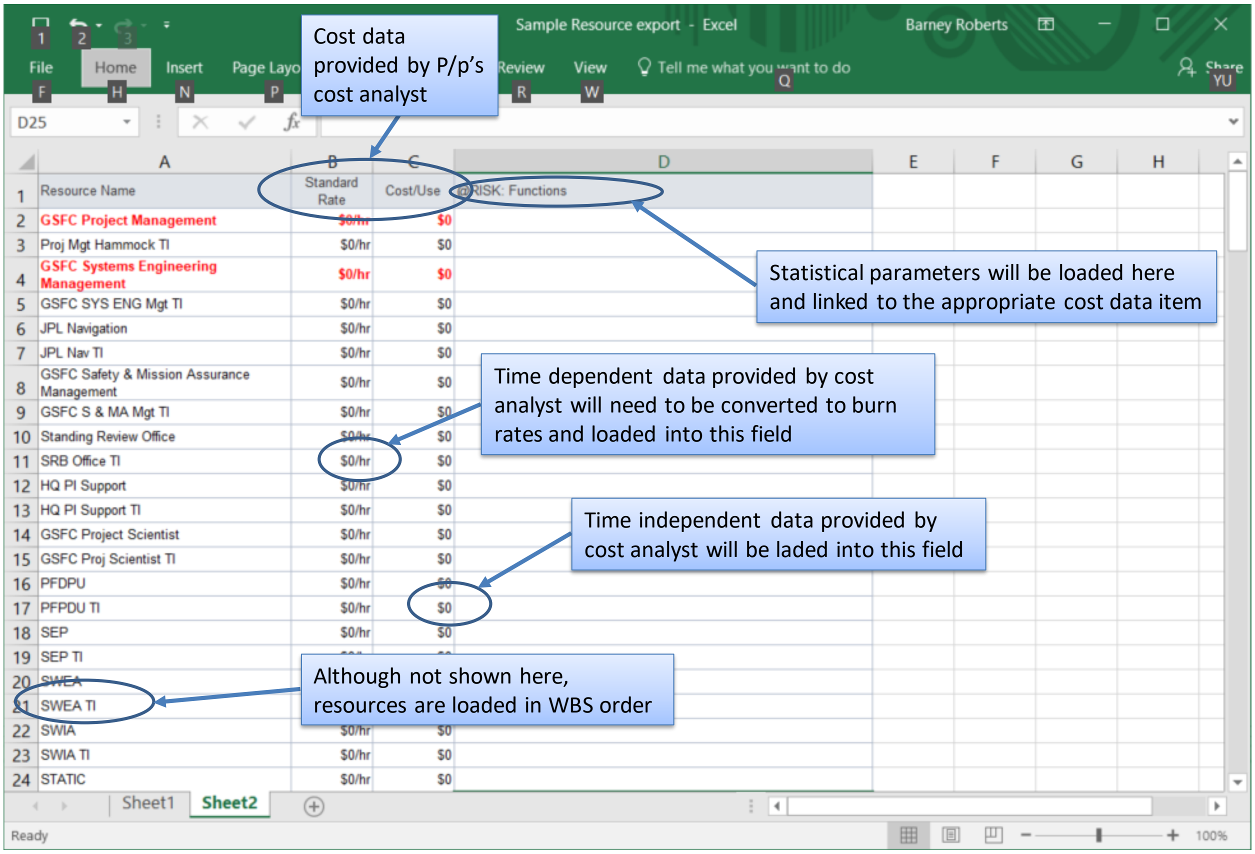


Figure 6-41. Example case of mapping costs from the cost model to the MS Project Resource Sheet.

6.3.2.4.2.1 Step 1. Export Resource Sheet

From our example case, the Resource Sheet from MS Project was copied and pasted into an MS Excel worksheet. Figure 6-42 is an excerpt from that worksheet. The Schedule Analyst needs to maintain the order of the resources so that they can be easily copied and pasted back into the scheduling software’s resource fields upon completion.



Cost data provided by P/p's cost analyst

Statistical parameters will be loaded here and linked to the appropriate cost data item

Time dependent data provided by cost analyst will need to be converted to burn rates and loaded into this field

Time independent data provided by cost analyst will be laded into this field

Although not shown here, resources are loaded in WBS order

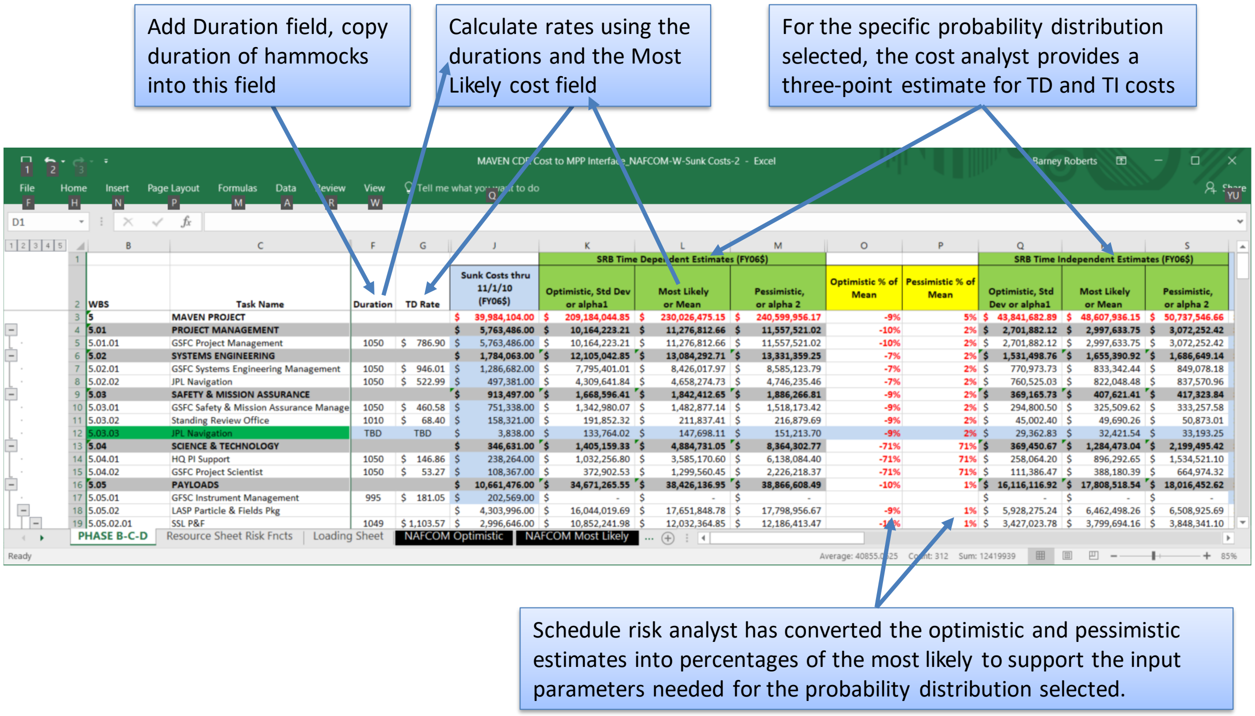
	A	B	C	D
1	Resource Name	Standard Rate	Cost/Use	@RISK: Functions
2	**GSFC Project Management**	**$0/hr**	**$0**	
3	Proj Mgt Hammock TI	$0/hr	$0	
4	**GSFC Systems Engineering Management**	**$0/hr**	**$0**	
5	GSFC SYS ENG Mgt TI	$0/hr	$0	
6	JPL Navigation	$0/hr	$0	
7	JPL Nav TI	$0/hr	$0	
8	GSFC Safety & Mission Assurance Management	$0/hr	$0	
9	GSFC S & MA Mgt TI	$0/hr	$0	
10	Standing Review Office	$0/hr	$0	
11	SRB Office TI	$0/hr	$0	
12	HQ PI Support	$0/hr	$0	
13	HQ PI Support TI	$0/hr	$0	
14	GSFC Project Scientist	$0/hr	$0	
15	GSFC Proj Scientist TI	$0/hr	$0	
16	PFDPU	$0/hr	$0	
17	PFPDU TI	$0/hr	$0	
18	SEP	$0/hr	$0	
19	SEP TI			
20	SWEA			
21	SWEA TI			
22	SWIA	$0/hr	$0	
23	SWIA TI	$0/hr	$0	
24	STATIC	$0/hr	$0	

Figure 6-42. Example of resource sheet exported to Excel.

Per the figure, note that the TI costs will need to be loaded in the field labeled "Cost Per Use". The TD costs need to be loaded in the field labeled "Standard Rate". Since these are cost parameters rather than actual resources, the cost analyst will not have that specific rate data. The Cost Analyst will have the total cost for each of the cost parameters. In addition, the exported sheet needs additional columns to capture the cost uncertainties. For these reasons, the exported sheet needs modification to support the development of the *ICSRA Model*. This is the topic of the next step.

6.3.2.4.2.2 Step 2. Create the Cost Interface Sheet

In this step, the exported resource sheet is modified to add the extra columns for the capture of the complete set of data needed for the *ICSRA Model*. By way of example, Figure 6-43 shows the modifications made to the exported resource sheet shown in Step 1.



Add Duration field, copy duration of hammocks into this field

Calculate rates using the durations and the Most Likely cost field

For the specific probability distribution selected, the cost analyst provides a three-point estimate for TD and TI costs

Schedule risk analyst has converted the optimistic and pessimistic estimates into percentages of the most likely to support the input parameters needed for the probability distribution selected.

	B	C	F	G	J	K	L	M	O	P	Q	R	S
1						SRB Time Dependent Estimates (FY06$)					SRB Time Independent Estimates (FY06$)		
2	WBS	Task Name	Duration	TD Rate	Sunk Costs thru 11/1/10 (FY06$)	Optimistic, Std Dev or alpha1	Most Likely or Mean	Pessimistic, or alpha 2	Optimistic % of Mean	Pessimistic % of Mean	Optimistic, Std Dev or alpha1	Most Likely or Mean	Pessimistic, or alpha 2
3	5	MAVEN PROJECT			$ 39,984,104.00	$ 209,184,044.85	$ 230,026,475.15	$ 240,599,956.17	-9%	5%	$ 43,841,682.89	$ 48,607,936.15	$ 50,737,546.66
4	5.01	PROJECT MANAGEMENT			$ 5,763,486.00	$ 10,164,223.21	$ 11,276,812.66	$ 11,557,521.02	-10%	2%	$ 2,701,882.12	$ 2,997,633.75	$ 3,072,252.42
5	5.01.01	GSFC Project Management	1050	$ 786.90	$ 5,763,486.00	$ 10,164,223.21	$ 11,276,812.66	$ 11,557,521.02	-10%	2%	$ 2,701,882.12	$ 2,997,633.75	$ 3,072,252.42
6	5.02	SYSTEMS ENGINEERING			$ 1,784,063.00	$ 12,105,042.85	$ 13,084,292.71	$ 13,331,359.25	-7%	2%	$ 1,531,498.76	$ 1,655,390.92	$ 1,686,649.14
7	5.02.01	GSFC Systems Engineering Management	1050	$ 946.01	$ 1,286,682.00	$ 7,795,401.01	$ 8,426,017.97	$ 8,585,123.79	-7%	2%	$ 770,973.73	$ 833,342.44	$ 849,078.18
8	5.02.02	JPL Navigation	1050	$ 522.99	$ 497,381.00	$ 4,309,641.84	$ 4,658,274.73	$ 4,746,235.46	-7%	2%	$ 760,525.03	$ 822,048.48	$ 837,570.96
9	5.03	SAFETY & MISSION ASSURANCE			$ 913,497.00	$ 1,668,596.41	$ 1,842,412.65	$ 1,886,266.81	-9%	2%	$ 369,165.73	$ 407,621.41	$ 417,323.84
10	5.03.01	GSFC Safety & Mission Assurance Manage	1050	$ 460.58	$ 751,338.00	$ 1,342,980.07	$ 1,482,877.14	$ 1,518,173.42	-9%	2%	$ 294,800.50	$ 325,509.62	$ 333,257.58
11	5.03.02	Standing Review Office	1010	$ 68.40	$ 158,321.00	$ 191,852.32	$ 211,837.41	$ 216,879.69	-9%	2%	$ 45,002.40	$ 49,690.26	$ 50,873.01
12	5.03.03	JPL Navigation	TBD	TBD	$ 3,838.00	$ 133,764.02	$ 147,698.11	$ 151,213.70	-9%	2%	$ 29,362.83	$ 32,421.54	$ 33,193.25
13	5.04	SCIENCE & TECHNOLOGY			$ 346,631.00	$ 1,405,159.33	$ 4,884,731.05	$ 8,364,302.77	-71%	71%	$ 369,450.67	$ 1,284,473.04	$ 2,199,495.42
14	5.04.01	HQ PI Support	1050	$ 146.86	$ 238,264.00	$ 1,032,256.80	$ 3,585,170.60	$ 6,138,084.40	-71%	71%	$ 258,064.20	$ 896,292.65	$ 1,534,521.10
15	5.04.02	GSFC Project Scientist	1050	$ 53.27	$ 108,367.00	$ 372,902.53	$ 1,299,560.45	$ 2,226,218.37	-71%	71%	$ 111,386.47	$ 388,180.39	$ 664,974.32
16	5.05	PAYLOADS			$ 10,661,476.00	$ 34,671,265.55	$ 38,426,136.95	$ 38,866,608.49	-10%	1%	$ 16,116,116.92	$ 17,808,518.54	$ 18,016,452.62
17	5.05.01	GFSC Instrument Management	995	$ 181.05	$ 202,569.00	$ -	$ -	$ -			$ -	$ -	$ -
18	5.05.02	LASP Particle & Fields Pkg			$ 4,303,996.00	$ 16,044,019.69	$ 17,651,848.78	$ 17,798,956.67	-9%	1%	$ 5,928,275.24	$ 6,462,498.26	$ 6,508,925.69
19	5.05.02.01	SSL P&F	1049	$ 1,103.57	$ 2,996,646.00	$ 10,852,241.98	$ 12,032,364.85	$ 12,186,413.47	[illegible]	1%	$ 3,427,023.78	$ 3,799,694.16	$ 3,848,341.10

Figure 6-43. This figure shows the additional columns added to the exported Resource Sheet. It also shows the derivation of the loading parameters for costs and the cost uncertainty probability distributions.

The columns to be added are:

1. **Duration.** The durations of the hammock tasks are needed such that the burn rates, or “Standard Rates”, can be calculated. As mentioned, the Cost Analyst is likely only going to be able to provide total costs for a hammock activity, thus the durations are needed to calculate the costs per unit time for input into the scheduling software’s resource sheet.

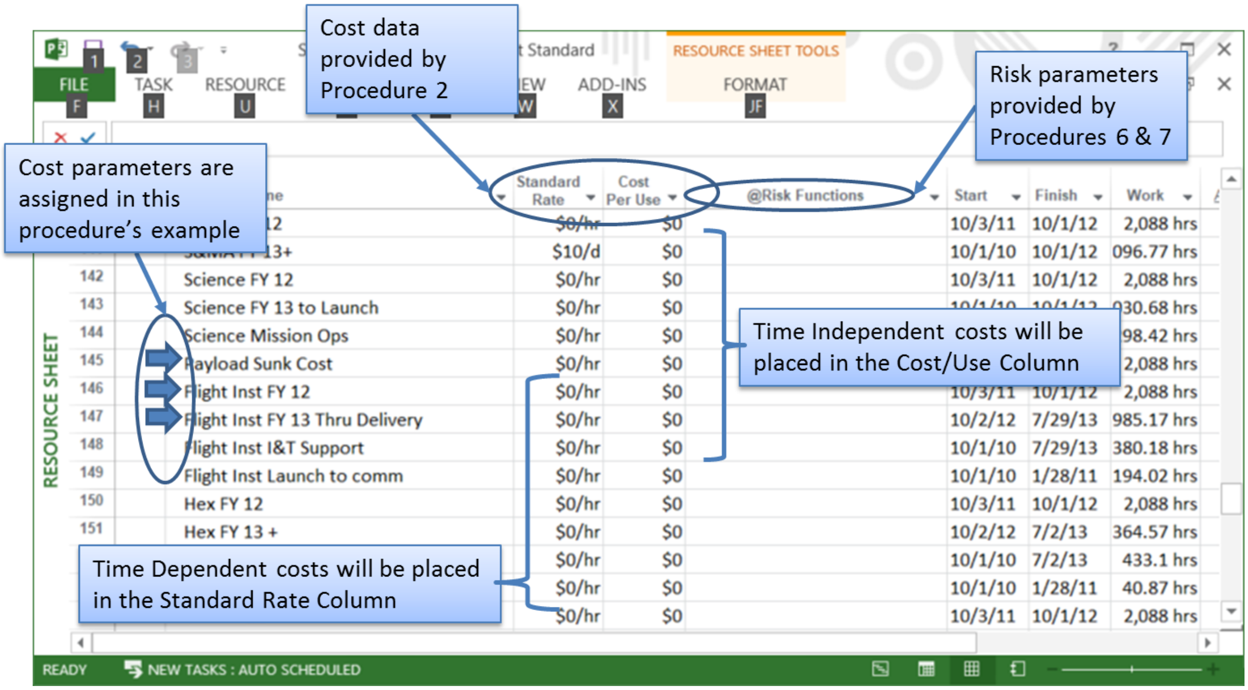
2. **Cost Uncertainty.** Fields need to be added to capture the cost uncertainty, both for the TD and TI costs. Up to, and shortly after PDR cost uncertainties should be available from the parametric estimating tools. In Figure 6-43, NAFCOM is used as a parametric estimating tool to determine the most likely value for cost. Then the NAFCOM input parameters are varied from best case to worst case to generate the optimistic to pessimistic (i.e., Min to Max) cost values for the cost uncertainties. Those variations are converted to percentages of most likely as an input to the probability model used. After that time, only most likely cost column is loaded with the current best estimate and the data from the EVM tools should be used to estimate cost uncertainties. Those uncertainties are loaded as percentages.

3. **Risk and Uncertainty Parameter Specification Fields.** The information provided by the Cost Analyst must be converted into the various formats used by the selected Monte Carlo simulation tool. For example, JACS and Polaris will need a parameter field to specify the type of distribution used and then up to 4 additional parameters to define the probability distribution. Those parameter fields are linked to the cost data provided by the Cost Analyst. @Risk does not use parameters, instead will need the actual formula for the distribution loaded into the scheduling software. The MS Excel “concatenate” formula can be used write those functions

where the probability parameters are linked to the data provided by the cost analyst. In all these cases, the parameter fields are assigned text fields in the scheduling software. That is one of the purposes of the *Activity Attributes* table that is used in Schedule Development, as described in Section 4.3.1.2.4. That table has set aside those needed text fields. Referring to that table will identify the text fields for the risk parameters.

6.3.2.4.3 Procedure 3. Map and Load the Costs

It is a best practice for costs (or resources) to be mapped to the appropriate level of activities in ICSRA. The entrance criteria for this step include the completion of the building of all the cost hammocks where needed, as well as the definition and formatting of the cost parameters to be loaded into the *ICSRA Model*. In this step, cost parameters are mapped to the hammocks. Continuing with the Flight Instrument example, there are three cost parameters needed; sunk costs, FY12 costs and the hammock to completion. Resource names were chosen that closely matched the activity name to facilitate construction and verification. When assigned, those cost parameters will appear in a resource table in the scheduling tool. Figure 6-44 is an excerpt from the Resource Sheet view from MS Project for our Sample Project. In this example, the cost fields are empty; those fields are filled by the next procedure. Also note that there is a field for the risk functions that is also empty and will be filled by Procedure 3. When Procedure 2 and Procedure 3 are completed, Procedure 4 loads those cost and risk parameters back into the resource sheet.



Cost data provided by Procedure 2

Risk parameters provided by Procedures 6 & 7

Cost parameters are assigned in this procedure's example

Time Independent costs will be placed in the Cost/Use Column

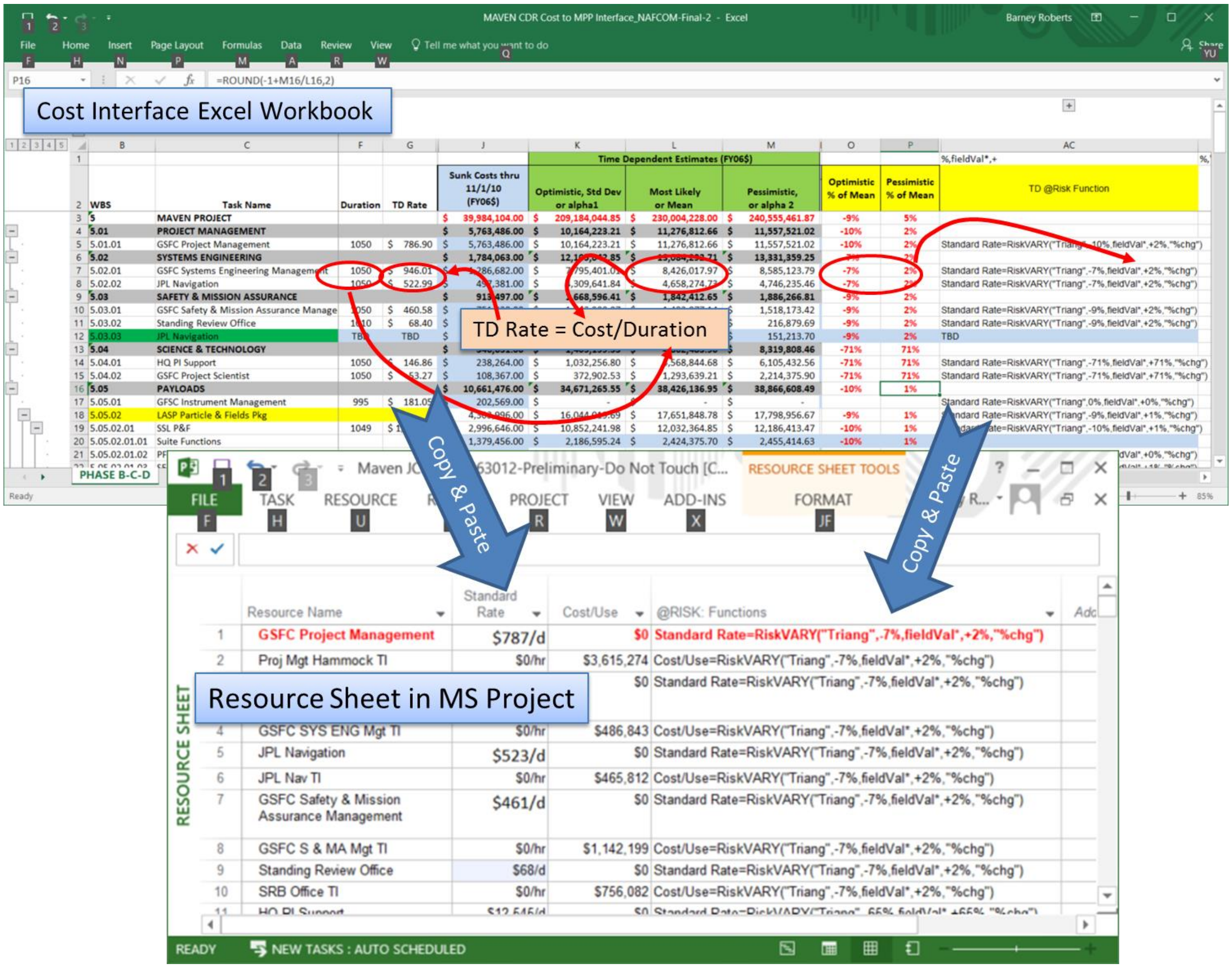
Time Dependent costs will be placed in the Standard Rate Column

	ne	Standard Rate	Cost Per Use	@Risk Functions	Start	Finish	Work
	12	$0/hr	$0		10/3/11	10/1/12	2,088 hrs
	13+	$10/d	$0		10/1/10	10/1/12	096.77 hrs
142	Science FY 12	$0/hr	$0		10/3/11	10/1/12	2,088 hrs
143	Science FY 13 to Launch	$0/hr	$0		10/1/10	10/1/12	030.68 hrs
144	Science Mission Ops	$0/hr	$0				98.42 hrs
145	Payload Sunk Cost	$0/hr	$0				2,088 hrs
146	Flight Inst FY 12	$0/hr	$0		10/3/11	10/1/12	2,088 hrs
147	Flight Inst FY 13 Thru Delivery	$0/hr	$0		10/2/12	7/29/13	985.17 hrs
148	Flight Inst I&T Support	$0/hr	$0		10/1/10	7/29/13	380.18 hrs
149	Flight Inst Launch to comm	$0/hr	$0		10/1/10	1/28/11	194.02 hrs
150	Hex FY 12	$0/hr	$0		10/3/11	10/1/12	2,088 hrs
151	Hex FY 13 +	$0/hr	$0		10/2/12	7/2/13	364.57 hrs
		$0/hr	$0		10/1/10	7/2/13	433.1 hrs
		$0/hr	$0		10/1/10	1/28/11	40.87 hrs
		$0/hr	$0		10/3/11	10/1/12	2,088 hrs

Figure 6-44. Sample resource assignment sheet from MS Project is illustrated in this figure.

Although not shown in the sample project model, cost model names should include WBS identifiers such that they can be arranged in hierarchical order. This will make it easier for the Schedule Analyst to load the cost data.

The burn rates are calculated from the most likely cost values and the hammock durations. The probabilistic equations or parameters are defined and linked to the cost data in the worksheet. Then the cost rates and the probabilistic uncertainty parameters are transferred to the Standard Rate field in the scheduling software's resource sheet. The case shown in Figure 6-45 is for MS Project using @Risk as the Monte Carlo simulation tool. The process is repeated for loading the TI cost values into the Cost/Use fields.



P16 =ROUND(-1+M16/L16,2)

	B	C	F	G	J	K	L	M	O	P	AC
1						Time Dependent Estimates (FY06$)					%,fieldVal*,+
2	WBS	Task Name	Duration	TD Rate	Sunk Costs thru 11/1/10 (FY06$)	Optimistic, Std Dev or alpha1	Most Likely or Mean	Pessimistic, or alpha 2	Optimistic % of Mean	Pessimistic % of Mean	TD @Risk Function
3	5	MAVEN PROJECT			$ 39,984,104.00	$ 209,184,044.85	$ 230,004,228.00	$ 240,555,461.87	-9%	5%	
4	5.01	PROJECT MANAGEMENT			$ 5,763,486.00	$ 10,164,223.21	$ 11,276,812.66	$ 11,557,521.02	-10%	2%	
5	5.01.01	GSFC Project Management	1050	$ 786.90	$ 5,763,486.00	$ 10,164,223.21	$ 11,276,812.66	$ 11,557,521.02	-10%	2%	Standard Rate=RiskVARY("Triang",-10%,fieldVal*,+2%,"%chg")
6	5.02	SYSTEMS ENGINEERING			$ 1,784,063.00	$ 12,1[illegible]	$ [illegible]	$ 13,331,359.25	[illegible]	2%	
7	5.02.01	GSFC Systems Engineering Management	1050	$ 946.01	$ [illegible]286,682.00	$ [illegible]795,401.0[illegible]	$ 8,426,017.97	$ 8,585,123.79	-7%	2%	Standard Rate=RiskVARY("Triang",-7%,fieldVal*,+2%,"%chg")
8	5.02.02	JPL Navigation	1050	$ 522.99	$ 4[illegible]7,381.00	$ [illegible],309,641.84	$ 4,658,274.7[illegible]	$ 4,746,235.46	-7%	2%	Standard Rate=RiskVARY("Triang",-7%,fieldVal*,+2%,"%chg")
9	5.03	SAFETY & MISSION ASSURANCE			$ 913,497.00	$ [illegible]668,596.41	$ 1,842,412.65	$ 1,886,266.81	-9%	2%	
10	5.03.01	GSFC Safety & Mission Assurance Manage	[illegible]050	$ 460.58	$ [illegible]	[illegible]	[illegible]	$ 1,518,173.42	-9%	2%	Standard Rate=RiskVARY("Triang",-9%,fieldVal*,+2%,"%chg")
11	5.03.02	Standing Review Office	1[illegible]10	$ 68.40	$ [illegible]	[illegible]	[illegible]	$ 216,879.69	-9%	2%	Standard Rate=RiskVARY("Triang",-9%,fieldVal*,+2%,"%chg")
12	5.03.03	JPL Navigation	TBD	TBD	$ [illegible]	[illegible]	[illegible]	$ 151,213.70	-9%	2%	TBD
13	5.04	SCIENCE & TECHNOLOGY			$ [illegible]	[illegible]	[illegible]	$ 8,319,808.46	-71%	71%	
14	5.04.01	HQ PI Support	1050	$ 146.86	$ 238,264.00	$ 1,032,256.80	$ [illegible]568,844.68	$ 6,105,432.56	-71%	71%	Standard Rate=RiskVARY("Triang",-71%,fieldVal*,+71%,"%chg")
15	5.04.02	GSFC Project Scientist	1050	$ [illegible]53.27	$ 108,367.00	$ 372,902.53	$ 1,293,639.21	$ 2,214,375.90	-71%	71%	Standard Rate=RiskVARY("Triang",-71%,fieldVal*,+71%,"%chg")
16	5.05	PAYLOADS			$ 10,661,476.00	$ 34,671,265.55	$ 38,426,136.95	$ 38,866,608.49	-10%	1%	
17	5.05.01	GFSC Instrument Management	995	$ 181.05	$ 202,569.00	$ -	$ -	$ -			Standard Rate=RiskVARY("Triang",0%,fieldVal*,+0%,"%chg")
18	5.05.02	LASP Particle & Fields Pkg			$ 4,3[illegible]996.00	$ 16,044,[illegible].69	$ 17,651,848.78	$ 17,798,956.67	-9%	1%	[illegible]ndard Rate=RiskVARY("Triang",-9%,fieldVal*,+1%,"%chg")
19	5.05.02.01	SSL P&F	1049	$ 1[illegible]	$ 2,996,646.00	$ 10,852,241.98	$ 12,032,364.85	$ 12,186,413.47	-10%	1%	[illegible]ate=RiskVARY("Triang",-10%,fieldVal*,+1%,"%chg")
20	5.05.02.01.01	Suite Functions			$ 1,379,456.00	$ 2,186,595.24	$ 2,424,375.70	$ 2,455,414.63	-10%	1%	
21	5.05.02.01.02	PF[illegible]									[illegible]dVal*,+0%,"%chg")

	Resource Name	Standard Rate	Cost/Use	@RISK: Functions
1	GSFC Project Management	$787/d	$0	Standard Rate=RiskVARY("Triang",-7%,fieldVal*,+2%,"%chg")
2	Proj Mgt Hammock TI	$0/hr	$3,615,274	Cost/Use=RiskVARY("Triang",-7%,fieldVal*,+2%,"%chg")
	[illegible]	[illegible]	$0	Standard Rate=RiskVARY("Triang",-7%,fieldVal*,+2%,"%chg")
4	GSFC SYS ENG Mgt TI	$0/hr	$486,843	Cost/Use=RiskVARY("Triang",-7%,fieldVal*,+2%,"%chg")
5	JPL Navigation	$523/d	$0	Standard Rate=RiskVARY("Triang",-7%,fieldVal*,+2%,"%chg")
6	JPL Nav TI	$0/hr	$465,812	Cost/Use=RiskVARY("Triang",-7%,fieldVal*,+2%,"%chg")
7	GSFC Safety & Mission Assurance Management	$461/d	$0	Standard Rate=RiskVARY("Triang",-7%,fieldVal*,+2%,"%chg")
8	GSFC S & MA Mgt TI	$0/hr	$1,142,199	Cost/Use=RiskVARY("Triang",-7%,fieldVal*,+2%,"%chg")
9	Standing Review Office	$68/d	$0	Standard Rate=RiskVARY("Triang",-7%,fieldVal*,+2%,"%chg")
10	SRB Office TI	$0/hr	$756,082	Cost/Use=RiskVARY("Triang",-7%,fieldVal*,+2%,"%chg")

Figure 6-45. The figure illustrates the procedure for transferring the data from the Cost interface workbook to the MS Project Resource Sheet.

6.3.2.4.4 Procedure 4. Develop and Load the Cost Uncertainty Parameters

It is a best practice for cost uncertainties to be quantified with respect to appropriate resources for inclusion in the ICSRA. Similar to developing and loading the schedule uncertainty parameters, this section discusses how to apply cost uncertainty distributions to the appropriate activities.

6.3.2.4.4.1 Step 1. Develop the Cost Uncertainty Parameters

Factors that influence the process for determining cost uncertainty distributions are similar to those that influence schedule uncertainty distributions, as are the methods for developing the basis for the cost uncertainties, as described in Section 6.3.2.3.2. When developing the *ICSRA*, the cost uncertainties are generally provided for each of the resource rates and/or burn rates by the Cost Analyst (or Cost Estimator, Business Manager for Resources, etc.).

Depending on where the P/p is in its life cycle, the Cost Analyst may quantify the probability distributions by describing the modeling uncertainty of all cost estimating relationships (CERs), cost factors, or other estimating methods, as well as the type of distribution (e.g., normal, triangular, lognormal). Prior to establishing the P/p baseline or tracking P/p performance, the Cost Analyst may use parametric cost estimating tools to develop the cost estimate. By varying the input parameters, the Cost Analyst can provide a most likely (M/L) estimate bounded by an optimistic (Min) and a pessimistic estimate (Max). These three points can be used as the uncertainty parameters for the cost inputs in the *ICSRA Model*. Once the P/p has begun to measure performance, the uncertainties can be determined from the actual performance data. For example, if the CPI is showing a value of 0.95 and is deteriorating, the analyst may consider using a percentage increase uncertainty parameter such as Triangular (+5%, +10+, +15%). For more information on defining cost uncertainties, please refer to the NASA Cost Estimating Handbook.[128]

Cautions When Developing Cost Uncertainty Parameters

The cautions associated with defining uncertainty parameters for schedule durations based on SME inputs, described in Section 6.3.2.3.2, also apply to cost. These include:

- **Double Counting.** Double counting is a situation that occurs in *ICSRAs*, whereby the potential impact of uncertainties and/or risks are incorrectly accounted for more than once in an *SRA/ICSRA*. Double counting usually occurs when: (1) uncertainties or risks are applied to costs whose estimates were based on past P/p data that already accounted for similar uncertainties/risks; (2) wide uncertainty distributions are applied to or costs that account for risk events, which are also applied separately as discrete risk impacts; and (3) schedule duration uncertainty drives cost impacts that are also applied separately as cost uncertainties or risks. The first two cases are described in Section 6.3.2.3.2, and the third case is described below.
  - **Overlapping Cost and Schedule Uncertainties/Risks.** Since some costs are time dependent, it is possible that cost uncertainty will be double counted if the SME's judgement regarding the uncertainty in cost is tied to how long the risk will take instead of the cost rates. The Schedule Analyst must work closely with the Cost Analyst to disambiguate potential uncertainty or risk overlaps between cost and schedule.
- **Underestimating the Uncertainty.** The second issue is that whenever SME judgment is used to develop uncertainty distributions, there is a tendency for SMEs to underestimate the range of uncertainty. It has been demonstrated that SMEs tend to only capture a portion of the true uncertainty in their estimate of the range of potential outcomes of an event.[129] Analysts and engineers tend to overestimate best-case outcomes and underestimate worst-case outcomes. Thus, it is important that the Cost Analyst compensate for this underestimation through the

---

[128] NASA Cost Estimating Handbook, Version 4.0. February 27, 2015. https://www.nasa.gov/sites/default/files/files/CEH_Appj.pdf

[129] Hubbard, D. W. "How to Measure Anything." John Wiley & Sons, Inc. 2012.

expansion of the parameters used in the uncertainty probability distribution to allow for a wider range of potential outcomes.

6.3.2.4.4.2 Step 2. Load the Cost Uncertainty Parameters

Once the uncertainties are determined, they may be loaded into the *ICSRA Model*. The different *ICSRA* tools allow uncertainties to be loaded in several ways: (1) into activity fields in the *IMS* or the *Analysis Schedule* that are then loaded into the *ICRA Model*; (2) through an uncertainty register within the *ICSRA Model*; or (3) into a separate input sheet that is imported into the *ICRA Model*. The examples in this handbook illustrate the third approach through the use of a Cost Interface Sheet to load the cost inputs, including the uncertainty parameters, into the *ICSRA Model*.

6.3.2.4.5 Procedure 5. Apply Cost Correlation

Similar to applying correlation in the *SRA Model* as described in Section 6.3.2.2.2.3, ***it is a best practice for cost correlation to be included in the ICSRA model.*** Correlation determines to what degree one WBS element's change in cost is related to another's and in which direction. For example, if the cost of the satellite's payload goes up and the cost of the propulsion system goes up, then there is a positive correlation between both subsystems' costs. Many WBS elements within space systems have positive correlations with each other, and the cumulative effect of this positive correlation tends to increase the range of the possible costs. Cost-to-cost, risk-to-cost, and cost-to-activity correlations are generated through the cost model and supplied by the Cost Analyst for input into the *ICSRA*. For more information on cost correlation and determining cost correlation values, see the NASA Cost Estimating Handbook.[130]

6.3.2.4.6 Procedure 6. Define and Load the Discrete Risk Parameters Impacting Schedule

It is a best practice for discrete risks to be assessed and quantified with respect to cost impacts for inclusion in the ICSRA. As with the discrete risk inputs to the *SRA Model*, each individual discrete risk input for the *ICSRA Model* will be assigned a probability distribution (e.g., normal, triangular, lognormal, beta, etc.) that simulates the risk impact. The Schedule Analyst should be able to trace the risk parameters directly to the RMS and defend the modeling approach to the risk owner and the P/p management team. If the discrete risks are not already quantified by the P/p, it is a recommended practice to build the risk parameters directly within the P/p's formal RMS.

6.3.2.4.6.1 Step 1. Select Pre- or Post-Mitigated Cost Risk Values

Follow the guidance for selecting pre- or post-mitigated risk values as described in Section 6.3.2.3.4, Step 1.

6.3.2.4.6.2 Step 2. Develop Cost Risk Parameters

Cost risks are modeled similar to how schedule risks are modeled. The only differences are: (1) the parameters used for the probability distributions are cost values, and (2) the cost risks are attached to a resource (e.g., resource or cost) rather than an activity duration. For example, if there is a 30% probability that a widget may cost between 10% and 20% more than its estimate, risk parameters would be applied to the Widget TI cost estimate using a Bernoulli distribution with a value of 30% and a

---

[130] NASA Cost Estimating Handbook, Version 4.0. Appendix G. February 2015.

Uniform distribution with parameters of 1.10 and 1.20. See Section 6.3.2.3.4, Step 2 for more information.

Cautions When Developing Cost Risk Parameters

Other important considerations regarding the modeling of risk parameters are as follows:

- **Not Including All Risks.** It is common for P/ps to capture only the top *x* number of risks, or perhaps just red and yellow risks. Just as for an *SRA*, for a successful and informative *ICSRA*, including all identified risks, even the green ones, provides a more holistic picture and may provide insight on where clusters of risks may impact the schedule. Sometimes a P/p will only include risks on the deterministic critical path. Doing this assumes that the P/p knows with complete certainty what the critical path is and limits the insights available through probabilistic analysis. If the P/p loads all the risks, it may find that a different path is more likely to be critical given the combined uncertainty and risk impacts affecting the schedule network. At the very least, applying all the risks will give better insight into the stochastic secondary, tertiary, etc. critical or driving paths. In addition, Agency resources such as historical CADRe data capture historical P/p risks that may be helpful in ensuring a more complete risk list.
- **Double Counting.** To avoid double counting, the Schedule Analyst should work with the Cost Analyst to take special care to segregate uncertainty caused by risks being modeled in the simulation from the underlying uncertainty of the P/p plan. This is of particular concern early in the formulation phase when parametric models and/or CERs are being used for cost estimates. Parametric models and CERs are based on the data from a large number of previous P/ps which were exposed to typical risks that P/ps normally face. Once the input risk is ready to be loaded into the model, it is a recommended practice that the Schedule Analyst work with the Cost Analyst to perform an "in/out" determination for each risk that is being considered for inclusion in the *ICSRA*. This is done by reviewing each risk and determining whether it is truly a discrete risk, "in", or covered by the uncertainty in the parametric cost analysis or schedule estimate, "out". It is important that the "out" risks be retained and deactivated, but not deleted from the risk analysis model. This is because the determination is somewhat arbitrary and may need to be revisited. Since the determination is arbitrary and sensitivity analyses should be run to ensure the P/p plan is robust enough to absorb the uncertainty in the "in/out" decision.
    - **Inherent Risk.** CERs include some inherent schedule risk and uncertainty. The Schedule Analyst and Cost Analyst needs to work with the Technical Leads to ensure that the discrete risks reported by the P/p are not already included in the P/p cost estimate. An example would be mass growth or design life. As long as the risk-reported mass growth or design life are within the range considered in the P/p cost estimate, it should not be included in the analysis. If there is any doubt regarding whether or not the estimate includes the possible risk impact, it is better to include the risk. (See similar rationale in Section 6.3.2.3.1 for Uncertainty Definitions.)
    - **Time Dependent Costs.** Risks are often identified as having a schedule impact *and* a cost impact. It is imperative that the cost impact associated with the TD impacts of a schedule-delay risk (e.g. labor) not be included in a risk impact identification. This is because the risk analysis model will automatically calculate those impacts as a result of the duration

uncertainty applied to the activities. The only costs that should be documented with a risk are the TI costs such as replacement parts or additional consumables.

- **Operational/Flight/Mission Risks.** It is common to categorize a specific risk as an operational, flight, or "mission" risk. The P/p will usually exclude this category of risks from an *ICSRA*, since they reflect impacts that are likely to happen beyond the launch date. It is important to examine risks in this category, because under the principle of "Test As You Fly," the P/p may have some exposure to these risks during AI&T that have not been captured in other discrete risk entries in the risk list.

6.3.2.4.6.3 Step 3. Append Cost Risks to the ICSRA Model

Some *ICSRA* tools support the preparation and entry of the cost and cost risk and uncertainty data from MS Excel spreadsheets as well as the entry of those data directly in the scheduling tool. It is a recommended practice to append the risk list at the bottom of the P/p's *SRA Model* (or *IMS* or *Analysis Schedule*), regardless of whether the software supports the use of a separate Excel input file for the risks. This allows for easier traceability of the risks and associated risk parameters when running the *ICSRA Model*.

Cautions When Appending Schedule Risk Parameters to the ICSRA Model

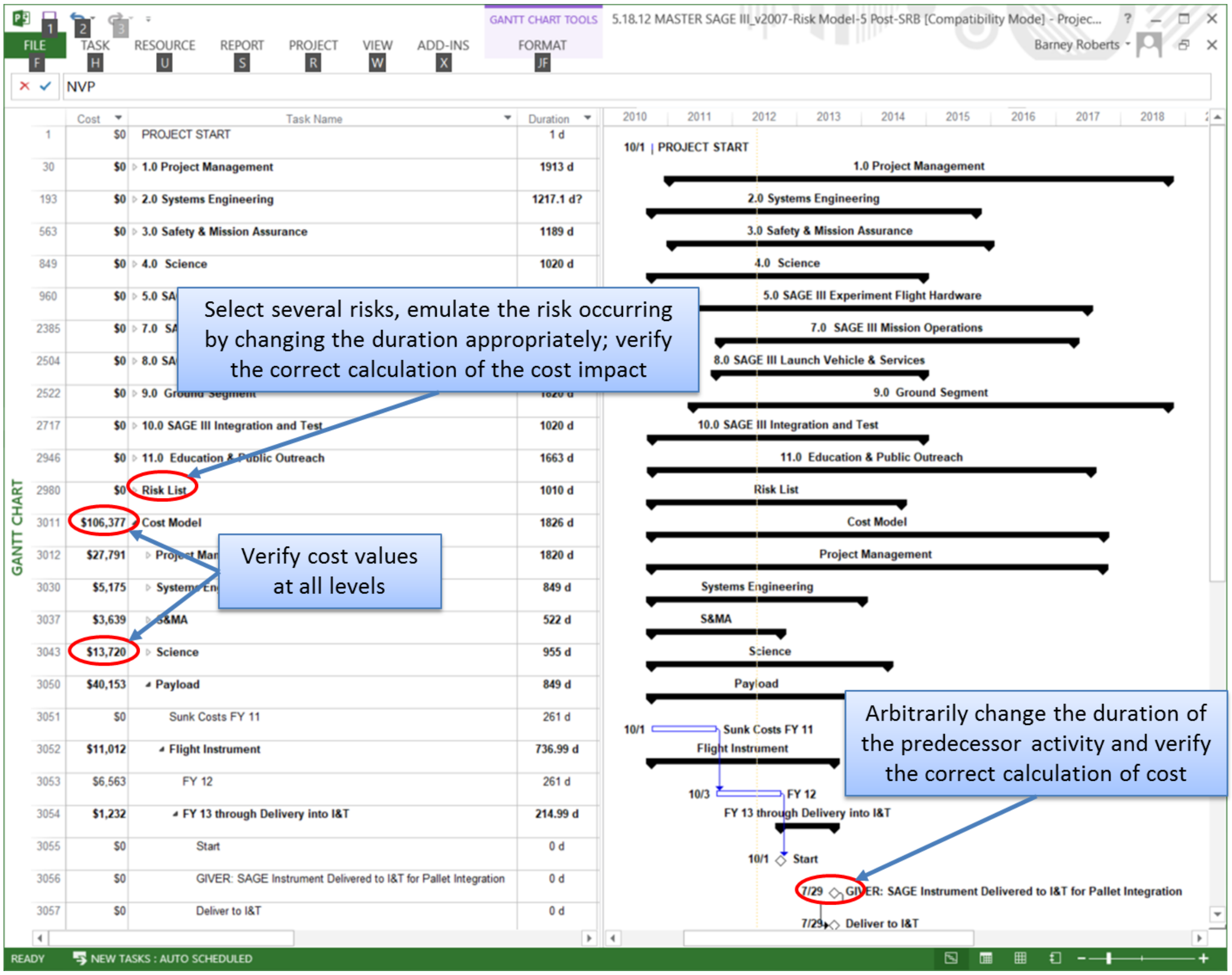
The cautions associated with appending cost risk parameters are similar to those of schedule risk parameters. See Section 6.3.2.3.4 for more information.

6.3.2.4.7 Procedure 7. Map Cost Risks to Relevant Activities

It is a best practice for discrete risks with cost impacts to be mapped to appropriate activities in the ICSRA. Once the risk parameter is appended to the *ICSRA Model*, the individual risks need to be linked to the tasks impacted by the risk. See Section 6.3.2.3.5 for more information on mapping discrete risks and the associated considerations.

6.3.2.4.8 Procedure 8. Test and Verify the Cost and Discrete Cost Risk Inputs

It is a best practice for the costs, cost uncertainties, and discrete cost risk inputs to the ICSRA Model to be reviewed to ensure that they are captured and calculating correctly in the ICSRA Model prior to running the simulation, and that they represent the intended model of the cost risk. As stated previously, appending all of the model components, cost and risk, at the bottom of the *IMS* or *Analysis Schedule* facilitates visibility and promotes easy test and verification that is clearly defensible. As shown in Figure 6-46, the Schedule Analyst should work with the Cost Analyst to perform a series of checks to test and verify that the cost hammocks are calculating accordingly, and that performance is consistent with what the cost estimates would predict for the same test cases.



	Cost	Task Name	Duration
1	$0	PROJECT START	1 d
30	$0	1.0 Project Management	1913 d
193	$0	2.0 Systems Engineering	1217.1 d?
563	$0	3.0 Safety & Mission Assurance	1189 d
849	$0	4.0 Science	1020 d
960	$0	5.0 SA	
2385	$0	7.0 SA	
2504	$0	8.0 SA	
2522	$0	9.0 Ground Segment	
2717	$0	10.0 SAGE III Integration and Test	1020 d
2946	$0	11.0 Education & Public Outreach	1663 d
2980	$0	Risk List	1010 d
3011	$106,377	Cost Model	1826 d
3012	$27,791	Project Man	1820 d
3030	$5,175	Systems En	849 d
3037	$3,639	S&MA	522 d
3043	$13,720	Science	955 d
3050	$40,153	Payload	849 d
3051	$0	Sunk Costs FY 11	261 d
3052	$11,012	Flight Instrument	736.99 d
3053	$6,563	FY 12	261 d
3054	$1,232	FY 13 through Delivery into I&T	214.99 d
3055	$0	Start	0 d
3056	$0	GIVER: SAGE Instrument Delivered to I&T for Pallet Integration	0 d
3057	$0	Deliver to I&T	0 d

Select several risks, emulate the risk occurring by changing the duration appropriately; verify the correct calculation of the cost impact

Verify cost values at all levels

Arbitrarily change the duration of the predecessor activity and verify the correct calculation of cost

Figure 6-46. Testing and verifying the ICSRA Model is shown in this figure.

6.3.2.4.8.1 Step 1. Verify Cost and Cost Uncertainty Inputs

Select a Gantt chart view from the scheduling software and unhide the cost and cost uncertainty fields and place them adjacent to the Name field. Figure 6-46 is that view from MS Project. Cross check the cost values with the cost data input provided for the analysis. Ensure that the cost values are replicated at both the summary levels as well as all of the lower levels. The values should agree within expected rounding errors.

6.3.2.4.8.2 Step 2. Verify the Hammock Cost Changes

Arbitrarily add days to the ending milestone for the selected hammock. Verify that the cost increase is consistent with the duration extension added to the milestone.

6.3.2.4.8.3 Step 3. Verify the Hammock Duration Changes

Go to the task up in the body of the *IMS* or the *Analysis Schedule* that is used to drive the ending milestone. Adjust the duration of the task and verify the performance of the hammock. It is likely that there exists a single activity in the *IMS* or *Analysis Schedule* that will impact more than one hammock. Select that activity and arbitrarily change the duration and verify the performance of all impacted hammocks.

6.3.2.4.8.4 Step 4. Verify Schedule-Risk and Cost-Risk Impacts

Arbitrarily select a risk and emulate the risk occurring by changing the milestone from zero days to a number of days that should impact the selected hammock. Verify that the hammock correctly captures the cost impact of that risk. Be wary that total float available in the network may absorb some of the risk impact before it can drive the hammock. Should that be the case, the Schedule Analyst needs to ensure the validity of the hammock. In most cases the total float impact will be small and can be neglected, but the Schedule Analyst must capture that discrepancy and note it in the list of assumptions included in the *BoE*.

6.3.2.5 Analysis Execution

The process for Schedule Analysis execution is defined by the P/p in the *SMP* and is consistent with overarching Agency, Mission Directorate, and Center requirements. Analysis execution involves testing and verifying the *SRA/ICSRA* simulation calculations, interpreting the simulation data and statistics, and analyzing the results to help inform decision making.

While the P/p may implement informal analysis on a routine basis that consists of many different input scenarios and simulation iterations, more formal analysis is typically executed in three cycles and a final update: a trial version to verify the modeling, a preliminary version to validate the outputs, a final version that is ready for external consumption and an update that addresses any feedback from the final review. Details of each version are shown in Figure 6-47.

Version	Objective	Notes/Activities
Trial	▪ Verify modeling	▪ Quality and consistency of data input not a requirement, but completeness is a requirement ▪ Outputs are reviewed but only for purposes of confirming the individual models – results should still be held suspect due to quality of inputs ▪ Review with P/p PP&C staff – Models valid?
Preliminary	▪ Verify inputs ▪ Validate outputs ▪ Define sensitivity studies	▪ Quality and consistency are mandatory requirements ▪ Peer review of models and results ▪ Review of results with PM and P/p PP&C staff – Results consistent with expectations? ▪ Identify additional sensitivity studies ▪ Review and update reporting format
Final	▪ Concur on conclusions and recommendations ▪ Develop forward action plan	▪ Quality and consistency are mandatory requirements ▪ Update data set with latest versions ▪ First exposure beyond P/p ▪ Address stakeholder's requests for additional information
Update	▪ Final review with stakeholders ▪ Final documentation	▪ Quality and consistency are mandatory requirements ▪ Update data set with latest versions

Figure 6-47. The figure shows the details of each of the three analysis versions and the final update.

Regardless of whether the analysis is informal or formal, it will be documented and communicated at some level. The analysis is communicated to stakeholders consistent with guidance in Section 8.3.2.

The analysis requirements, assumptions, inputs, and outputs are documented as part of the *BoE* and backed up/archived consistent with guidance in Section 8.3.3.

6.3.2.5.1 Test and Verify the Simulation Calculation

It is a best practice for the SRA/ICSRA inputs to be reviewed through an initial simulation run to ensure that they are captured appropriately and calculating correctly through the outputs. Once the *SRA/ICSRA Model* has been built and the inputs have been tested prior to the simulation, it is important for the Schedule Analyst to ensure that the simulation is calculating the inputs correctly to produce reliable outputs. Unfortunately, experience has shown that it is sometimes incorrectly assumed that if the inputs are captured and calculate through the *SRA/ICSRA* Model prior to a simulation run as expected, then the results of the simulation are accurate. All Monte Carlo software packages have the capability to produce statistical plots of the inputs versus the outputs as they were calculated during the simulation. Many errors with the inputs or modeling parameters have been discovered by looking at actual simulation data results. Sometimes the Schedule Analyst discovers that the modeling should be different than what was implemented or there may be an error in the Monte Carlo software. It is not sufficient to only verify the parameter inputs into the tool, but consideration should be given in how the inputs are being calculated through the simulation. This can be done through the help of preliminary simulation runs.

6.3.2.5.1.1 Step 1. Test and Verify the Simulation Calculation due to Uncertainties

Uncertainty is inherent in the planned schedule because all schedule durations are “estimates”. Thus, it is important to understand how the uncertainty inputs affect the *SRA Model* prior to including discrete risks in the simulation run. Running the simulation with “uncertainty only” provides a baseline case from which the inherent risk can be understood and separated from the potentially manageable or accepted discrete risks. By turning off all of the discrete risks (i.e., deselecting the risks or setting the likelihoods to 0% prior to running the simulation), spot checks can be performed to understand the impact of duration uncertainties on individual paths that aggregate in the uncertainty posture for the overall schedule. The Schedule Analyst should ensure that the effects of the uncertainty distributions loaded in the *SRA Model* are calculating as expected. Changes in the “likely” or probabilistic critical path activities due to uncertainty impacts should be cross-checked for reasonableness. If using an *Analysis Schedule* with differing levels of detail for different WBS elements, it may be necessary to revisit how uncertainty was applied to discrete work package-level activities versus summarized activities.

6.3.2.5.1.2 Step 2. Test and Verify the Simulation Calculation due to Discrete Risks

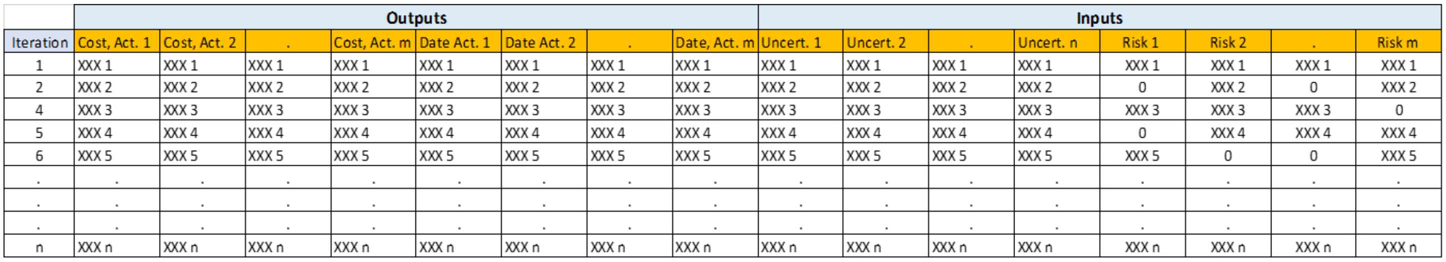
Once the uncertainty impacts are tested and understood, discrete risk calculations can be checked. How a discrete risk impacts the overall simulation results depends not only on its assigned likelihood, consequence distribution and distribution type, but also on whether the activity to which it is mapped falls on a stochastic (i.e., probabilistic) critical path, or driving path. A risk’s effective impact is also dependent on whether discrete risks form clusters and have cumulative impacts along certain paths. While it is difficult to anticipate the effective impact of any single risk on the overall schedule (i.e., this is the reason why SRAs are performed), a quick check can be performed to show how a risk is calculating based on how it is modeled. By turning on one risk at a time and applying a likelihood of 100% so that it is effectively sampled for every iteration of the simulation, the resulting impact of a risk can be observed. This can be done iteratively for risks assigned to different paths to understand how the individual risks are calculating based on how they are modeled. Risks that are mapped to activities on the deterministic critical path will likely have more of an overall impact than risks mapped to non-critical path activities. However, if the “likely” or stochastic critical path activities change due to the impacts of uncertainty, then the discrete risks tied to these stochastic critical paths will likely have a greater impact on the schedule finish or end item delivery date.

6.3.2.5.2 Interpret the Simulation Data and Statistics

Once the simulation calculations have been spot checked for accuracy, a simulation can be run on the full *SRA/ICSRA Model*. The Schedule Analyst should review the simulation data, detailed statistics and other output measures and indices related to activity durations, costs and risks to ensure a complete understanding of how the model is calculating the results.

6.3.2.5.2.1 Simulation Data

The simulation data output is a table of every iteration of the Monte Carlo simulation, which includes the value of every input and every output. It is also the fundamental source for all statistics produced from the simulation. The simulation data table is useful for verifying the inputs because one can look at the values for the inputs for each simulation and verify that they are as expected. And, if the input is a risk with a specified probability of occurrence, it should have a count of sampled values that is proportional to the simulated probability. For example, if the probability is 30% and there are 1,000 samples drawn, ~700 of those drawn values for a specific risk should be zero and 300 should have values. Figure 6-48 illustrates the simulation data output.



	Outputs								Inputs							
Iteration	Cost, Act. 1	Cost, Act. 2	.	Cost, Act. m	Date Act. 1	Date Act. 2	.	Date, Act. m	Uncert. 1	Uncert. 2	.	Uncert. n	Risk 1	Risk 2	.	Risk m
1	XXX 1	XXX 1	XXX 1	XXX 1	XXX 1	XXX 1	XXX 1	XXX 1	XXX 1	XXX 1	XXX 1	XXX 1	XXX 1	XXX 1	XXX 1	XXX 1
2	XXX 2	XXX 2	XXX 2	XXX 2	XXX 2	XXX 2	XXX 2	XXX 2	XXX 2	XXX 2	XXX 2	XXX 2	0	XXX 2	0	XXX 2
4	XXX 3	XXX 3	XXX 3	XXX 3	XXX 3	XXX 3	XXX 3	XXX 3	XXX 3	XXX 3	XXX 3	XXX 3	XXX 3	XXX 3	XXX 3	0
5	XXX 4	XXX 4	XXX 4	XXX 4	XXX 4	XXX 4	XXX 4	XXX 4	XXX 4	XXX 4	XXX 4	XXX 4	0	XXX 4	XXX 4	XXX 4
6	XXX 5	XXX 5	XXX 5	XXX 5	XXX 5	XXX 5	XXX 5	XXX 5	XXX 5	XXX 5	XXX 5	XXX 5	XXX 5	0	0	XXX 5
.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
n	XXX n	XXX n	XXX n	XXX n	XXX n	XXX n	XXX n	XXX n	XXX n	XXX n	XXX n	XXX n	XXX n	XXX n	XXX n	XXX n

Figure 6-48. A generalized image of the simulation data table is shown in the figure.

The simulation data table is also used to scatterplots, and correlation parameters. The scatterplots are then used to determine the *JCLs* for specific selected outputs, usually cost and milestone completion date. The *JCL* is one source of information used to assist management in establishing the MA and ABC.

6.3.2.5.2.2 Detailed Statistics

For every variable selected for output, detailed statistics are available. The simulation software will collect the results of every simulation run and place the number of times a specified value for the selected output fell into a specified bin. The bins are predetermined, and the size of the bins can be varied. This will produce the frequency histogram. The area under the frequency histogram will be equal to the number of samples collected by the Monte Carlo simulation.

Normalizing the frequency histogram produces a similar histogram with a total area of 1.0. That curve is the Probability Density Function (PDF) and will yield the probability of occurrence of any value selected along the x-axis. If one were to integrate the PDF, it would result in the Cumulative Distribution Function (CDF). The CDF is often called the Sigmoid-curve (S-curve), which plot the confidence levels associated with possible dates and/or costs. For the CDF, selecting any point along the x-axis, the corresponding y-axis value will give the probability that the x-value or less will occur, and conversely, the probability that a value greater than the x-value will not occur. Figure 6-49 illustrates these functions for a game of Craps. Figure 6-50 is an actual output from a NASA project showing the complete statistics for a selected output, the frequency histogram and the CDF.

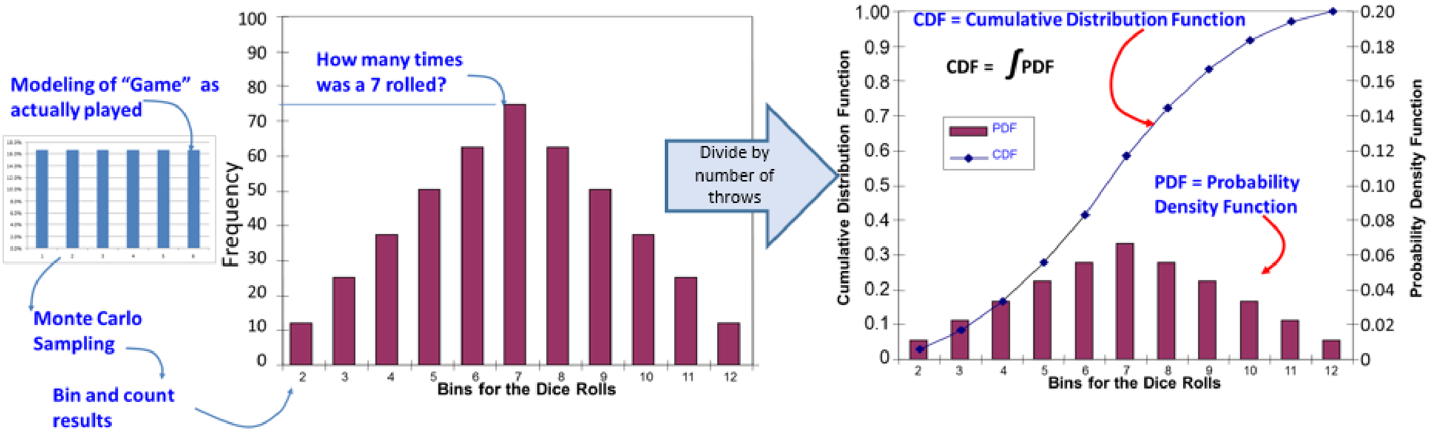
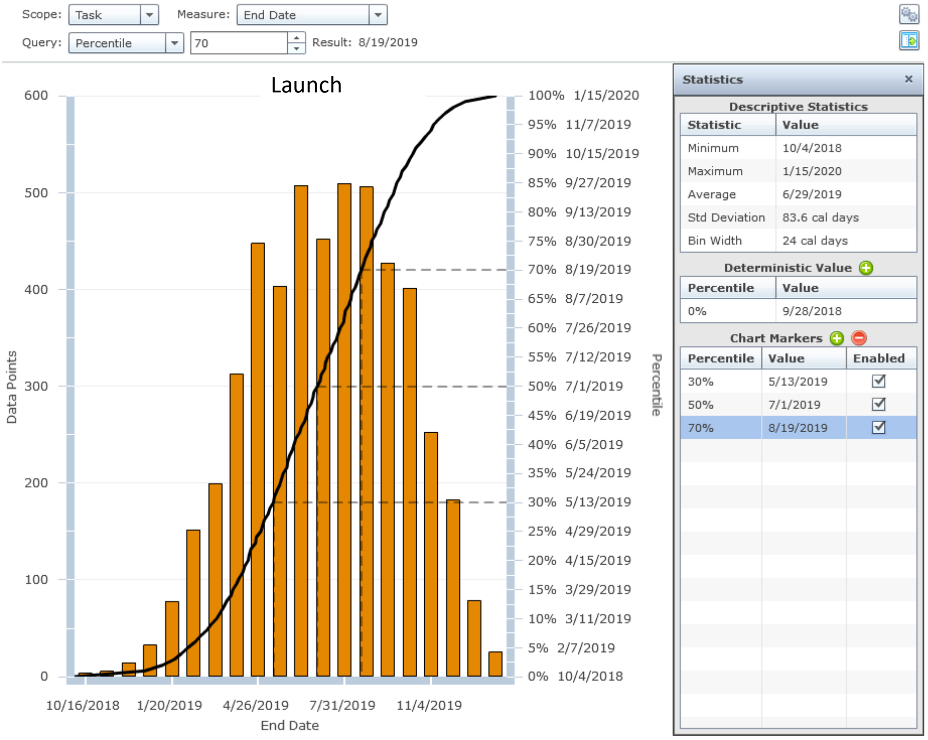


Figure 6-49. The figure illustrates the relationship between the frequency histogram, the PDF and the CDF for Craps.


Scope: Task Measure: End Date

Query: Percentile 70 Result: 8/19/2019

Descriptive Statistics

Statistic	Value
Minimum	10/4/2018
Maximum	1/15/2020
Average	6/29/2019
Std Deviation	83.6 cal days
Bin Width	24 cal days

Deterministic Value

Percentile	Value
0%	9/28/2018

Chart Markers

Percentile	Value	Enabled
30%	5/13/2019	☑
50%	7/1/2019	☑
70%	8/19/2019	☑

Figure 6-50. An example of the frequency histogram and the CDF for a recent NASA project is shown in the figure.

Figure 6-51 illustrates some important characteristics of the CDF and PDF that are useful in interpretation.

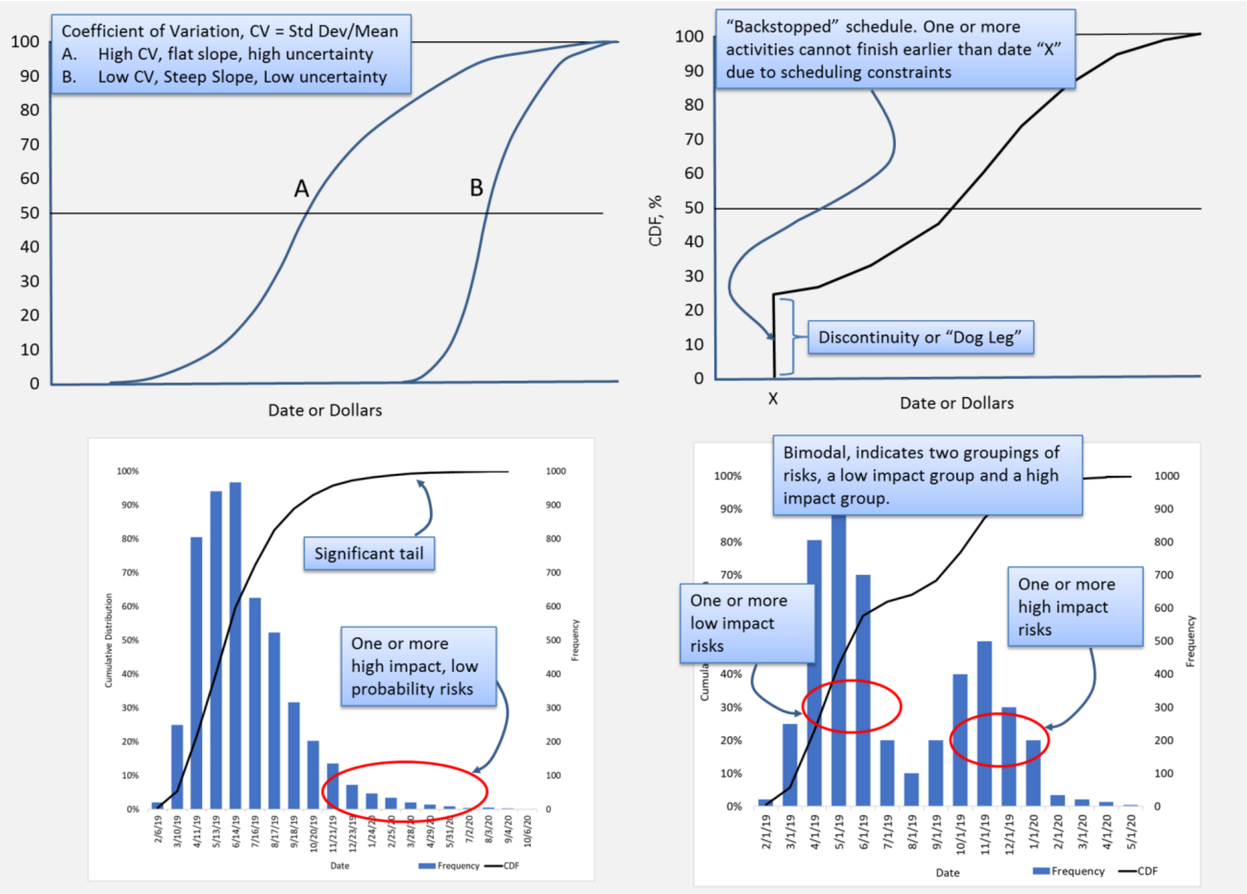


Figure 6-51. Examples of CDF and PDF curves that illustrate characteristics useful for interpretation.

- **Slope of the S-curve (top left).** The Coefficient of Variation (CV) is a normalized measure of the dispersion of a probability distribution. Mathematically, CV is the ratio of the standard deviation to the mean and describes the amount of uncertainty in the estimate, expressed as a percentage. A high CV is associated with a flat slope of the S-curve and conversely, while a low CV is associated with a steep slope of the S-Curve. High CVs are typical early in the P/p life cycle because of the higher uncertainty in the cost and schedule data and usually a greater number of risks, themselves having significant variation in their impact estimates. Later in time, usually after PDR, the P/p may observe a steepening of the S-curve as the P/p becomes more certain about the cost and schedule estimates and risks begin to be retired and have lower uncertainty.

- **"Backstopped" Schedules (top right).** The "dog-leg" on the left in the S-curve indicates that there is a date "X" at which the P/p can finish no earlier than. This can be a common occurrence. For example, test facilities are often a shared resource and schedules tend to be rigid. Even if a P/p is ready to proceed to testing early, it may still have to wait until its pre-planned time slot in the test facility becomes available.

- **Long Tails (bottom left).** P/ps often will have one or more high impact low probability risks. The CDF shows a "tail" that continues to the right with increasing dates. The PDF also shows the behavior of the tails in that there are a number of low frequency samples that seem to continue as time (date) increases. These cases usually occur with P/p's having a difficult technology development component on or near the critical path. More common are high impact risks that occur during I&T. Most I&T risks are "fix-in-place", but there are always a few low probability risks that will require de-integration of the assembly and ship a component back to the manufacturer.

- **Bimodal (bottom right).** When the PDF has "humps" as shown in the bottom right figure, it is indicating that there are two groups of risks or uncertainties that have similar impacts, one group with low impacts and another with high impacts. This is also seen in the S-curve. It is not smooth, exhibiting "bumps" that integrate over the two humps in the PDF. This is often seen in P/ps with low risk development but complex I&T with high impact risks.

6.3.2.5.2.3 Sensitivity, Criticality, and Cruciality

Most schedule risk analysis tools will collect several measures and indices to aid in understanding the uncertainty and risk impacts to the schedule. The more common measures and indices are described below.

Sensitivity. Sensitivity answers the question "how big;" it's the size of the impact. Sensitivity can be measured on tasks, risk events or uncertainties. Duration sensitivity is a measure of the correlation between the duration of a task and the overall duration of the P/p, or a selected task or milestone. The task with the highest duration sensitivity is the task that is most likely to increase the P/p duration. The sensitivity of a risk event is a measure of the correlation between the occurrence of any of its impacts and the overall duration of the P/p. "Tornado" charts are typical outputs of Monte Carlo simulation tools. A sample from a NASA project is shown below. The chart below shows that risk activity 2733 has a 60% correlation with the completion date. It is important to note that if activity-to-activity correlations have been applied, the activities' sensitivity calculations are likely to be similar.

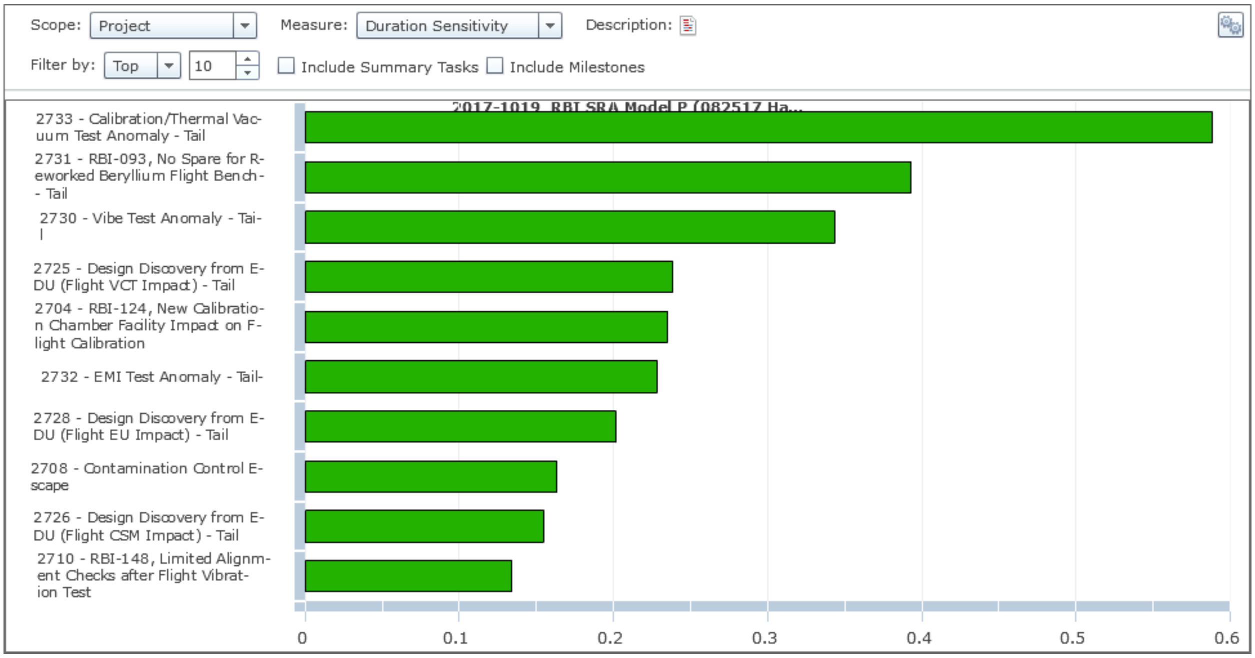
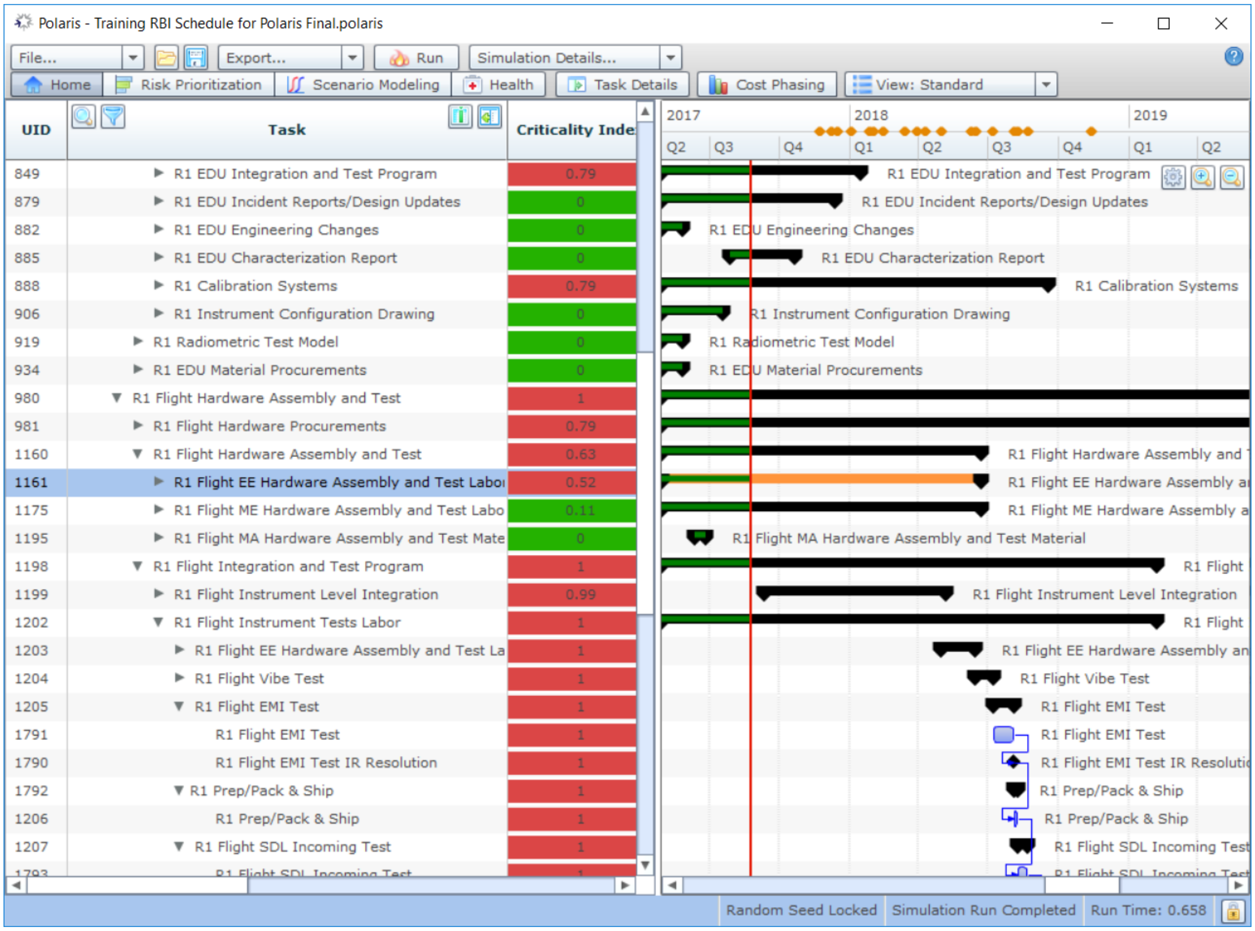

Scope: Project
Measure: Duration Sensitivity
Description:
Filter by: Top 10
☐ Include Summary Tasks ☐ Include Milestones

Figure 6-52. Schedule sensitivity tornado chart shows the correlation of risks with project completion date.

Similarly, Cost Sensitivity is a measure of the correlation between the cost of a task and the cost of the P/p. The task with the highest cost sensitivity is the task that is most likely to increase the P/p cost. Cost Sensitivity of a risk event is a measure of the correlation between the occurrence of any of its impacts and the overall cost of the P/p. Although not a standard output in all SRA/ICSRA tools, Duration-Cost Sensitivity is a measure of the correlation between the duration of a task and the overall P/p cost.

Criticality. Criticality answers the question "how often;" it's the frequency of the impact. It identifies tasks that if delayed will delay the P/p end date. Every time an activity is on the critical path, a flag is set. Upon completion of the simulation the percentage of times that the activity was on the critical path is calculated. That percentage value is the criticality index and is used to find stochastic critical paths in the schedule network. In Figure 6-53, a sample output from a NASA project is shown. The criticality is shown in the figure and is represented by the percentage of times that the activity was on the critical path. From this data, images of groups of tasks and their criticality index can be developed and produce a stochastic critical path diagram. An example of a stochastic critical path can be found in Figure 6-56. P/p management can use the stochastic critical path diagram to focus management attention and avoid surprises. Criticality is also used in the calculation of cruciality.



UID	Task	Criticality Inde
849	▶ R1 EDU Integration and Test Program	0.79
879	▶ R1 EDU Incident Reports/Design Updates	0
882	▶ R1 EDU Engineering Changes	0
885	▶ R1 EDU Characterization Report	0
888	▶ R1 Calibration Systems	0.79
906	▶ R1 Instrument Configuration Drawing	0
919	▶ R1 Radiometric Test Model	0
934	▶ R1 EDU Material Procurements	0
980	▼ R1 Flight Hardware Assembly and Test	1
981	▶ R1 Flight Hardware Procurements	0.79
1160	▼ R1 Flight Hardware Assembly and Test	0.63
1161	▶ R1 Flight EE Hardware Assembly and Test Labo	0.52
1175	▶ R1 Flight ME Hardware Assembly and Test Labo	0.11
1195	▶ R1 Flight MA Hardware Assembly and Test Mate	0
1198	▼ R1 Flight Integration and Test Program	1
1199	▶ R1 Flight Instrument Level Integration	0.99
1202	▼ R1 Flight Instrument Tests Labor	1
1203	▶ R1 Flight EE Hardware Assembly and Test La	1
1204	▶ R1 Flight Vibe Test	1
1205	▼ R1 Flight EMI Test	1
1791	R1 Flight EMI Test	1
1790	R1 Flight EMI Test IR Resolution	1
1792	▼ R1 Prep/Pack & Ship	1
1206	R1 Prep/Pack & Ship	1
1207	▼ R1 Flight SDL Incoming Test	1

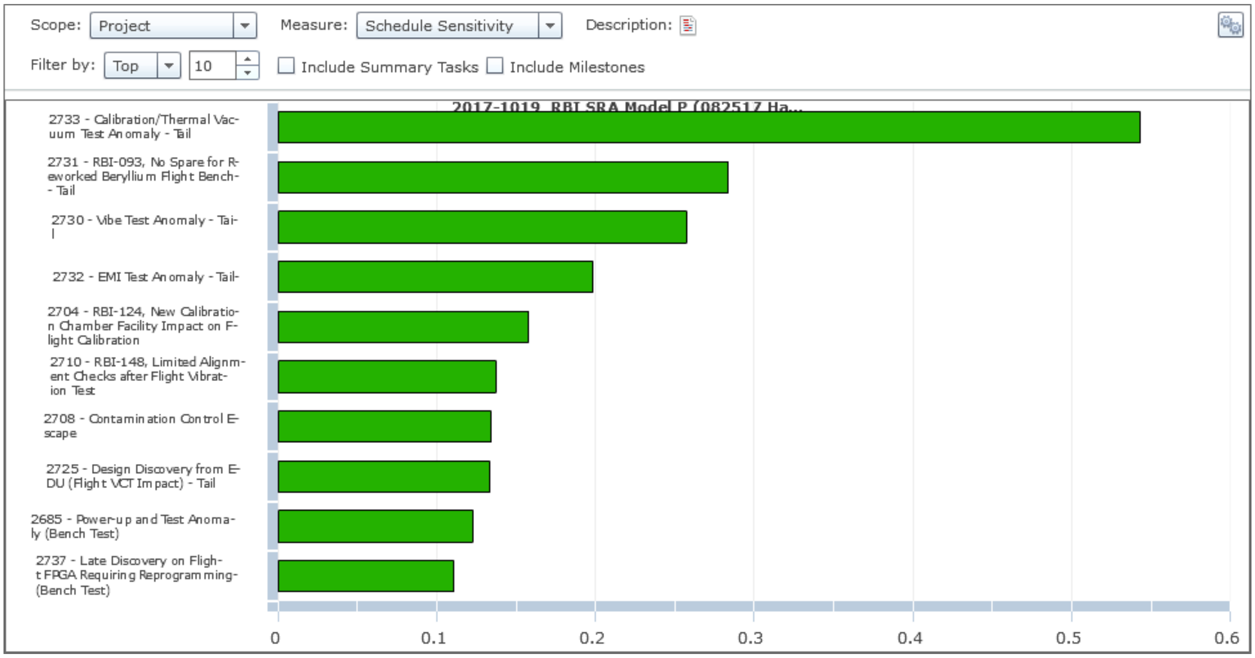
Figure 6-53. Schedule criticality chart shows the criticality index associated with each activity.

Cruciality. Cruciality answers the question "how big and how often;" it's a combined look at the size and frequency of the impact. It is a measure of how crucial the task duration is to the P/p duration. The calculation multiplies the duration sensitivity by the criticality index. A task with a high cruciality is highly likely to affect the P/p plan duration and therefore the finish date or end item delivery date. A cruciality output will show not only if the activity is a driver to a reporting milestone or activity, but whether it is on the overall network critical path. A driver for a key milestone that is not on the critical path may show up as having 0% cruciality because the criticality is 0%. This means that while it is a driver to the key milestone, it is not driving the overall P/p critical path.

Schedule Sensitivity Index (SSI). SSI identifies activities most likely to affect the P/p finish. SSI of an activity is calculated as follows:

$$SSI = Criticality\ Index\ of\ Activity \times \frac{Standard\ Deviation\ of\ Activity\ Duration}{Standard\ Deviation\ of\ Project\ Duration}$$

Combining criticality with the activity duration standard deviation gives the highest values to activities which are on the critical path and have a large range of uncertainty. A sample output is shown in Figure 6-63.



Scope: Project

Measure: Schedule Sensitivity

Description:

Filter by: Top 10

☐ Include Summary Tasks ☐ Include Milestones

Figure 6-54. SSI is a measure used to find the tasks most likely to impact P/p completion.

SSI is a measure of *activity* duration uncertainty and may not specifically capture the impact of a *risk* with low uncertainty but high impact. Consider for example a 20-day activity with a risk with a triangular distribution of 40, 45, 50 days. This risk has a low standard deviation but a huge impact on the activity duration. The activity may have a large SSI but the risk impacting it will have a low SSI.

Caveat. Caution is urged when using these sensitivity indicators. First, they only measure the correlation of activities and risks against the completion dates or total cost. The correlation values range from 1.0, perfectly correlated, to -1.0 perfectly uncorrelated. They cannot provide an actual measure of the cost and schedule impact. Secondly, picking the top-n from the list can be misleading since the P/p logical network can cause the correlations to re-sort the activities and risks when the risks be removed one (or more) at a time.

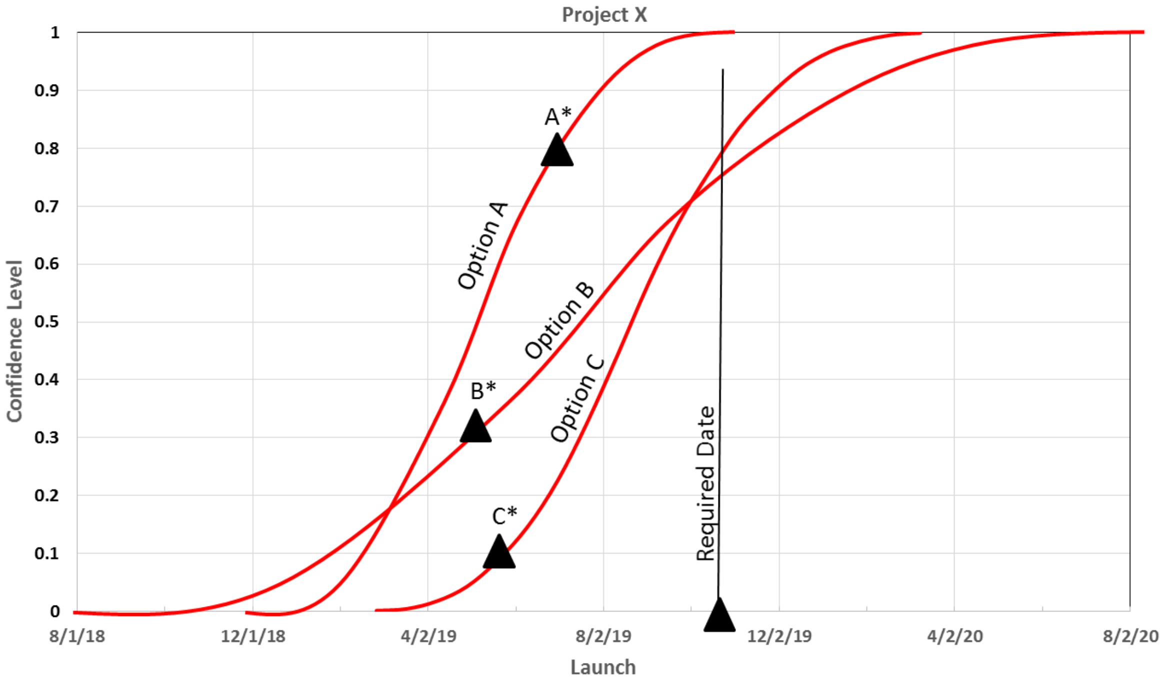
6.3.2.5.3 Analyze the Simulation Results to Manage the P/p

Monte Carlo simulations are named after the gambling hot spot in Monaco, since chance and random outcomes are central to the modeling technique, much as they are to games like roulette, dice, and slot machines. Basically, it involves building a model of the game, including all the random variable functions, then simulating the game many times randomly drawing from the functions that describe the random variables, and tabulating all the outcomes. The Monte Carlo simulation is simple and straight forward; the hard part is using the information to make rational decisions. The following sections discuss the basic outcomes and present several techniques for using the data for risk-informed decision making. *SRAs/ICSRAs* are the basis for a variety of useful analysis when the P/p wants to understand:

- Schedule options based on alternative workflows or alternative technical options (e.g., Analysis of Alternatives)
- The "most likely" critical/driving path(s) given associated risks and uncertainties (e.g., Stochastic Critical Path Analysis)
- Uncertainty and risk drivers, as well as risk prioritization for mitigation activities (e.g., Risk Sensitivity/Prioritization Analysis)
- The probability of meeting the planned schedule or finishing the P/p on time given the associated uncertainties and discrete risks (i.e., Confidence Level/Completion Range Analysis)
- The probability of meeting both the planned cost and the planned schedule given the associated uncertainties and risks (e.g., *JCL* Analysis)
- The potential impact of uncertainties and discrete risks on schedule margin (e.g., Margin Allocation and Sufficiency Analysis)
- The potential impact of uncertainties and discrete risks on funding and UFE (e.g., Funding/Reserves Analysis)
- Risk-informed forecasting changes over time (e.g., Risk-based Trend Analysis)

6.3.2.5.3.1 Analysis of Alternatives

It is a best practice for an SRA (or ICSRA) to be performed for Analysis of Alternatives (AOA) to explore schedule options as they pertain to technical, budget, and/or time frame constraints. Early in the Formulation Phase of a P/p, schedule options are explored to optimize the technical approach or to fit within a specified budget or time frame. An AOA may also be used when the P/p needs to replan or to rebaseline. Because the risks will likely vary between the different options being considered, supporting the AOA with an *SRA/ICSRA* assists the P/p management in making risk-informed decisions. Figure 6-55 is a typical example illustrating the use of the cumulative distribution function (CDF), commonly called the S-Curve, to evaluate three optional approaches for a P/p.



*Note. Indicates deterministic date from IMS

Figure 6-55. This plot illustrates typical results from an SRA developed to support risk-based options analysis for completion date.

Examples of how the options analysis can be used for risk-informed decision-making follow.

- Option A. The black triangle on the Option A S-curve is the deterministic launch date that results from the *IMS* output from the Scheduling software. The *SRA* shows that the probability of achieving that date is 80%, furthermore it shows that the probability of achieving the required date is near certainty. At first glance, this seems to be the optimum, lowest risk option. But suppose this option is not technically robust and it is desired to push some technology advancements to achieve better performance, such as option B and C.
- Option B. Option B has a low probability (30%) of achieving the planed date and has about a 25% chance of exceeding the required launch date. Option B does have a fair probability of coming in earlier than any of the other two options. The Option B S-Curve is shallower than the others indication lower certainty in the outcome (a higher coefficient of variation).
- Option C. Option C has a very low probability of achieving the planed date but almost the same probability of achieving the required date as B. Option C has a steeper curve meaning that there is more certainty in the outcome; option B is less certain and has a tail that could result in much later launch dates.

Decision Making. The *SRA* is very useful in helping stakeholders to weigh and understand the schedule options based on alternative workflows or alternative technical options. Information from the *SRA* provides a richer decision space. In the example illustrated above, note that all three deterministic dates meet the completion date requirement. However, without the *SRA*, the P/p is likely to select

Option B, which is not the best choice if meeting the completion date is of highest priority. If advancing technology to achieve a more robust solution is a higher priority than completion date, the P/p would not have what it needed to make a decision, both B and C seem acceptable. With the SRA data, Option C, even though its deterministic date is later, is the best choice, because the result is more certain and meeting the date requirement has an acceptable probability.

6.3.2.5.3.2 Stochastic Critical Path Analysis

It is a best practice for an SRA (or ICSRA) to be routinely performed to identify/validate the stochastic (probabilistic) critical paths. Typically, a P/p will focus management on at least the top three deterministic critical paths (primary, secondary, and tertiary critical paths) as output from the scheduling software. This management approach can be misleading should there be significant risks within the P/p plan. In such cases, there are often stochastic critical paths lurking in the background waiting for the opportunity to surprise the P/p management. The best practice advises the use of an SRA/ICSRA to seek out the stochastic critical paths to: (1) determine if any of the risk-informed, stochastic critical paths are likely to overwhelm the deterministic critical paths and demand management attention for early controls, and (2) focus risk mitigation investments should the stochastic critical paths threaten P/p performance.

Figure 6-56 shows the criticality results of an SRA performed on a NASA project. The subsystems have been generalized because the data is SBU. The figure shows a probabilistic critical path that has a 32% probability of becoming critical (see "Sys Data Validation" box) and should warrant proportional management attention and possibly some risk mitigation investments.

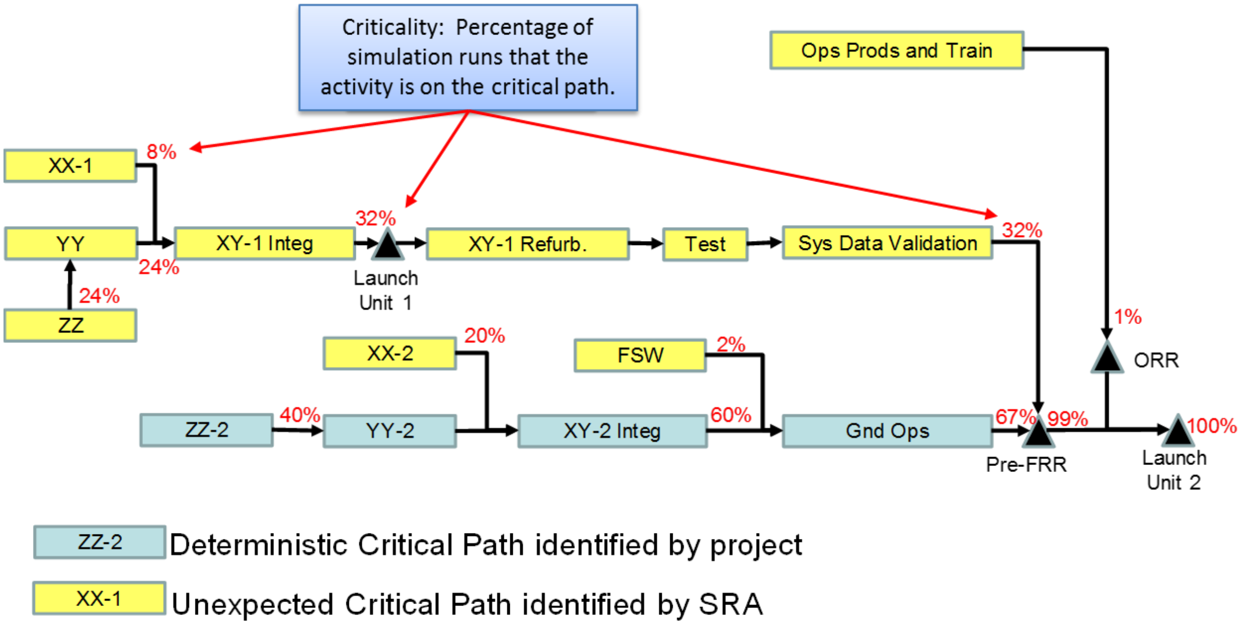


Figure 6-56. Using the SRA to find the stochastic critical paths can help the P/p avoid surprises. The percentages listed in the figure are the percent of the samples that were on the critical path (i.e., "criticality").

Decision Making. The SRA is very useful in helping stakeholders to understand the "most likely" critical/driving path(s) given associated P/p uncertainties and risks. No matter the criticality of the probabilistic critical path(s), each path should warrant proportional management attention and possibly some risk mitigation investments. Paths with higher criticality may warrant more attention than paths with lower criticality. In the example described above, the P/p used this data to replan the upper path (the 32% path) to reduce the likelihood to zero.

6.3.2.5.3.3 Risk Sensitivity/Prioritization Analysis

It is a best practice for an SRA (or ICSRA) to be routinely performed for risk sensitivity analysis and risk prioritization throughout the P/p life cycle. Because risks are uncertain events, it is not always obvious which risks pose the greatest threat to the schedule, so a more precise measurement of risk probability and impact on P/p objectives is needed. An *SRA* can help identify which risk events are most significant. Thus, using an *SRA* to can help prioritize risks and focus risk mitigation investments.

There are several different methods for determining the risk drivers. While risk tornado charts based on correlation coefficients are widely used and supported by probabilistic *SRA* tools, recent research has shown that "ranking risks by correlation coefficients is not a good sensitivity measure, especially for schedule."[131] However, most other alternatives for determining risk prioritization are more computationally difficult to implement.[132] Thus, the approach typically implemented involves removing the top risk in the tornado chart and rerunning the simulation to provide an idea about how much impact the "top risk" has as it relates to the remaining risks. With this approach, risks are backed out of the analysis (i.e., likelihood of the risk is set to 0%) with the simulation rerun each time and a new tornado chart generated for each iteration to reveal the subsequent "top risk." It is important to note that the order of the "top risks" is dependent on the combination of risks applied to the simulation at any given time. For example, some risks have greater overall impact on a schedule when combined with a particular set of other risks. Removing one risk may change the critical path, making a different set of risks more critical than if the first "top risk" had not been removed. Therefore, it is necessary to rerun the simulation after removing each risk.[133] Figure 6-57 shows a risk sensitivity analysis performed for a NASA project.

---

[131] Kuo, Fred. "A Mathematical Approach for Cost and Schedule Risk Attribution." NASA Cost Symposium. 2014.

[132] Fussell, Louis. "Margin Allocation Using the Ruhm-Mango-Kreps Algorithm." NASA Cost Symposium. 2016.

[133] "Concurrently Verifying and Validating the Critical Path and Margin Allocation Using Probabilistic Analysis." Joint Space Cost Council (JSCC) Scheduler's Forum. Pages 20-21. March 2017.

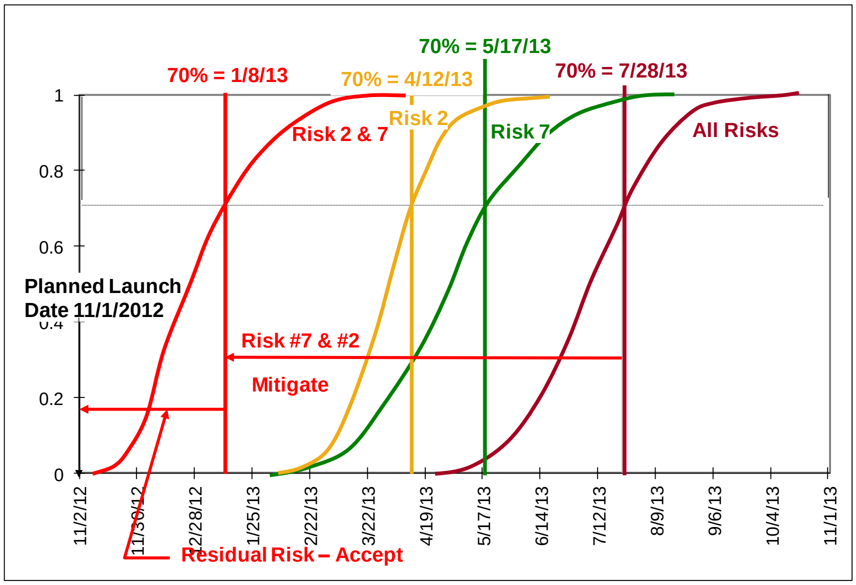
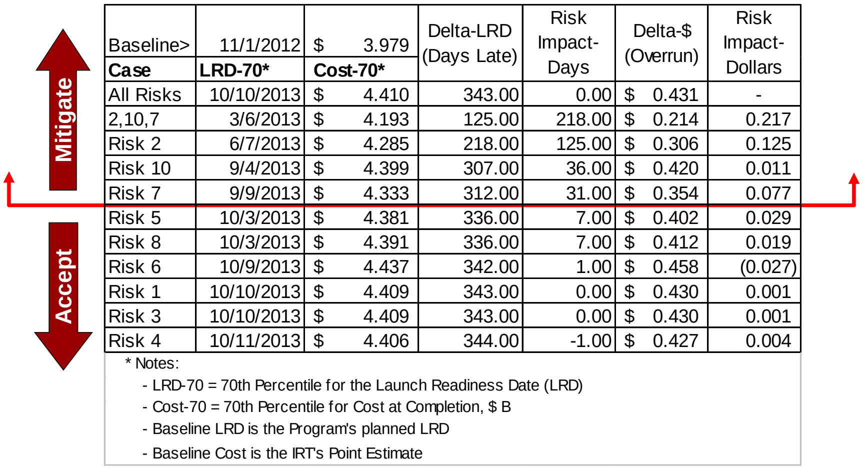


Figure 6-57. Typical example of using the SRA to make risk mitigation decisions.

The curve to the far right shows the S-Curve for all risks included. The Schedule Analyst performed a sensitivity study to find the driver risks. After walking through the risks one-at-a-time, it was determined that the greatest impact was caused by only two risks. Figure 6-58 shows the risk driver list. By mitigating those two risks, the project can save 6 months and move the S-Curve back to where there is a 70% probability of completing on 1/8/2013. Not shown here, but perfectly eliminating all risks does not significantly improve the completion date. Therefore, it was recommended to mitigate risk 2 and 7 and accept the impact of all remaining risks.

At a later date for this same project, an *ICSRA* was also ran which would provide the cost savings assuming that the risks could be perfectly mitigated. Figure 6-58 shows the results of the *ICSRA* and indicates that the value of mitigating risks 2, 10 and 7 in both Delta Days and Delta Dollars. Analyses such as this one provides the project with the information needed to make wise mitigation investments.



Baseline>	11/1/2012	$ 3.979	Delta-LRD (Days Late)	Risk Impact-Days	Delta-$ (Overrun)	Risk Impact-Dollars
Case	**LRD-70***	**Cost-70***				
All Risks	10/10/2013	$ 4.410	343.00	0.00	$ 0.431	-
2,10,7	3/6/2013	$ 4.193	125.00	218.00	$ 0.214	0.217
Risk 2	6/7/2013	$ 4.285	218.00	125.00	$ 0.306	0.125
Risk 10	9/4/2013	$ 4.399	307.00	36.00	$ 0.420	0.011
Risk 7	9/9/2013	$ 4.333	312.00	31.00	$ 0.354	0.077
Risk 5	10/3/2013	$ 4.381	336.00	7.00	$ 0.402	0.029
Risk 8	10/3/2013	$ 4.391	336.00	7.00	$ 0.412	0.019
Risk 6	10/9/2013	$ 4.437	342.00	1.00	$ 0.458	(0.027)
Risk 1	10/10/2013	$ 4.409	343.00	0.00	$ 0.430	0.001
Risk 3	10/10/2013	$ 4.409	343.00	0.00	$ 0.430	0.001
Risk 4	10/11/2013	$ 4.406	344.00	-1.00	$ 0.427	0.004

* Notes:
- LRD-70 = 70th Percentile for the Launch Readiness Date (LRD)
- Cost-70 = 70th Percentile for Cost at Completion, $ B
- Baseline LRD is the Program's planned LRD
- Baseline Cost is the IRT's Point Estimate

Figure 6-58. The risk driver list after performing the risk sensitivity analysis by removing risks one-at-a-time. The ICSRA provides the cost impacts of perfectly mitigating the risks. Risks 2, 10, and 7 cause the majority of the risk impact.

Since some risks are not able to be fully mitigated, risk sensitivity and risk prioritization analysis can be performed using both pre-and post-mitigated risk quantifications.   We want to understand the effect of risk mitigation plans on schedule confidence.

Decision Making. Using an SRA to perform risk sensitivity and risk prioritization analysis is an integrated schedule management and risk management strategy that can help the PM to proactively manage P/p discrete risks and increase schedule (and cost) confidence through understanding the schedule's sensitivity to both uncertainties and risks. In the example described above, this analysis was used to help prioritize risk mitigations and to provide guidance for the project's schedule replanning exercise.

6.3.2.5.3.4 Confidence Level/Completion Range Analysis

It is a best practice for an SRA/ICSRA to be routinely performed to produce schedule confidence levels associated with achieving preliminary and baseline IMS milestones. A schedule confidence level is a statistical measure of the reliability of the P/p schedule. It provides the likelihood (%) that a P/p will achieve its objectives on time or earlier. It is a condition in which there is the probability that a given P/p's schedule will be equal to or less than the targeted schedule for completion. Using *SRAs* to produce confidence levels is helpful any time the P/p wants to quantify the probability of finishing key milestones or the P/p on time. SRAs can be run on an updated basis to help the P/p stay informed about how changing uncertainty and risk postures, as well as actual P/p performance, are impacting the confidence levels associated with the P/p's planned schedule milestones.

As described in Chapter 5, the *IMS* is essentially the P/p's "point estimate" or time-phased plan for performing the P/p's approved total scope of work and achieving the P/p's goals and objectives within a determined timeframe. Because point estimates are exactly that, "estimates", the actual P/p schedule will typically fall within some range of dates with a range of confidence levels that includes the point estimate. At various times in the P/p life cycle, schedule completion ranges (and cost range estimates), are required by NPR 7120.5 for the overall targeted P/p schedule (and cost).[134] While the NPR does not specify a specific method for determining the completion ranges, ***it is a best practice for an SRA/ICSRA to be routinely performed to estimate P/p schedule completion ranges associated with achieving planned milestones (at least as often as required).*** The range provides stakeholders with a high and low bounds for the likely P/p finish (or end item completion) date, complete with confidence levels identified for the high and low values of the range. Although there are no specific requirements as to which high and low confidence levels should bound the range, it is typical for the PM to request the dates associated with the 30% and 70% confidence level values to establish the range. If the PM wants to be more conservative, dates associated with 20% and 80% confidence level values may be requested.

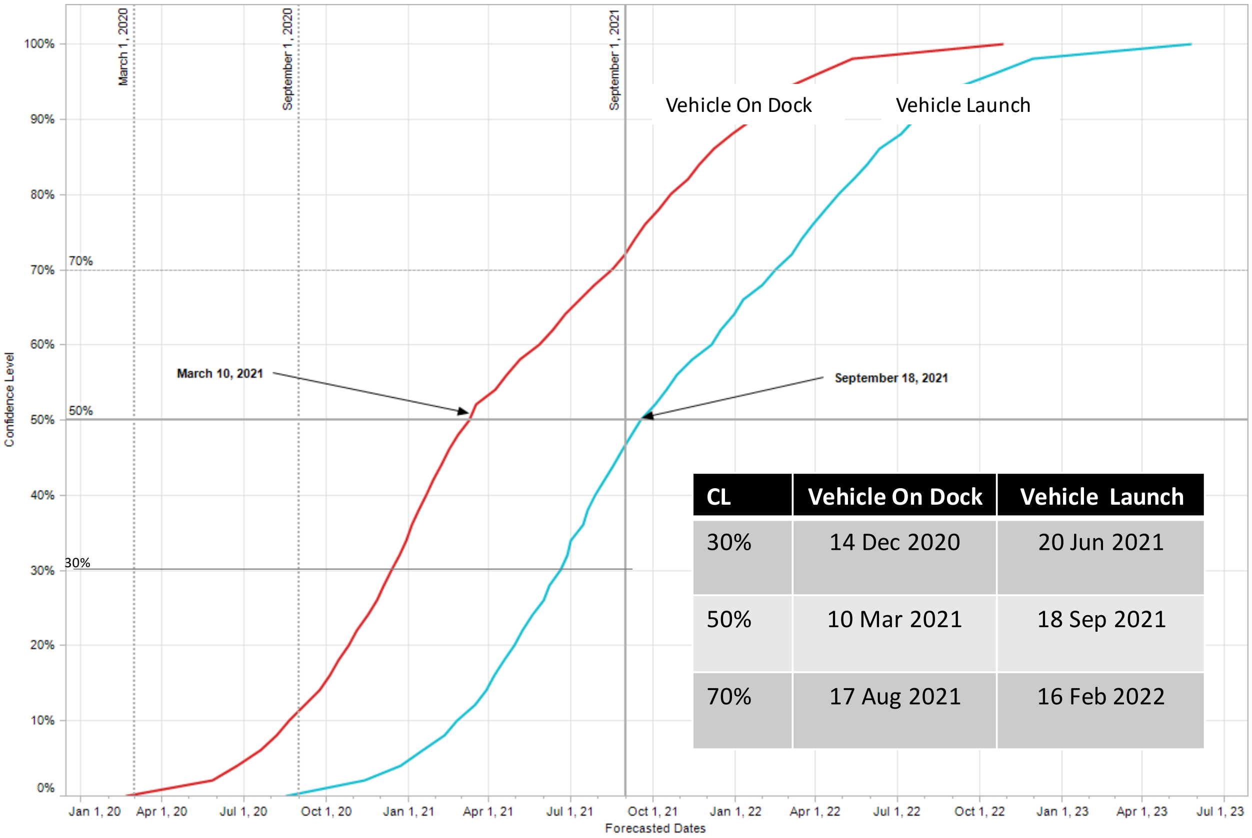
Note: The Agency's guidance related to establishing the schedule baseline centers on the *JCL*. Considering the 70% *JCL* "frontier curve," described in Section 6.3.2.5.3.5, if one picks the point from the "knee in the curve" of where the percentage for cost is equal to the percentage for schedule, the corresponding percentage along the S-curve is typically between 78% and 84%, depending on the

---

[134] NPR 7120.5E. NASA Space Flight Program and Project Management Requirements. Effective Date: August 14, 2012. Expiration Date: August 14, 2020.

correlation utilized in the *ICSRA Model*. As a result, selecting the 80th percentile from an *SRA* S-curve allows for traceability back to Agency guidance.

Figure 6-59 illustrates an example of determining completion ranges using an *SRA* for a recent NASA Program.



CL	Vehicle On Dock	Vehicle Launch
30%	14 Dec 2020	20 Jun 2021
50%	10 Mar 2021	18 Sep 2021
70%	17 Aug 2021	16 Feb 2022

Figure 6-59. An SRA was used to establish the schedule completion ranges for this project.

Decision Making. Performing an *SRA* early in the P/p life cycle not only provides the data needed to satisfy the requirement for range estimates, it helps the P/p management understand the probability of meeting the planned schedule given the associated uncertainties and risks. Subsequent *SRAs* help the P/p track how uncertainties, risks, and P/p performance are impacting the schedule confidence level, which can inform Schedule Control decisions throughout the life cycle.

6.3.2.5.3.5 JCL Analysis

It is a best practice for an ICSRA to be performed to produce a Joint Confidence Level (JCL) for cost and schedule associated with achieving planned cost and schedule commitments (at least as often as required). Although a *JCL* (or *ICSRA*) is only required for spaceflight P/ps at certain times during the life cycle, by NPR 7120.5, it is a recommended practice to perform the *JCL* routinely to assess the risk impacts and ensure that the MA and ABC can be achieved with acceptable risk.[135] The *JCL* is determined from the scatterplot by finding those cost-schedule pairs that have the specified confidence level. While 70% is the requirement for single-project Programs and projects exceeding an LCC of $250M, it is typical for the P/p management to request the 30%, 50% and 70% *JCL* points for the purposes of planning as well as establishing and tracking performance to the MA and the ABC.

- **What is a scatterplot?** The scatterplot is created from the simulation data table. The simulation data table is an output from the Monte Carlo simulation tool that tabulates all inputs and outputs for each iteration during the simulation. For every iteration, there exists a cost and schedule pair. Those pairs are plotted with the date as the x-axis and cost as the y-axis. For example, in the plot below, the Monte Carlo simulation ran 5000 iterations and each point on the chart is a cost-schedule pair. There are 5000 points on the chart and each point is equally likely, meaning each point has a one chance in 5000 of occurring.

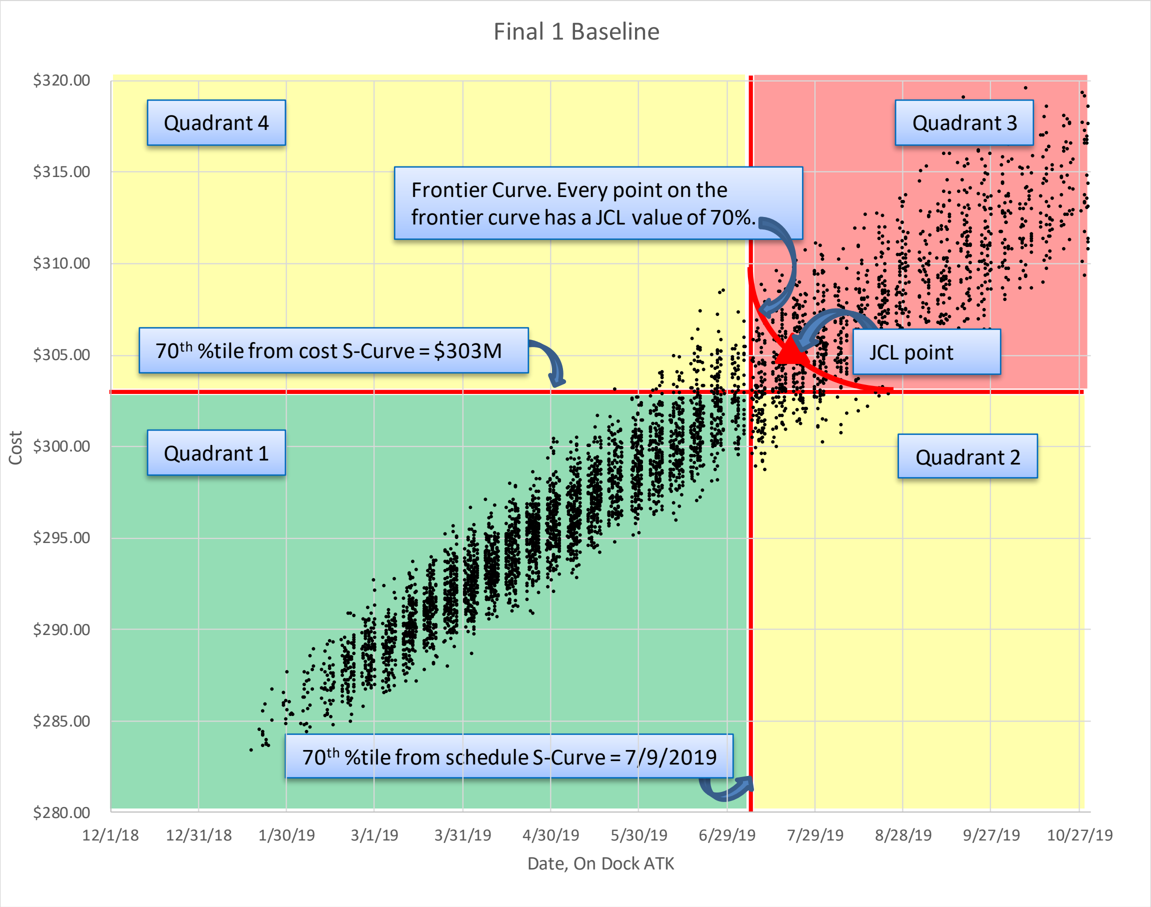


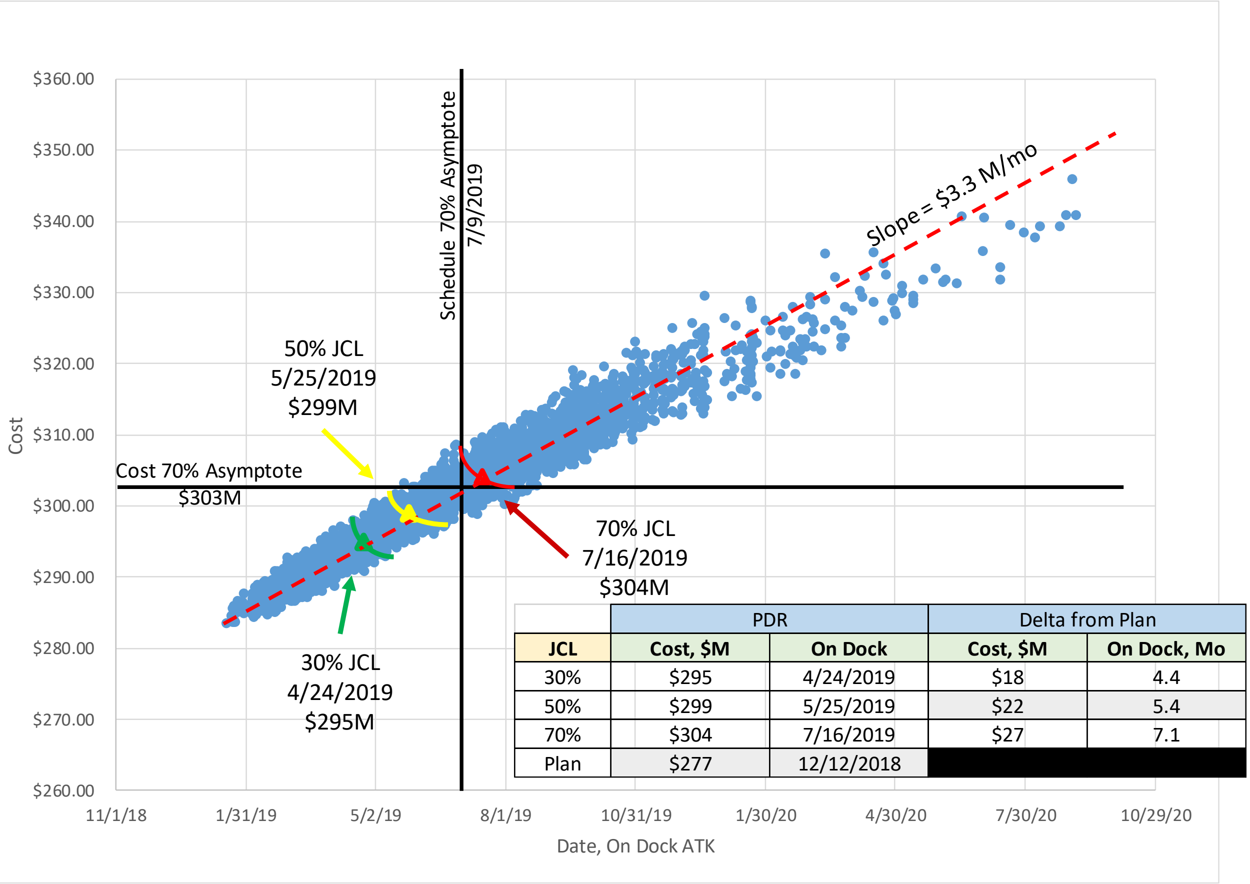
Figure 6-60. This figure shows an example scatterplot from a Monte Carlo simulation with 5000 iterations. Each point represents a single output from the simulation.

---

[135] NPR 7120.5E. NASA Space Flight Program and Project Management Requirements. Effective Date: August 14, 2012. Expiration Date: August 14, 2020.

- **Frontier Curve and the JCL Value.** There is not a single point that will have the specified *JCL* or less, but many points will have that *JCL* value or less. These values will produce a curve on the scatterplot that is referenced as the Frontier Curve. Data points up and right of the Frontier Curve will have *JCL* values greater than the Frontier Curve and those below and to the left will have *JCL* values less than the Frontier Curve. Since a single value is desired for the *JCL*, it is a recommended practice for the single point on the scatterplot where the cost and schedule have the same probability of occurring, usually referred to as the "knee in the curve", to be selected as the targeted value for the *JCL*.
- **Asymptotes.** There are two asymptotes on the scatterplot. In the figure above, the Frontier Curve is plotted for the 70th percentile *JCL*. In doing so, the Frontier curve must asymptotically approach the individual cost and schedule 70th percentiles. This is because as one traces the Frontier curve up and to the left, the cost value becomes more likely and the schedule less likely, but schedule cannot go below the 70th percentile, hence asymptotically approaching the vertical line. Likewise, for the cost value, as one traces the Frontier Curve down and to the right, the cost value becomes less likely until it reaches the asymptote. Placing the asymptotes on the *JCL* curve helps in locating the Frontier Curve.
- **Voids.** A question often asked is, "What causes the vertical voids in the scatterplot?" Those are weekends and holidays. Since the calendar does not permit work on those days, the P/p cannot finish on those days, hence no possible solutions.
- **Quadrants.** In Quadrant 1, every solution is less than the individual 70th percentile cost and schedule confidence levels. The percentage of the solutions in this quadrant yields the likelihood of the P/p being under cost and ahead of schedule (~66% in this example). In Quadrant 2, the percentage of solutions in this quadrant yields the probability of being over schedule and under cost (~3% in this example). In Quadrant 3, the percentage of solutions yields the probability that the P/p will be over schedule and over cost (~28% in this example). In Quadrant 4, the percentage of solutions will yield the probability of being under schedule but over cost (~3% in this example).

A NASA project JCL example follows, and the scatterplots include notes on how management used the information for decision-making. Figure 6-61 illustrates the determination of the *JCL* per the NASA requirement for a P/p at the PDR milestone. Figure 6-62 represents a *JCL* (i.e., *ICSRA*) performed for a Mars mission at CDR to understand the joint cost and schedule confidence levels associated with the open and close dates of the planetary launch period.



	PDR		Delta from Plan	
JCL	**Cost, $M**	**On Dock**	**Cost, $M**	**On Dock, Mo**
30%	$295	4/24/2019	$18	4.4
50%	$299	5/25/2019	$22	5.4
70%	$304	7/16/2019	$27	7.1
Plan	$277	12/12/2018		

Figure 6-61. Scatterplot and JCL for a project at PDR. Note from the shape of the scatter plot that cost and schedule are highly correlated. Often, the asymptotes for the 70% JCL value will not fall on the individual cost and schedule 70% asymptotes.

Figure 6-61 shows the scatterplot for a NASA project as used to establish the *JCL* at PDR. In this example, the cost and schedule are highly correlated, evident by the small scatter about the regression line. In fact, that correlation was approximately $3.3 M/month. This was because there was a significant amount level-of-effort activity. The values selected for the *JCL* were at the point where both cost and schedule had the same confidence level, in this case 73%. **Note:** The frontier curve will always be asymptotic to the selected percentile values for cost and schedule individually.

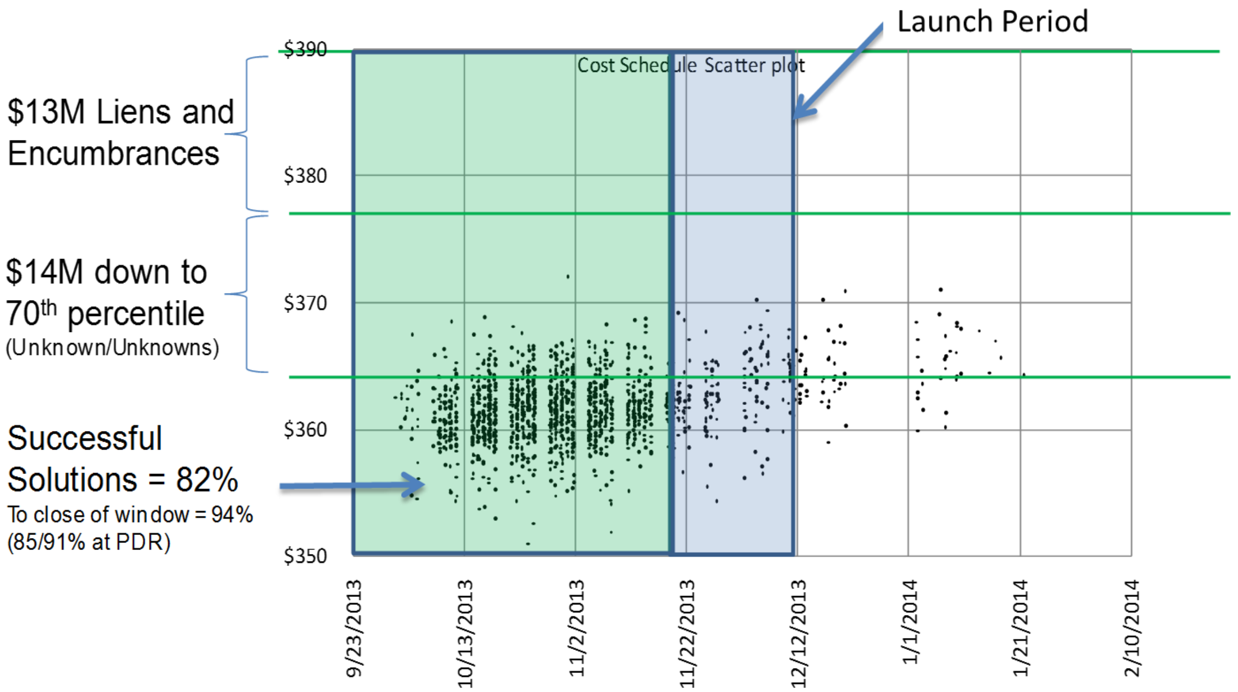


Figure 6-62. Scatterplot for a Mars robotic mission.

Figure 6-62 shows the scatterplot for a Mars robotic mission. The analysis was performed at the CDR. Mars missions have a narrow launch period and careful attention must be paid to the risk environment throughout the project DDT&E period. For this case, a *JCL* curve was not needed. Instead, the project needed to estimate the likelihood it would launch within the launch period and be able to do so with the available budget. On the plot, there are three rectangular boxes. The one to the left captures all of the solutions that were ready before the launch period opened, the middle captured the additional solutions that were ready within the launch period, and the right-most box were the cases where the project would miss the launch period and need to wait 27 months for the launch period to reopen.

The scatterplot illustrates the following:

1. Unlike the previous figure, there is very little cost-schedule correlation.
2. The number of solutions in the left-most box represented 82% of the total, meaning there was an 82% probability of being ready on or before the opening of the launch period.
3. Adding in the solutions in the narrow middle box gave a probability of 94% of being able to launch before the period closed.
4. Walking downward from the $390M budget, and subtracting the known liens and encumbrances left a comfortable $14M margin down to the 70th percentile cost confidence level.
5. The project determined that the $14M margin and 94% likelihood of making the launch period was an acceptable risk posture for the project and continued their current plan without further risk mitigation.

Decision Making. Performing an _ICSRA_, helps the P/p to understand the probability of meeting both the planned cost and the planned schedule given the associated uncertainties and risks. This information can aid the PM in making trades between cost and schedule, as necessary. In the example illustrated above, the PM provided the information to the stakeholders to help validate the MA and ABC. In addition, the regression line with a slope of $3.3M/month was used to make "what-if" estimates for project delays. The PM used the scatterplot to validate the sufficiency of funding reserves. With an 82% likelihood of completing by the opening of the period, the PM chose to focus on launching early to take advantage of greater flight performance margin if needed.

6.3.2.5.3.6 Margin Allocation and Sufficiency Analysis

It is a best practice for an SRA (or ICSRA) to be performed early in the P/p life cycle to establish and allocate margin within the preliminary and/or baseline IMS, as well as routinely throughout the P/p life cycle, to ensure sufficiency of margin to accommodate uncertainties and risks. Early in formulation, it is typical to allocate margin based on either previous experience or organizational guidance, such as GSFC Gold Rules or the JPL Design Principles documents, summarized in Figure 5-30. Sufficiency of margin is usually determined by comparative means, from analogous missions, or Center or Mission Directorate guidelines. Although these elements can provide insight for establishing the schedule margin, as discussed in Section 5.5.9, a more risk-informed determination of schedule margin should be made as the P/p matures through the life cycle and more information becomes available. Performing an _SRA_ can help the P/p determine the adequacy and placement of margin in the schedule based on the P/p's uncertainty and risk postures and schedule performance-to-date. Once the _SRA_ results have been considered in establishing how much schedule margin is need for successful P/p completion, P/ps can insert margin tasks into the schedule to represent the time necessary to account for estimated uncertainty and schedule risks.[136]

There are two cases to consider when using the _SRA_ to establish the margin: Case A is the determination of sufficiency of margin for a required date, and Case B is for the renegotiation of a completion date to achieve adequate margin. In Case A, if margin is inadequate, replanning or risk mitigation are the only options available. In Case B, the completion date is renegotiated to provide sufficient margin. In Case B, the completion date is renegotiated to provide sufficient margin. Figure 6-63 illustrates these techniques.

---

[136] PASEG, Version 3.0. National Defense Industrial Association (NDIA), Integrated Program Management Division (IPMD). March 9, 2016. Page 73.

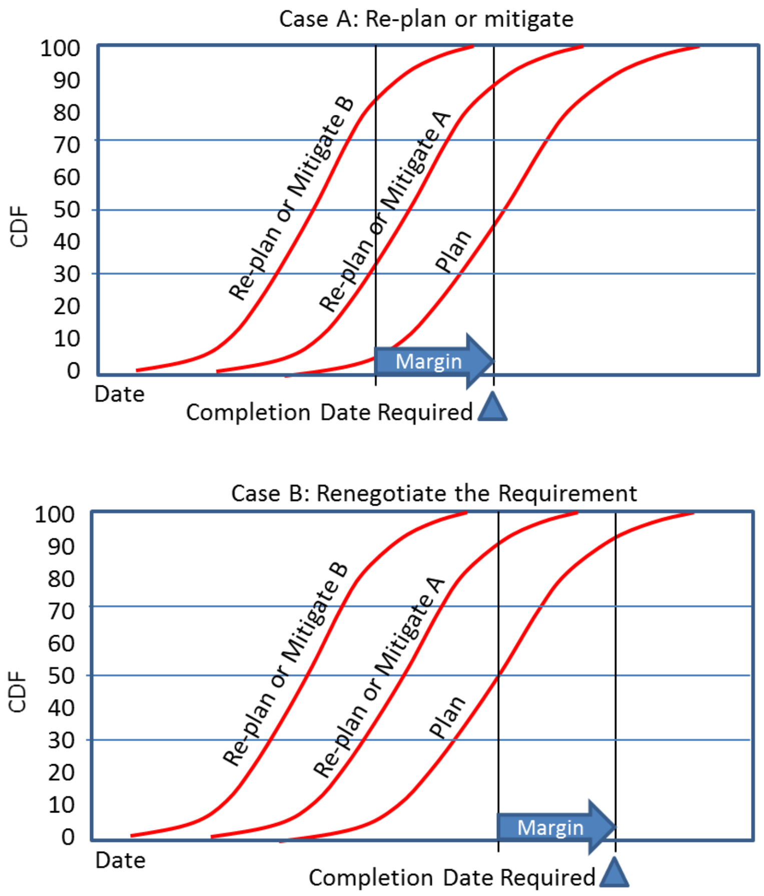


Figure 6-63. Examples of how the SRA is used to confirm adequacy of margin.

- Case A. The Plan S-Curve shows that even if all margin is utilized to accommodate risks, there is only a 40% likelihood of achieving the required completion date. A risk-prone P/p may choose to accept this position, but not usually. Replan or mitigate option A will yield a 30% likelihood of on-time completion without having to allocate any margin and the margin covers risks all the way to a 90% likelihood of on-time completion. A risk-averse P/p may want to opt for replan or mitigate option B which shows margin that covers the range from 80% to near certainty.
- Case B. In this case, the project and the stakeholders agree to renegotiate the completion date until there is adequate margin to cover risks and uncertainties. Again, the propensity for risk acceptance will affect the choice just as it would in Case A. For example, the Plan S-Curve shows that margin will cover risk impacts between the 50 and 90th percentiles, however a risk-averse P/p might want to go with Option B.

Decision Making. Performing an *SRA* can help the P/p determine the adequacy and placement of margin in the schedule based on the P/p's uncertainty and risk postures and schedule performance-to-date. When performed early in the P/p life cycle, this analysis can influence the schedule baseline to include adequate schedule margins. For example, the P/p can select the 50th percentile as the planned schedule completion date and hold schedule margins to the 70th percentile. Also, by selecting the *SRA* outputs for subsystems feeding into I&T, the P/p can use the same strategy to establish margins for subsystem deliveries. This approach is most helpful before the baseline is established (PDR), because the P/p still has the flexibility to adjust the schedule to align the completion date with the desired confidence level.

6.3.2.5.3.7 Funding/Reserves Analysis

It is a best practice for an ICSRA to be routinely performed to demonstrate that the schedule of activities is consistent with the funding/phasing strategy. Sections 5.5.12 and 5.5.13 demonstrated that having a time phased, resource loaded schedule will help ensure that NASA P/ps can meet their commitments. Although a P/p may have high confidence in meeting schedule commitments, integrating the funding and resource parameters may create a different programmatic picture. Therefore, performing an *ICSRA* will continue to provide a holistic picture on whether the P/p has the ability to achieve cost and schedule goals under the influence of discrete risks and uncertainties.

It is a best practice for an ICSRA to be routinely performed to demonstrate the cost reserves are sufficient to accommodate schedule delays due anticipated uncertainty and risk impacts. Oftentimes reserves levels are dictated by standards and rules of thumbs. However, conducting *ICSRA* will provide further insight on whether currently held cost reserves are sufficient to identified uncertainties and risks.

Decision Making. Performing an *ICSRA* will provide, perhaps, an early indicator of whether there are insufficiencies in the budget based on the P/p schedule plan. P/p planning can be enhanced by integrating costs to the schedule, as well as risks. The results generated from an *ICSRA* facilitate a better understanding of the adequacy of reserves and the importance of schedule and cost alignment. An indication of inconsistent schedule and cost alignment may warrant that the *Health Check, Resource Integration Assessment,* and the *Critical Path and Structural Check* should all be executed again to address errors or defects

6.3.2.5.3.8 Risk-Based Trend Analysis

It is a best practice for an SRA (or ICSRA) to be routinely performed to support P/p management decisions regarding schedule and cost performance trends throughout the life cycle. By routinely performing the risk analysis the P/p can observe trends and better predict the sufficiency of the allocated margins and reserves. Figure 6-64 below, shows how a NASA project used the *SRA* to track risk mitigation performance over the life cycle. Early in the life cycle, it was obvious that significant risk mitigation strategies needed to be employed to get the likelihood of completion up into the launch period. By CDR, the project had mitigated risks such that they were within the launch period with 80% certainty, but still needed all margin available to cover the risks and uncertainties. At the next review point after CDR, the margin was more than adequate. Risks had been retired or appropriately mitigated. In addition, the project had more information and could reduce the uncertainty of the risk impacts. Hence the blue uncertainty bar had shrunk by that time. However, one of the low likelihood risks with high impact hit them shortly thereafter causing the drop down into the yellow caution area, but impact was still covered by the margin.

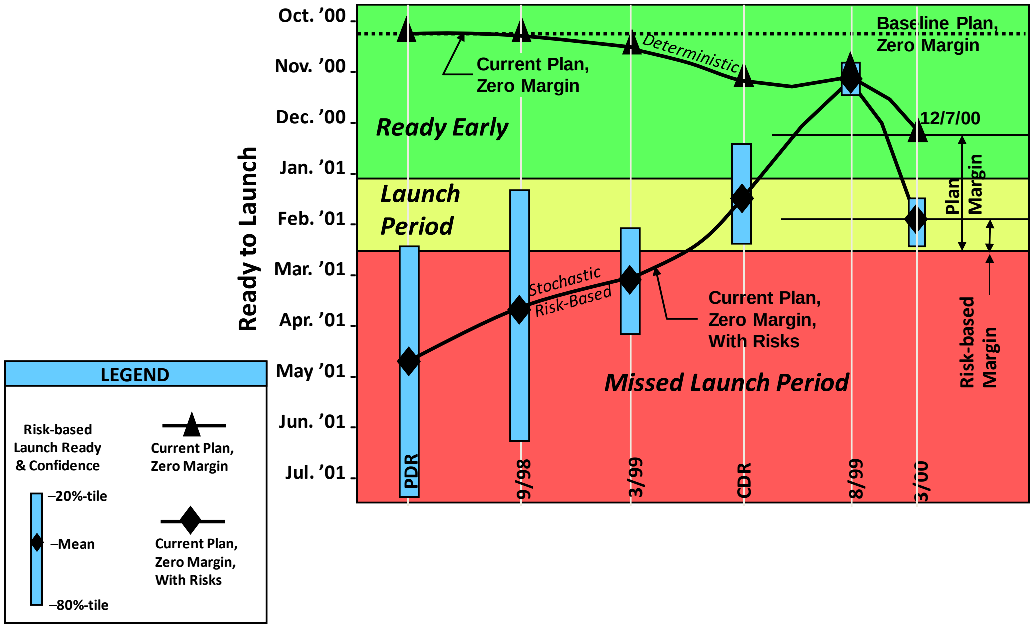


Figure 6-64. An example of how the SRA can be used to track the adequacy of margin to accommodate the risk exposure over the life cycle of a project.

Decision Making. The project used the information to target risk mitigation investments over time. At the last point, where the completion date moved into the yellow caution area, the result was considered with other information to consider whether or not to replan the launch.

6.3.3 Exit Criteria for the Schedule Analysis Sub-function

The Schedule Analysis sub-function is complete when:

- All stated objectives of the Schedule Analysis have been met.
- All Schedule Analysis output data products and the associated input data products are archived in the same location and marked as appropriate.
- All Schedule Analysis reports are complete and archived in the same location.

6.4 Skills and Competencies Required for Schedule Assessment and Analysis

The skills and competencies required for Schedule Assessment and Analysis can be found on the ScoPe website.[137]

7 Schedule Maintenance and Control

It is a best practice for the schedule to be maintained and controlled according to the Schedule Management Plan and/or Schedule Control Plan.[138] The *Schedule Maintenance and Control Plan*

---

[137] SCoPe website, https://community.max.gov/x/9rjRYg

[138] NPR 7120.5 requires that P/ps develop a Technical, Schedule, and Cost Control Plan. The schedule control portion of this plan is sometimes captured in the Schedule Maintenance and Control Plan, which is a sub-plan to the *SMP*.

captures the requirements managing schedule data throughout the Schedule Management life cycle. More specifically, it is about establishing a schedule plan, statusing/updating that plan, and then measuring and controlling the P/p's performance to the plan. As noted in Chapter 5 – Schedule Development, the *IMS* is the backbone not only for managing the P/p successfully but also for communicating the overall work plan and the current progress made toward completing the plan. PMI further defines the need for Schedule Maintenance and Control:

> "Most every P/p will inevitably experience changes. To ensure successful P/p execution, effective change control and disciplined maintenance procedures are necessary. The key is to determine how the project will approve and track changes as they occur throughout the P/p life cycle. Change can occur simply by work progressing more quickly or slowly than planned, as well as when changes in other elements of the P/p occur and/or whether the P/p team decides to modify its approach to the P/p work."[139]

The Schedule Maintenance sub-function ensures that the schedule is updated routinely and maintained with accurate progress status and approved changes. In addition to establishing the schedule baseline, the Schedule Control sub-function consists of the measurement of current performance and the estimating of future performance, as well as the corrective actions required to bring the performance back into compliance. It is a NASA requirement that the P/p regularly ensure it can meet the internal MA and the external ABC with acceptable risk. Maintaining the schedule and tracking and monitoring performance metrics, variances, and trends helps to identify the corrective actions needed to maintain internal and external commitments.

7.1 Best Practices

Figure 6-5 details the best practices for Schedule Maintenance and Control.

SM.MC.1 Schedule is Maintenance and Control Follows the SMP	• The schedule is maintained and controlled according to the Schedule Management Plan.
SM.MC.2 Schedule is Baselined	• The schedule is baselined at the required, or otherwise appropriate, point in the P/p life cycle.
SM.MC.3 Schedule Baseline/Updates are Informed by PPBE	• The schedule baseline and subsequent updates are informed by the Planning Programming Budgeting and Execution (PPBE) process.
SM.MC.4 Schedule Baseline is Reviewed and Validated	• The schedule baseline is validated by means of a review that includes P/p management, P/p staff, peers and stakeholders.
SM.MC.5 Schedule is Maintained Updated Using Actual Progress	• The schedule is maintained/updated to reflect the current status using actual progress.

---

[139] PMI. Practice Standard for Scheduling. Second Edition. Page 33.

SM.MC.6 Schedule Performance is Tracked and Measured Against Schedule Baseline	• Schedule performance is routinely tracked and measured against the schedule baseline to identify, monitor, and control schedule variances and trends.
SM.MC.7 Deterministic Techniques/Metrics are Used to Measure Schedule Performance and Monitor Trends	• Deterministic techniques and metrics (both EVM-based and non-EVM-based) are used to measure schedule performance and monitor trends.
SM.MC.8 Schedule Margin is Tracked and Monitored	• Schedule margin is tracked and monitored throughout the P/p life cycle.
SM.MC.9 Probabilistic Risk-Based Techniques/Metrics are Used to Measure Schedule Performance and Monitor Trends	• Probabilistic risk-based techniques and metrics used to measure schedule performance and monitor trends.
SM.MC.10 Corrective Actions are Identified and Tracked throughout the P/p Life Cycle	• Corrective actions are identified and tracked throughout the P/p life cycle to facilitate traceability to formal schedule baseline changes.
SM.MC.11 Schedule Baseline is Updated according to Corrective Actions	• The schedule baseline is updated according to corrective actions (replanning or rebaselining), as needed, as part of the P/p's change control process.

Figure 7-1. Schedule Maintenance and Control Best Practices.

7.2 Prerequisites

Schedule Maintenance and Control can be initiated when:

- The *SMP* sub-plan, *Schedule Maintenance and Control Plan,* which captures the requirements for updating the schedule, tracking performance measurements, and taking corrective actions to control the schedule throughout the lifecycle, is available
- The *Schedule Database* is completely developed and populated with all data, including:
    - Completion of all *BoEs*
    - Output of the *IMS*, *Summary Schedule*, and *Analysis Schedule* if appropriate
    - Collection of all supporting documentation (e.g., PPBE guidance document)
- A P/p CM/DM process exists

This complete set of information and data must be identified, marked, and archived according to the P/p's CM/DM process. Once the *Schedule Database* is complete and entered into version control, the P/p must ensure that the *IMS* has been successfully verified through the Assessment and Analysis sub-functions described in Chapter 6 of this document before baseline approval. For Space Flight P/p's (NPR

7120.5), if the LCC exceeds $250M, the P/p will be required to perform an *ICSRA* to determine the *JCL*, which is used in decision making to establish the MA and ABC, prior to baselining.

7.3 Maintain and Control the Schedule

After Schedule Development is complete and the *Schedule Database* is fully populated, a schedule performance baseline can be established. The schedule performance baseline, or simply, the schedule baseline or baseline *IMS*, is the time-phased schedule of all the work to be performed, against which performance measurements are tracked and corrective actions are taken to ensure that the P/p is performing to plan with acceptable risk. The schedule baseline informs the P/p's integrated baseline content, or formal PMB, when applicable. The schedule baseline is maintained through routine updates supported by CM/DM and controlled through the P/p's change control process.

The Schedule Maintenance and Control sub-functions consists of two Maintenance procedures and three Control procedures that are intertwined as shown in Figure 7-2. Procedure 1 establishes and validates the schedule baseline. Procedure 2 enters the current performance reports into the *Schedule Database*. This procedure does not change any baseline data within the *Schedule Database* but reports actuals and current performance against that baseline. Procedure 3 measures performance against a set of performance metrics with thresholds that require specific actions when exceeded by current performance. Procedure 4 determines whether corrective actions are necessary, what actions to take, and prepares the corrective action reports. Procedure 5 changes the *IMS* via P/p change orders (e.g., logic changes, duration changes, etc.).

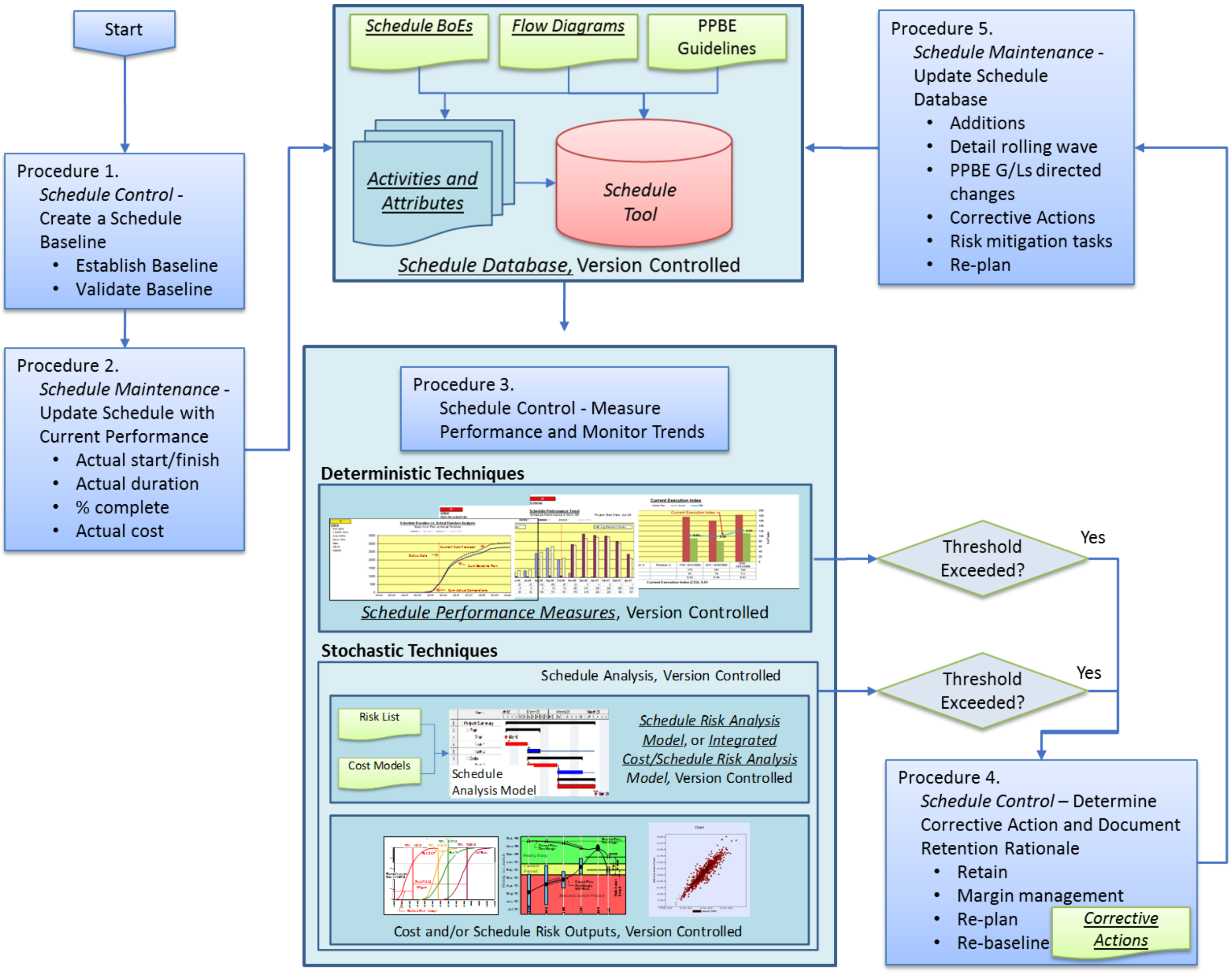


Figure 7-2. The Schedule Maintenance and Control sub-function consists of two maintenance and three control procedures.

7.3.1 Procedure 1. Control – Create a Schedule Baseline

The schedule baseline, or baseline *IMS*, is the original, approved, time-phased P/p schedule plan that serves as the basis for performance measurement during P/p implementation. It is the instance of the schedule against which corrective actions are taken to ensure that the P/p is performing to plan with acceptable risk. There are two general methods for establishing the schedule baseline that influence the methods of baseline control required:

- Baseline the entire *IMS*
- Baseline a subset of the *IMS*, usually key contractual and programmatic (target) milestones

Either method is acceptable. However, the first method (baseline the entire *IMS*) would necessitate a more rigorous, disciplined, and labor-intensive baseline control process since any change to schedule baseline data would need to be documented. The second method, sometimes referred to as "notification and control," still requires baseline control with documented changes but only for those tasks and milestones that have been selected as part of the schedule performance baseline (or formal

PMB, if applicable). This enables the P/p team to make adjustments to planned tasks without formal baseline change documentation as long as the changes do not impact the selected baseline data.

If using a "notification and control" approach, schedule control should be focused on a carefully selected and meaningful set of tasks and/or milestones from the baseline *IMS*. This set of control tasks and milestones may include, but are not limited to, items such as:

- Contract Milestones
- Major Integration Milestones
- Key Procurement Milestones
- Critical Test Activities
- Hardware Deliveries
- Facility Readiness Milestones
- Technical Reviews
- Verification Milestones
- Operational Readiness Milestones

Another important consideration relative to baseline content is whether the P/p has a requirement to implement EVM. For P/ps requiring EVM, there is a more direct and rigorous relationship to be maintained between the total schedule baseline and performance measurement processes, since the schedule baseline is an integral component of the PMB, which is used as a basis for EVM calculations. For P/ps not employing EVM, there is usually more flexibility in determining the schedule baseline content.

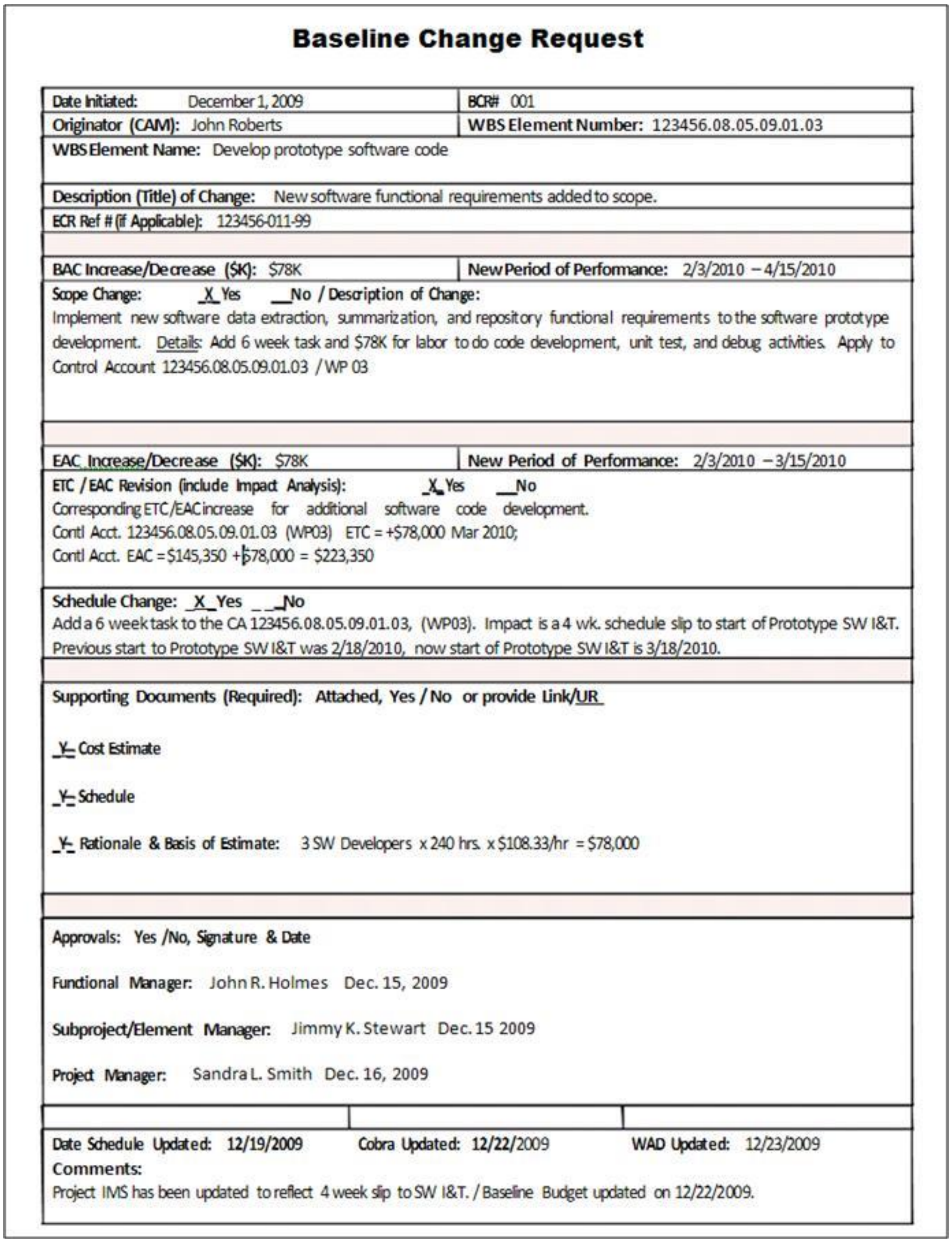
Change Control Process

Regular convening of a Schedule Change Control Board (CCB), enables the P/p management team to identify, manage, and control critical milestones, reviews, and major events across the P/p. The effective communication of prospective changes by the CCB allows for collaborative decision making by the P/p management teams and facilitates the coordination and relaying of changes to the wider P/p team and with NASA Headquarters. Utilizing a systematic method of tracking and recording changes to all critical milestones as the P/p evolves, enables accessibility to schedule change history, ensures accountability, and promotes consistent coordination of schedule data with the entire team

The schedule CCB is made up of selected members of the P/p management and support teams who are responsible for the schedules and who have decision making responsibilities at the P/p level. The CCB can be established at the project level with representation from major subsystems (e.g., observatory manager, instrument systems manager, integration manager, etc.), or depending upon the organizational structure and interfaces, at the Program level with representation from various projects (i.e., Deputy PMs, Technical Leads, Integration Managers, Resource/Business Managers, etc.).

The CCB meets on a regular basis to discuss upcoming known or anticipated changes to selected critical milestones, LCRs or other major reviews, KDPs, or key integration events identified in the schedule.

When warranted, the board members initiate and review Baseline Change Requests (BCRs), as shown in Figure 7-3, evaluate potential impacts, and decide which changes can be accepted (or rejected), implemented, and reported out. This documentation typically consists of an MS Excel file listing each non-compliant item and the appropriate response, providing either a corrective action or retention rationale. Other formats are acceptable if they serve the same purpose. The proposed corrective action or retention rationale report must be approved by P/p management. BCRs are routed through the P/p's CM/DM process.



Baseline Change Request

Date Initiated: December 1, 2009 | **BCR#** 001

Originator (CAM): John Roberts | **WBS Element Number:** 123456.08.05.09.01.03

WBS Element Name: Develop prototype software code

Description (Title) of Change: New software functional requirements added to scope.

ECR Ref # (if Applicable): 123456-011-99

BAC Increase/Decrease ($K): $78K | **New Period of Perfomance:** 2/3/2010 – 4/15/2010

Scope Change: _X_ Yes __No / Description of Change:

Implement new software data extraction, summarization, and repository functional requirements to the software prototype development. Details: Add 6 week task and $78K for labor to do code development, unit test, and debug activities. Apply to Control Account 123456.08.05.09.01.03 / WP 03

EAC Increase/Decrease ($K): $78K | **New Period of Perfomance:** 2/3/2010 – 3/15/2010

ETC / EAC Revision (include Impact Analysis): _X_ Yes __No

Corresponding ETC/EAC increase for additional software code development.
Contl Acct. 123456.08.05.09.01.03 (WP03) ETC = +$78,000 Mar 2010;
Contl Acct. EAC = $145,350 + $78,000 = $223,350

Schedule Change: _X_ Yes ___No

Add a 6 week task to the CA 123456.08.05.09.01.03, (WP03). Impact is a 4 wk. schedule slip to start of Prototype SW I&T. Previous start to Prototype SW I&T was 2/18/2010, now start of Prototype SW I&T is 3/18/2010.

Supporting Documents (Required): Attached, Yes / No or provide Link/UR

_Y_ Cost Estimate

_Y_ Schedule

_Y_ Rationale & Basis of Estimate: 3 SW Developers x 240 hrs. x $108.33/hr = $78,000

Approvals: Yes /No, Signature & Date

Functional Manager: John R. Holmes Dec. 15, 2009

Subproject/Element Manager: Jimmy K. Stewart Dec. 15 2009

Project Manager: Sandra L. Smith Dec. 16, 2009

Date Schedule Updated: 12/19/2009 | **Cobra Updated: 12/22/2009** | **WAD Updated:** 12/23/2009

Comments:
Project IMS has been updated to reflect 4 week slip to SW I&T. / Baseline Budget updated on 12/22/2009.

Figure 7-3. Example of baseline change request (BCR) for the IMS.

If the CCB approves a corrective action, the P/p's CM/DM or change control process will help to manage the technical and programmatic baseline changes. What follows is a description of the typical process sequence for a P/p engaged in schedule baseline control. This process is used regardless of whether the proposed change impacts the internal or external baseline commitment.

- A BCR, or equivalent, for the *IMS* is initiated by a responsible P/p Technical Lead, responsible contractor, or other outside customer or stakeholder source.
- The P/S should coordinate with the responsible change initiator who originates the BCR to determine the resulting impacts caused by the proposed change. Impact analysis should be conducted on both external and internal schedule baselines. This may require the preparation of "what-if" versions to assess the impact of the proposed change utilizing either the original baseline plan, the currently approved baseline plan, or the current updated *IMS*.
- The BCR not only documents a clear description of the proposed change, but also the "before" and "after" effects of the proposed change on the internal and external schedule and budget baselines.
- The BCR is then brought to the governing P/p CCB and reviewed in accordance with the P/p's *Schedule Control Plan* and Configuration Management Plan. **Note:** If the proposed schedule changes impact Schedule MA or Schedule ABC, then review and approval will also be required by the appropriate governing change boards and stakeholders.
- Once the schedule BCR has been formally approved by all the applicable CCBs, the P/S issues an updated schedule with a new revision designator.
- Changes to baseline data are important and should be tracked at the level of detail baselined. The P/p P/S should maintain a schedule baseline change log to record and track approved changes to the baseline, as shown in Figure 7-4. This log provides the on-going schedule baseline traceability required for sound P/p configuration control.

Baseline Change Request (BCR) Number	Schedule Change Request (SCR) Number (if no BCR)	Originator and Code	Origination Date	Approval Date	Date of Implementation into IMS	BCR or SCR Description	Rationale for Revision	CWBS(s) Affected	Impact of Revision on Overall Contractual Deliverable	Notes

Figure 7-4. An example of a schedule baseline change log.

7.3.1.1 Step 1. Establish the Schedule Baseline

It is a best practice for the schedule to be baselined at the required, or otherwise appropriate, point in the P/p life cycle. Only one official NASA baseline exists for a P/p, and it is the external Agency Baseline

Commitment (ABC).[140] The Management Agreement (MA) is an internal agreement and is often subset of the ABC.[141] Unless otherwise directed, the P/p's integrated baseline content, which includes the schedule baseline, is the basis for the MA. The following definitions and guidance are provided to ensure conformity with current Agency policy for P/p schedule baseline management:

- **Agency Baseline Commitment (ABC).** The ABC is NASA's commitment to Congress that the P/p will not exceed its identified external development cost and or schedule. The schedule portion of the ABC (Schedule ABC) is typically the planned launch date for a Space Flight P/p but may be a different end-item delivery date or key milestone date for other P/p types, such as Research and Technology P/ps. For Space Flight P/ps (NPR 7120.5), the ABC is established as part of KDP C approval. For Research and Technology P/p's (NPR 7120.8), the ABC is established as part of the Program Approval KDP. The ABC is documented in a Decision Memorandum (DM).
- **Management Agreement (MA).** The MA is the internal agreement between the Center, the Mission Directorate, the P/p, and the NASA Administrator that the P/p will not exceed its identified internal development cost and or schedule targets. The schedule portion of the MA (Schedule MA) is typically set to a prior to the ABC Schedule and is consistent with the P/p's baseline *IMS*, as well as the P/p's integrated performance baseline, or PMB. The MA is documented in a DM. The period of time between the Schedule MA and Schedule ABC indicates the available schedule margin between the internal and external commitment dates, usually controlled and funded by the Mission Directorate. The MA date should be included in the P/p *IMS* to facilitate execution and performance measurements, as well as in associated schedule reporting products to aid in decision making and communication with stakeholders. In some cases, P/ps will establish an internal baseline end-item delivery or launch date in advance of the MA date to allow for additional schedule margin.

Figure 7-6 describes the relationship between the P/p baseline schedule, integrated baseline, MA, and ABC.

---

[140] Per NPR 7120.5, "The ABC establishes and documents an integrated set of project requirements, cost, schedule, technical content, and an agreed-to Joint Confidence Level that forms the basis for NASA's commitment with the external entities of OMB and Congress."

[141] Per NPR 7120.5, "Within the Decision Memorandum, the parameters and authorities over which the PM has management control constitute the P/p Management Agreement. A PM has the authority to manage within the Management Agreement and is accountable for compliance with the terms of the agreement."

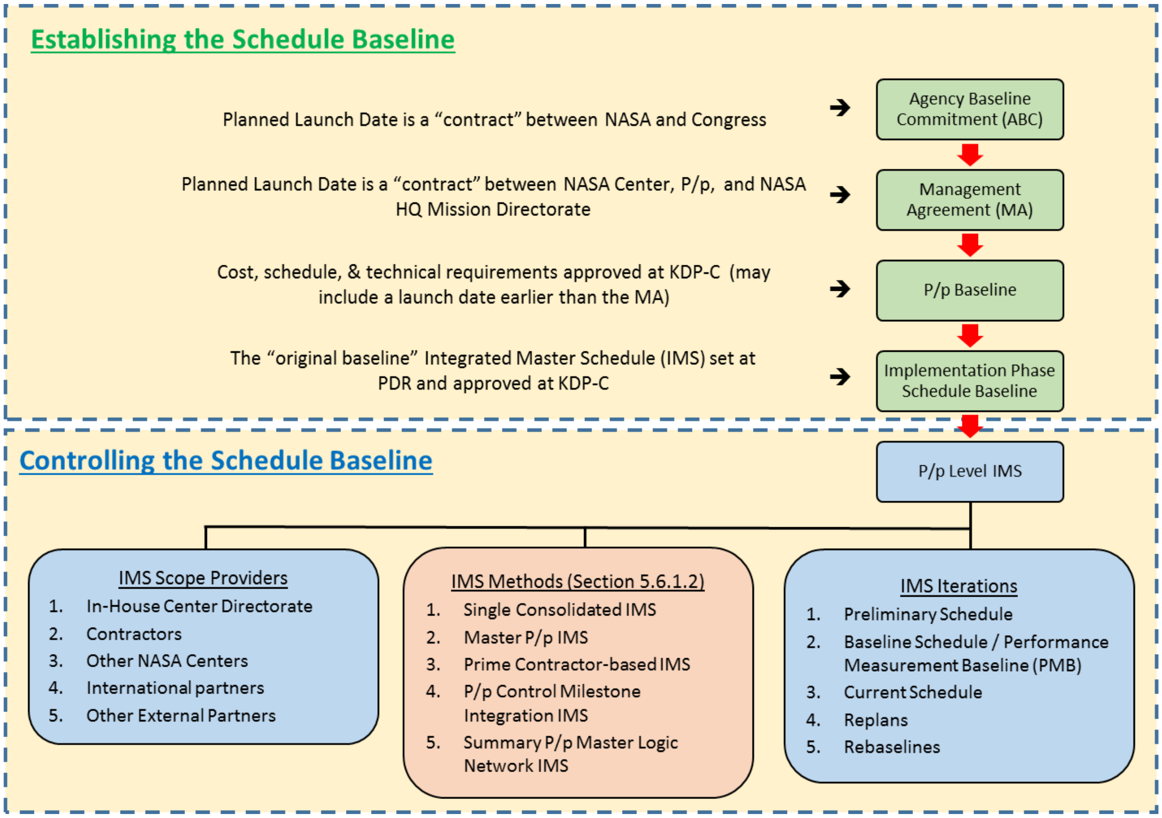


Figure 7-5. Illustration of the relationship between the P/p baseline schedule, the P/p integrated baseline, the MA, and the ABC.

Figure 7-6 illustrates how an MA and ABC are related to the P/p's life cycle.

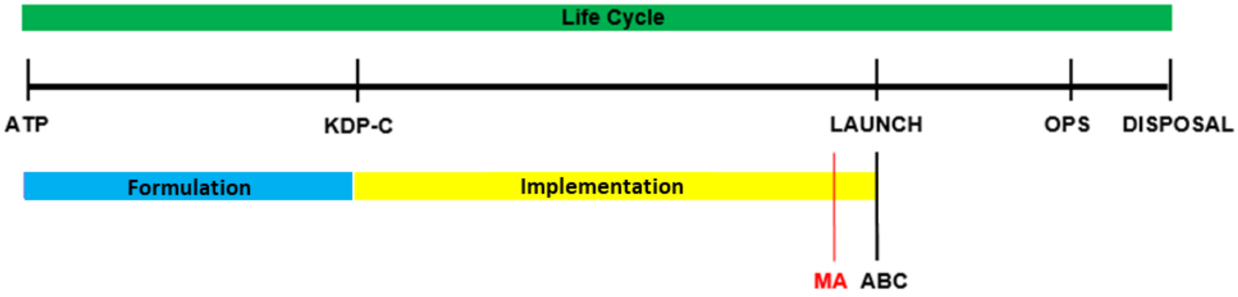


Figure 7-6. Illustration of MA and ABC as it pertains to the NASA P/p life cycle.

Note: The ABC is not always established as the P/p's "work-to" finish date (e.g., launch date), but may have additional margin to accommodate risks and uncertainties to ensure that the ABC can be met with acceptable risk. The period of time between the MA date and the ABC date often indicates the HQ-held schedule margin.

When creating the schedule baseline, it is necessary to establish what schedule content will be formally maintained and controlled. It is important to consider the external schedule commitments made and where they are included in the *IMS*. It is crucial that the schedule baseline encompasses the total approved scope of work, as defined in Section 5.3, and accurately models the P/p's plan for implementation. The *SMP* describes how the P/p encompasses the total approved scope, which depends on whether the P/p is primarily in-house, or includes contractor work or external partners:

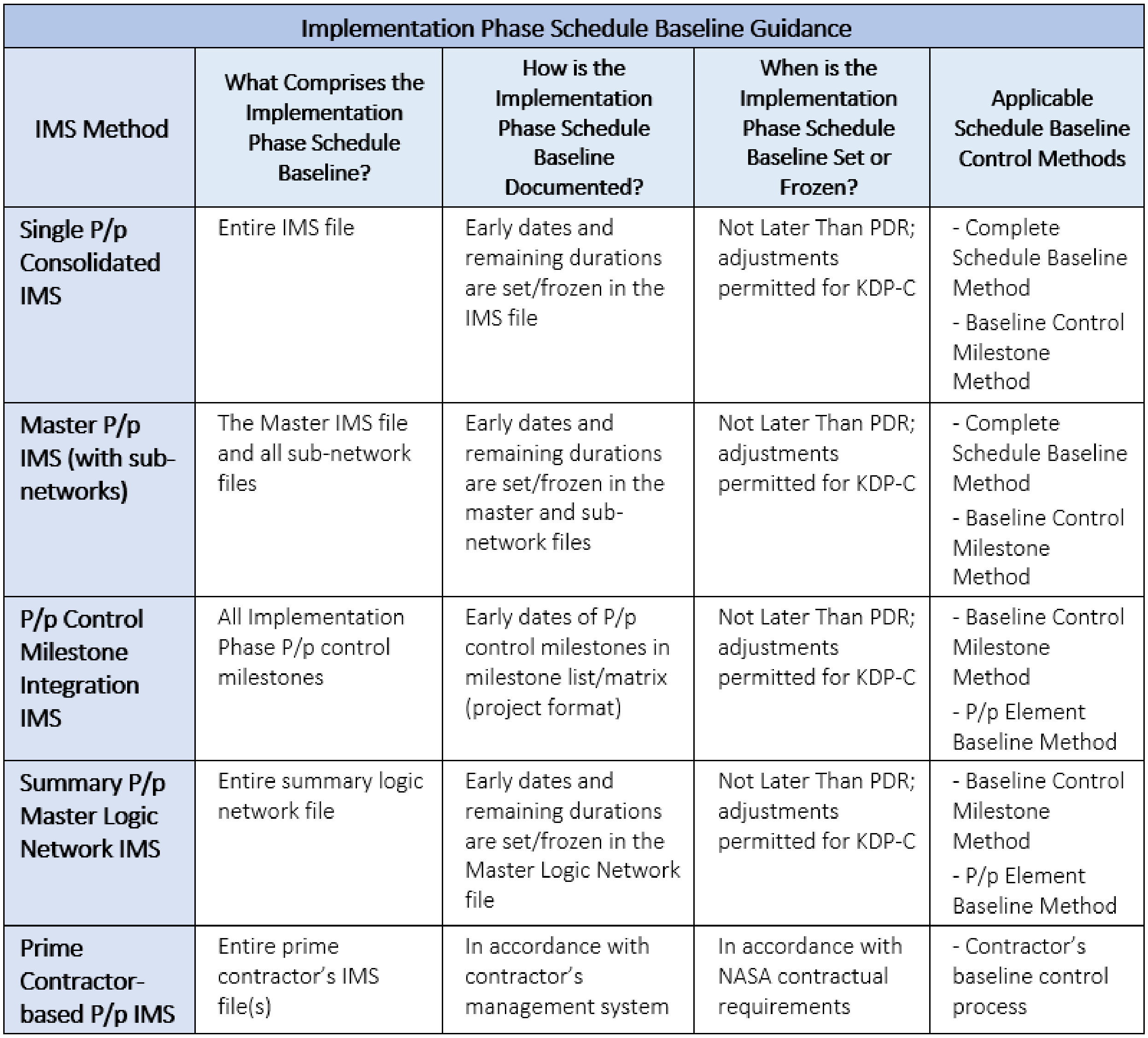
- **In-house Schedule Coordination.** The P/S(s) should support the Technical Leads for all scheduling requirements and perform Schedule Management Planning coordination and detailed Schedule Management Development for all in-house P/ps in partnership with other organizations, as required, to facilitate the Schedule Control sub-function. In-house effort could include the entire P/p, or a major element within the P/p such as the spacecraft, a single scientific instrument, or systems integration and test. The role of support service contractors would also be considered part of in-house effort.
- **Contractor Schedule Coordination.** To effectively integrate contractor schedule data into the P/p *IMS* to enable Schedule Control, it is imperative that a clear understanding exists between the government and contractors about such details as schedule content, level of detail, formats, reporting frequency, tools, thresholds, responsibilities, and controls. Anything that can be done during P/p initiation and Schedule Management Planning to clarify what is expected of the contractor will reap huge benefits in saving time and money and reduce stress and frustration levels in the personnel carrying out P/p implementation. This approach will also serve to provide additional risk mitigation throughout the P/p life cycle.
- **External Partner Schedule Coordination.** External partners include those with other Agencies, universities or other research institutions, international partnerships, or other business arrangements not involving contracts or procurements. Reporting requirements dictate the level of detail from partner schedules included in the P/p *IMS*. While Schedule Control of external partner schedule inputs is often limited, it should be noted that some arrangements permit NASA schedule expertise to be used in the development of partner schedules to facilitate integration for enhanced management capabilities, including Schedule Control. For example, some Science Mission Directorate (SMD) projects with deliverables provided by universities often provide direct scheduling support to the institution from their own project scheduling staff to assist in schedule development and status reporting.

Phase B Schedule Baseline

For 7120.5 P/ps, it is a NASA requirement to develop a preliminary *IMS* no later than the System Design Review (SDR) or Mission Definition Review (MDR). For 7120.8 P/ps, it is a requirement to develop a preliminary schedule no later than the Authority to Proceed (ATP) KDP. The preliminary *IMS* serves as the Phase B schedule baseline. Frequently, the Phase B schedule baseline encompasses the preliminary schedules for the major mission milestones and in-house work, as well as estimated schedules for anticipated contracted work scope, or out-of-house work. The reason a schedule baseline is set for Phase B is to provide a target or benchmark for what the P/p intends to accomplish by PDR. Although not required, it is a recommended practice to control the preliminary *IMS* for changes.

Implementation Phase Schedule Baseline

For 7120.5 P/ps, it is a NASA requirement to develop a preliminary *IMS* at KDP B, followed by a baseline *IMS* at the KDP C milestone. For 7120.8 P/ps, the baseline is set at the Program Approval KDP. A P/p's integrated performance baseline, or official Performance Measurement Baseline (PMB), is typically tied to the MA. P/ps may tailor their approach to establishing the Implementation Phase schedule baseline using the guidance in Figure 7-7.



Implementation Phase Schedule Baseline Guidance

IMS Method	What Comprises the Implementation Phase Schedule Baseline?	How is the Implementation Phase Schedule Baseline Documented?	When is the Implementation Phase Schedule Baseline Set or Frozen?	Applicable Schedule Baseline Control Methods
Single P/p Consolidated IMS	Entire IMS file	Early dates and remaining durations are set/frozen in the IMS file	Not Later Than PDR; adjustments permitted for KDP-C	- Complete Schedule Baseline Method - Baseline Control Milestone Method
Master P/p IMS (with sub-networks)	The Master IMS file and all sub-network files	Early dates and remaining durations are set/frozen in the master and sub-network files	Not Later Than PDR; adjustments permitted for KDP-C	- Complete Schedule Baseline Method - Baseline Control Milestone Method
P/p Control Milestone Integration IMS	All Implementation Phase P/p control milestones	Early dates of P/p control milestones in milestone list/matrix (project format)	Not Later Than PDR; adjustments permitted for KDP-C	- Baseline Control Milestone Method - P/p Element Baseline Method
Summary P/p Master Logic Network IMS	Entire summary logic network file	Early dates and remaining durations are set/frozen in the Master Logic Network file	Not Later Than PDR; adjustments permitted for KDP-C	- Baseline Control Milestone Method - P/p Element Baseline Method
Prime Contractor-based P/p IMS	Entire prime contractor's IMS file(s)	In accordance with contractor's management system	In accordance with NASA contractual requirements	- Contractor's baseline control process

Figure 7-7. The table provides guidance on establishing the schedule baseline using different methods.

The Implementation Phase schedule baseline is established (i.e., "set," "struck," or "frozen") at the task level of the *IMS* based on the early start dates, early finish dates, and durations for the tasks in the *IMS* for all of the *IMS* methods. In some cases, for out-of-house work, the contractor schedules may already be baselined in accordance with contractual requirements or internal contractor PP&C or EVM policies and procedures. This presents challenges for how P/ps will establish the Implementation Phase schedule baseline in a manner that includes these out-of-house elements. Options include:

- Overriding the contractor's schedule baseline (if any) by setting new baseline dates at PDR or Program Approval, as appropriate, or when a rebaseline occurs

- Including the contractor’s current baseline dates as contained in their native schedules (normally the preferred approach)
- Negotiating with the contractor’s scheduling office for the contractor to set (or reset) the schedule baseline dates in designated *IMS* file fields

If a summarization of the contractor’s *IMS* is included as part of the P/p *IMS* using one of the *IMS* methods described in Section 5.6.1, the P/S must ensure traceability between the contractor’s *IMS* and the summary *IMS* prepared by the P/S.

Some contractors have adopted approaches that use the “late” start and finish dates for setting the schedule baseline. While this concept may be part of these contractors’ PP&C processes, a “late date” approach is a gaming technique designed to minimize schedule variance reporting to customers. P/ps may have little leverage changing this approach used by some contractors and will need to recognize it when examining schedule performance.

Before statusing and updating, or incorporating changes through replanning or rebaselining, an “original baseline” version of the Implementation Phase baseline *IMS* should be documented. Recommended approaches for documenting the original baseline include archiving a copy of the Implementation Phase baseline *IMS* file or using one of the alternative sets of baseline fields, date fields, or start/finish fields within MS Project (or other scheduling tool) to save the tasks’ baseline early start dates, early finish dates, and remaining durations.

Schedule Performance Baseline

The schedule performance baseline, or simply, the schedule baseline or baseline *IMS*, is the time-phased schedule of all the work to be performed, against which performance measurements are tracked and corrective actions are taken to ensure that the P/p is performing to plan with acceptable risk. The schedule baseline informs the P/p’s integrated baseline content, which is referred to as the Performance Measurement Baseline (PMB) for Space Flight P/ps.

- **Performance Measurement Baseline.** The PMB is the time-phased cost plan for accomplishing all authorized work scope in a P/p's life cycle, which includes both NASA internal costs and supplier costs. The P/p's performance against the PMB is measured using earned value management, if required, or other performance measurement techniques if EVM is not required. The PMB does not include UFE.[142]

For Research and Technology P/p’s, NPR 7120.8 requires that the P/p, “Document the initial estimated LCC, the annual cost breakdown, or other appropriate cost description for the P/p, including costs for each participating Center, if applicable, that is consistent with the project WBS, schedule, and performance parameters to form the project estimate baseline.”[143]

---

[142] NPR 7120.5E. NASA Space Flight Program and Project Management Requirements. Effective Date: August 14, 2012. Expiration Date: August 14, 2020. Page 60.

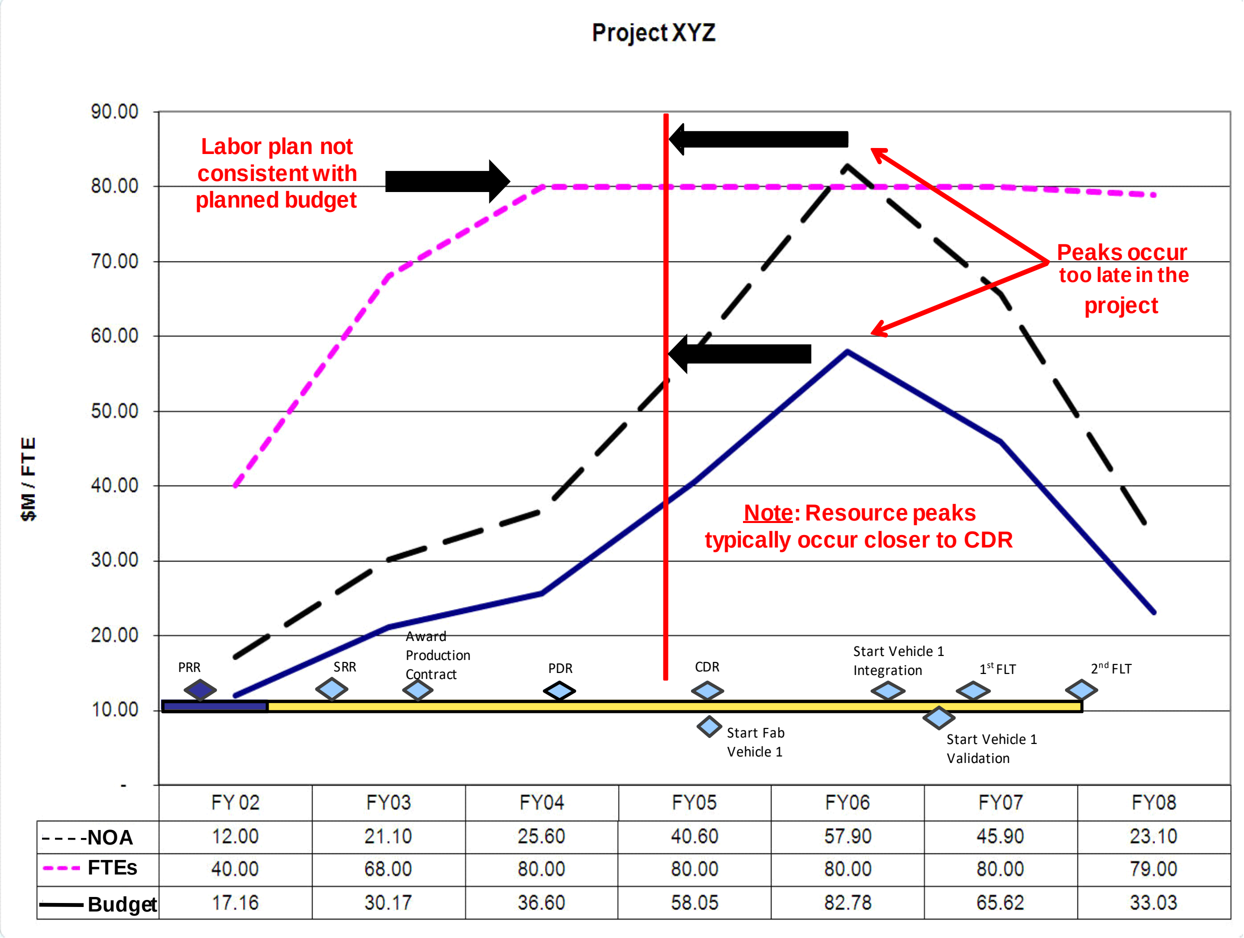
[143] NPR 7120.8A. NASA Research and Technology Program and Project Management Requirements. Effective Date: September 14, 2018. Expiration Date: September 14, 2023. Page 73.

Many NASA P/ps will be required to implement EVM. A key element of a successful EVM implementation is establishing the P/p's time-phased budget, referred to as the PMB.

7.3.1.2 Step 2. Validate and Approve the Schedule Baseline

The P/p's integrated baseline, which includes the technical, cost and schedule baselines, is set at KDP C for 7120.5 Space Flight P/ps and at Program Approval for 7120.8 P/ps. Thus, the P/p schedule should be integrated not only with the total scope of work to be performed, but also with the P/p's budget plan. In fact, the schedule baseline should never be approved unless the schedule plan consistently aligns with the budget plan. ***It is a best practice for the schedule baseline and subsequent updates to be informed by the Planning Programming Budgeting and Execution (PPBE) process.*** The schedule baseline should also correlate to the P/p's resource plan. All three of these (schedule, resource, and budget) should be in phase with each other. Ultimately, the P/p should have a commitment from each affected Resource Manager to provide the required resources in the timeframe indicated by the approved schedule baseline.

One very simple but useful technique for cross-checking P/p resources during Schedule Development prior to baselining is a summary-level cost/schedule correlation check, as shown in Figure 7-8. This approach provides a means for quickly determining if planned resource usage peaks correlate appropriately with major P/p milestones and phases. For example, in a typical development P/p, the resource peak should occur a short time prior to the Critical Design Review (CDR). This is due to the required overlap of many skill types during the transition from hardware design to hardware fabrication and test. If this cross-check indicates the peek is too early or late, the P/p management team should review and adjust the budget/resource plan accordingly.



Labor plan not consistent with planned budget

Peaks occur too late in the project

Note: Resource peaks typically occur closer to CDR

	FY 02	FY03	FY04	FY05	FY06	FY07	FY08
- - - -NOA	12.00	21.10	25.60	40.60	57.90	45.90	23.10
- - - - FTEs	40.00	68.00	80.00	80.00	80.00	80.00	79.00
—— Budget	17.16	30.17	36.60	58.05	82.78	65.62	33.03

Figure 7-8. The figure illustrates a summary-level cost/schedule correlation check.

Schedule baselines must be approached as an integrated P/p team product. Whether the P/p is primarily composed of in-house, contractor, or external partner effort, it is the total P/p team, including contractors and external partners, if applicable, which must claim ownership of the schedule content and its validity. As data is reviewed and changes are identified, final revisions should be made to the schedule before approving the baseline. A schedule management process should be implemented within each P/p organization that dictates that prior to schedule baselining, the PM along with each of the responsible government, contractor, and/or external partner Technical Leads, Programmatic Leads, and associated COTRs (and/or his designated representatives) must perform a thorough *IMS* review. Thus, ***it is a best practice for the schedule baseline to be validated by means of a review that includes the P/p management team, P/p staff, peers, and stakeholders (e.g., contractors, external partners, etc.).*** This review should cover not only schedule content, but also task/milestone sequencing, associated resources, slack (float) analysis, probabilistic schedule uncertainty, and all valid constraints that apply.

At a minimum, the P/S should review the results of these changes with all the affected P/p team members. During the final *IMS* review the following activities should occur:

- Verify major P/p milestones that have changed and gain approval from the PM and the affected organizations. In the event that the result of these revisions causes a major milestone date change that is unacceptable, the P/p team must return to the review process.
- Evaluate P/p risks that have already been documented as well as identify potential new risks to ensure impacts have been adequately factored into either task duration, risk, or duration uncertainty estimates, as well as overall P/p duration estimates. **Note:** The aggregate duration impact of task duration uncertainties and discrete risks will also help in evaluating the adequacy of schedule margin identified in the *IMS*.
- Evaluate and ensure that there is adequate schedule margin and that it is clearly identified as such in the P/p schedule. Performing an *SRA* as described in Chapter 6 will assist in this evaluation.
- Ensure that the schedule is in congruence with the budget and workforce baselines.
- Enlist a commitment to P/p management from all P/p stakeholders affected and responsible entities to adhere to the plan as reflected in the baseline. This will involve all required resource and task performance commitments (i.e., dates, facilities, personnel, etc.).
- Save and archive an electronic copy of the approved P/p baseline for Schedule Communication and Documentation purposes, as described in Chapter 8.
- Establish configuration control of both in-house NASA and contractor schedule baselines.

Validation of the schedule baseline must be completed prior to the KDP C milestone to support the pre-approval reviews (e.g., EVM Assessment, IBR, PDR, as applicable). Review and approval of the schedule baseline should not be taken lightly, and any changes should be carefully controlled.[144] This is especially true when utilizing EVM techniques.

- **When EVM is Required:** For P/ps whose LCC exceeds $250M, it is a requirement to perform EVM.[145] Whenever EVM is to be performed, a PMB is required to ensure that the P/p's work is properly linked with its cost, schedule, and risk and that the management processes are in place to conduct project-level EVM.[146] Per 7120.5, "for P/ps requiring EVM, Mission Directorates shall conduct a Pre-Approval IBR as part of their preparations for KDP C to ensure that the P/p's work is properly linked with its cost, schedule, and risk and that the management processes are in

---

[144] NASA/SP-2014-3705, NASA Space Flight Program and Project Management Handbook states, "IBR is required to verify technical content and the realism of related performance budgets, resources, and schedules. It is a risk-based review of a supplier's PMB conducted by the customer (e.g., the Mission Directorate, the program, the project, or even the contractor over its subcontractors). While an IBR has traditionally been conducted on contracts, it can be effective when conducted on in-house work as well. The IBR ensures that the PMB is realistic for accomplishing all the authorized work within the authorized schedule and budget and provides a mutual understanding of the supplier's underlying management control systems. Subsequent IBRs may be required when there are significant changes to the PMB such as a modification to the project requirements (scope, schedule, or budget) or a project replan." Page 369. https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20150000400.pdf

[145] NPR 7120.5E. NASA Space Flight Program and Project Management Requirements. Effective Date: August 14, 2012. Expiration Date: August 14, 2020. Page 29.

[146] NASA-SP-2016-3406. NASA Integrated Baseline Review (IBR) Handbook. March 2016. https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20160005291.pdf

place to conduct P/p-level EVM." The initial IBR should be accomplished within the first three to six months after contract award or after approval of the P/p Plan by the Mission Directorate Associate Administer (MDAA), or Mission Support Office Director (MSOD). On P/ps of short duration, it may be necessary to initiate the review earlier in order to make best use of the information derived from the review. During this review joint contractor and government teams review the total P/p cost, schedule, and technical baseline for the purpose of ensuring that a valid baseline is in place and that a mutual understanding and agreement exists in the scope of work and in the amount of resources required. An IBR additionally identifies and alerts the P/p team to potential P/p risks.

- **When EVM is Not Required:** For P/ps less than $250M, it is a recommended practice to use concepts and procedures defined in the NASA IBR Handbook to tailor an appropriate review to validate the baseline prior to KDP C.

These types of reviews should be carried out prior to initial P/p baselining and then repeated as necessary after major P/p changes or at specified intervals and/or events (i.e., Program Planning Budget Execution (PPBE) updates, Preliminary Design Reviews (PDR), Critical Design Reviews (CDR), etc.) accompanied by PM buy-in to ensure on-going schedule integrity. It must be stressed however, that establishing new *IMS* baseline schedule dates should only occur when major scope and/or budgetary changes have been encountered, which require formal approval by P/p management and may require formal rebaselining procedures as detailed in Section 7.3.4.7.

7.3.2 Procedure 2. Maintenance – Update Schedule with Actual Progress

It is a best practice for the schedule to be maintained/updated to reflect the current status using actual progress. Establishing and maintaining a credible schedule baseline is integral to sound P/p Schedule Management. The *IMS* reflects both the P/p-approved time-phased plan (including all subsequent approved changes), and the time-phased plan with its current task progress, sequence, and forecasts. Once the *IMS* has been baselined, the *Schedule Database* is routinely updated with current progress so that the scheduling tool can recalculate the total float, critical and driving paths, and the projected completion dates. It is critically important for the *IMS* to accurately and realistically reflect the current plan to complete the remaining authorized scope as contained in the baseline.

It should be understood that schedule baseline data represents the original plan, while current schedule data reflects actual and forecasted outcomes. The "current schedule" is defined as the schedule baseline with all approved content changes as of "time now", or the status date. All work to the left of time now reflects "actuals" or work that has already occurred. All work to the right of time now is "future work". Schedule updates are typically provided by the Technical Leads, contractors, and/or external partners according to a status window that encompasses any updates since the last status update to time now. It is a recommended practice that all updates to the schedule be provided according to a single status date. The time now status date is typically aligned to month-end closeout dates. Routine updating ensures that the *IMS* reflects the current status and logically calculated forward plan of the P/p. As the *IMS* is updated, the P/p can track performance against the schedule baseline.

Status updates should be made as frequently as feasible. The frequency is oftentimes dependent upon what phase the P/p is in, who is doing the work (in-house NASA, contractor, or both), as well as the number of resources available to gather, input, and analyze the new status updates. Typically, early in a multi-year P/p, a monthly update is adequate, but if the necessary resources and processes are in place, then weekly or bi-weekly may be the preferable interval. P/p scope that is being implemented by in-house NASA organizations provides the flexibility of updating progress weekly or bi-weekly. P/ps with prime contractor involvement will generally get an updated *IMS* from the contractor monthly. This situation limits the capability of providing management with a fully integrated and updated *IMS* to a monthly cycle. There are always some exceptions to the update guidelines established by a P/p that may come into play, such as, the type of work being done may dictate the frequency or the level of visibility required. Also, some schedule items are designated as "management reporting" tasks/milestones and may require a more frequent update cycle.

It is important to note that this procedure is not indeed to change any baseline data within the *Schedule Database*. The baseline data is a part of the integrated performance baseline, or PMB, and cannot be changed without going through the formal CM/DM process for making changes. For instance, activity durations and workflows can be replanned as part of the routine updating processes, as long as they do not impact the formally tracked baseline dates in the schedule (i.e., activity and milestone types identified in Procedure 1. However, when changes to baseline dates are required, they must be formally processed through the P/p's CM/DM process. Any non-compliances, defect reports, and resolutions should be documented. Procedure 4 in Section 7.3.4 explains the process for when schedule maintenance updates impact the schedule baseline and require official corrective actions, such as replan or rebaseline activities.

7.3.2.1 Routine Schedule Updates

Necessary inputs used for updating activity progress are captured in the *SMP*, and usually include at a minimum, actual start/finish dates and/or actual duration, as well as actual cost. Routine *Schedule Database* updates may consist of, but not be limited to:

- Verifying/modifying activity and milestone durations
- Revising or adding logic interdependencies
- Additions of new activities and/or milestones and their associated logic ties
- Re-allocation or assignment of resources
- Calendar changes
- Other miscellaneous, minor schedule adjustments

Revise Activity/Milestone Data

Revising activity/milestone data may entail a change of activity/milestone dates, duration, resource allocation, or location within the data structure (i.e., WBS). Actual activity/milestone dates (start or finish) should be entered as accurately as possible. Planned activity/milestone dates should be calculated by the scheduling tool used, not manually entered by the tool user. Duration, or remaining duration, should be updated as required to reflect the most current estimate. Resource allocation changes should also reflect the most current estimate. When changing an activity/milestone location within the data structure, ensure that existing interdependencies with other activity/activities are still valid and accurately reflected.

Activities may also require informational changes, which are revisions to task/milestone notes, descriptions, or coding data. If a change control process is in use, it should be consulted and followed for these revisions. If a change control process is not in use, it is recommended that changes of this nature be done in a consistent fashion and in keeping with the existing P/p guidelines for task nomenclature and coding.

Note: Minor modifications to network logic are necessary on occasion to maintain an accurate reflection of the work being performed. It is highly recommended however, that a change control process be established and adhered to for logic changes that result in impacts to contractual or other management control milestones. Logic modifications have a direct impact on the planned (calculated) dates for activities, including contractually required and management-directed events. Before and after any significant logic modification, an electronic copy of the schedule should be made and stored for safekeeping. A record of the change should be kept in appropriate notes fields in the *IMS*, along with the reason for the change, and the person authorizing the change, particularly if the change impacts a baselined activity or milestone reflecting a P/p commitment.

Add New Activities/Milestones

New activities and/or milestones may be added to better define existing work scope or to add new work scope. Both scenarios require adherence to existing schedule controls for descriptions, structure, coding, network logic, duration, resource allocation, and risk data. Often the addition of new activities results in a longer duration for the overall schedule, making it necessary to address some of the assessment and analysis sub-functions defined in Chapter 6. When risk mitigation activities are added as new work to the schedule, it is a recommended practice that they be flagged or coded as such within the *IMS*.

Note: During the P/p's schedule status update cycle (e.g., monthly), it is not uncommon to add new activities to the *IMS* in the very near term (i.e., within the following month) for increased schedule management visibility. It is optional whether the P/p sets baseline dates for these tasks since they can be considered logical enhancements to the current schedule forecast and are valuable for managing the P/p effort. For example, if the status date of the *IMS* is June 30th, and three new activities are added to the current *IMS* for completion in July, it is not necessary to set baseline start and finish dates for them. The process for handling these activity additions in the current P/p *IMS* should be described in the P/p's *SMP*.

Delete Existing Activities/Milestones

As changes are made to the technical content of the P/p or when descope plans are executed, activities will need to be deleted. Before deleting any task or milestone from the *Schedule Database*, existing network logic interdependencies and resource allocations should be reconciled. It is a recommended practice to properly codify and retain deleted activities within the *IMS* for a few update cycles just to be able to retrace, verify, or restructure logic ties should an error be discovered.

7.3.2.2 As-Needed Schedule Updates

Schedule updates may also occur on an ad hoc basis for reasons including, but not limited to:

- Decomposing high level tasks into detailed tasks or planning packages into work packages as part of ongoing rolling wave planning

- Further refining schedule detail
- Replacing preliminary estimates of contractor schedules with contractor-provided schedules
- Making retroactive changes to correct errors, as well as applying progress

The impact, if any, of these updates should be assessed against and/or reconciled with the *IMS* baseline.

7.3.2.3 Steps for Updating the Schedule

The detailed steps for updating the schedule are listed below:

- Gather task/milestone status. This may be accomplished in various ways such as providing task owners with a printout containing their specific tasks that require update information, face-to-face meetings with task owners to discuss and redline the schedule copy, or establish weekly, bi-weekly, and/or monthly P/p *IMS* update meetings with all task owners participating by verbally providing their status. Regardless of the strategy for gathering updates, the P/p must ensure that progress given is consistent with the pre-established task completion criteria documented in the *SMP*.
- Incorporate the gathered status updates into the *Schedule Database*. Enter Actual Start and Actual Finish dates into the *Schedule Database*. For in-progress activities, the percent complete is entered. It is important to understand that many scheduling tools offer different "% Complete" fields with different functions. The "% Complete" commonly in the default view for most scheduling tools is actually "percent duration complete" and may or may not be directly related to the "physical work percent complete." This is particularly important when using earned value because earned value does not reflect days consumed but dollars consumed. If subject to EVM, the same PMTs identified during Planning should be used for making updates to the schedule activities. PMTs are further discussed in Procedure 3. For resource-loaded schedules, the scheduling tool may also have "Actual Work" or "Remaining Work" fields that help the P/S from arbitrarily entering percentages that may not be physically calculating. Using these fields will automatically update the value in the "% Complete" field.
- Ensure that data is provided for all activities that are time phased to the left of the current status date. Reflect activities as actually started and in-progress (with proper completion forecast), actually completed, or re-forecasted to a more accurate start and/or completion date. (Beware that some schedule management tools, such as MS Project, do not force the user to update the status of on-going or behind schedule tasks/milestones). It is important that all incomplete tasks/milestones in the schedule be updated to a single status date, including tasks/milestones that should have started or completed, but have not.
- Use "Remaining Duration" as the primary method for providing status of in-progress activities. This will keep projected finish dates accurate, as well as successor linked activities/milestones properly time phased.
- Analyze schedule impact and resolve issues. After all status updates have been incorporated into the *Schedule Database*, it is important to analyze schedule impacts and resolve all issues resulting from the new status updates. This analysis includes, but is not limited to: identifying the current critical path and comparing to the previous critical path, identifying and correcting

status input errors, identifying tasks/milestones with missing status, identifying new schedule related risks, identifying necessary logic, resource, and calendar changes that are required, etc.

- Ensure the *IMS* reflects, as accurately as possible, the current plan for accomplishing the remaining work. This will involve updates to network logic, remaining durations, and actual start and finish dates.

- Copy and archive *IMS* versions to the P/p's schedule repository and the Agency Schedule Repository, if applicable, prior to each update cycle.[147] This will ensure proper historical records for future audit activity and to provide a source of reliable schedule duration information for future duration estimating and validation. It also supports the P/p's CM/DM function.

7.3.3 Procedure 3. Control – Measure Performance and Monitor Trends

It is a best practice for schedule performance to be routinely tracked and measured against the schedule baseline to identify, monitor, and control schedule variances and trends. The purpose of the schedule baseline is to provide a basis for progress measurements that the P/p can use to control the schedule performance. It is important to note that "progress" is a status of "where things are at" on the P/p, whereas "performance" is a determination of "how well a P/p is executing to plan." Tracking progress against the schedule baseline according to the *Schedule Performance Measures*, as documented in the *SMP*, and executing prescribed actions when predefined thresholds are breached is how the P/p adjusts the plan to meet stakeholder commitments. For instance, the P/p can use these performance indicators throughout the life cycle to further inform future activity duration estimates, possibly enabling the P/p to employ replanning techniques to control the schedule without having to formally rebaseline.

The control processes established for managing the schedule based on current performance inputs should not be confused with the formal baseline change process. The purpose of the measuring current performance and monitoring trends is to provide an accurate reflection of what has been accomplished along with an accurate representation of how the future work will be carried out, regardless of what the baseline schedule shows. Maintaining accurate current schedule performance data should not be hampered by formal control processes, but rather by informal rules. These informal rules may include, but are not limited to the following:

- Maintain close communication and coordination with all P/p team members
- Gain informal approvals from responsible technical leads
- Gain approvals by PMs
- Maintain continual Schedule Assessment and Analysis (to ensure proper forecasting, progress, and changes are incorporated)

In-house, contractor, and external partner schedules must be continually monitored to assure successful P/p performance. To do so requires the in-house entities (e.g., sub-projects), contractors, and/or

---

[147] Agency Policy Guidance to Enhance Earned Value Management (EVM) and Create a Schedule Repository. June 4, 2019. https://community.max.gov/display/NASA/Schedule+Community+of+Practice

external partners to routinely and electronically submit their fully integrated schedules to NASA's P/S in its native file format (e.g., MS Project, Primavera, etc.). Having access to the respective *IMSs* in their native file formats makes it possible for the P/S to integrate the information into the P/p *Schedule Database* to effectively monitor and evaluate, at any level of detail, the quality and integrity of its task sequencing, projected dates, critical and driving paths, assigned constraints, resources, coding, structure, and current status. For example, on contracts, a P/p-level IPMR is typically provided on a monthly basis to provide, technical, schedule, and cost status information. The purpose of the IPMR is to provide early identification of problems that may have significant cost, schedule, and/or technical impacts and report the effects of management actions and P/p status information for use in making and validating management decisions. P/ps integrate contract IPMR, in-house, and other data to produce a P/p-level IPMR. As P/p work is accomplished and task/milestone forecast start/finish dates move earlier or later, it is important to monitor and keep the P/p management team informed of changes to need dates for various hardware milestones and development efforts. Close communication of this information between P/p team members, the Acquisition and Contract Management function, and associated vendors will help ensure parts and material are available when needed.

Performance measurements are made using a selected set of performance metrics as specified in the *SMP*. The metrics are divided into two classes, deterministic and stochastic. The deterministic methods measure the current performance to the plan using a number of different techniques that evaluate the variances between the baseline and current schedule dates and durations. Those techniques can be used to estimate future performance but are limited to the knowledge provided by past performance. Stochastic measurements are predictions of future performance using a Monte Carlo simulation which models the impacts of risks and uncertainties. Performance measurements are routinely reported to the P/p management staff through the Communication sub-function discussed in Chapter 8. For P/ps with contracts, tracking measurements are collected per the DRDs as described the *Schedule Management and Control Plan.* Performance measurements and trend monitoring of this type should be made available to the PM and Technical Leads for consideration and/or correction. This approach enables the total integrated P/p team to more effectively identify potential schedule risks in a timely manner and to select the best strategies for mitigation.

While performance can be measured for all activities in the schedule, changes to activity and milestone dates will not require approval through the formal baseline change control process unless their movement impacts a task or milestone that is baseline controlled. The formal control of the schedule baseline is limited to control of approved activity and milestone types identified in Procedure 1. However, it should be understood that in carrying out Schedule Maintenance there may be issues and conflicts that are identified that will precipitate the need for a formal Baseline Change Request (BCR). In these situations, a BCR will be initiated and processed through a Change Control Board (CCB) in a manner as outlined in Procedure 4.

The nature of this control procedure can be standardized and tailored for each P/p, depending upon the size and complexity of the *IMS* and the P/p's needs. Implementing *IMS* version control during the update process is a simple technique for ensuring that the P/p team and stakeholders are using the latest schedule information. Practical control of current schedule data can be enhanced through the use of incremental schedule versions and/or release dates, and also by keeping copies of prior schedule versions.

7.3.3.1 Step 1. Measure Deterministic Performance and Monitor Trends

It is a best practice for schedule metrics (both EVM-based and non-EVM-based) to be used to measure deterministic schedule performance and monitor trends. It is imperative that P/p teams establish sound performance evaluation practices from the very start of implementation. The P/p management team needs as much meaningful and credible performance information as possible to help keep the P/p on track in order to meet planned objectives and commitments. It is a recommended practice that periodic performance trend analyses be executed on *IMS* data as depicted in the examples shown below.

The following sections introduce a set of schedule performance metrics intended to assist the P/p management in using the *IMS* to make sound programmatic decisions. These metrics include both EVM and non-EVM based metrics, such as:

- Activity/Milestone Variances and Schedule Variances (SV)
- Activity/Milestone Performance Trends
- Baseline Execution Index (BEI), Current Execution Index (CEI), and Hit or Miss Index (HMI)
- Schedule Performance Index (SPI), Time-based Schedule Performance Index (SPI_t) and Earned Schedule (ES)
- Critical Path Length Index (CPLI)
- Margin and Float (Slack) Erosion

This list of metrics is a representative example and not an exhaustive list of schedule execution metrics available to the P/p. The metrics and the thresholds for action are selected and defined by the P/p during the Schedule Management Planning sub-function and documented in the *SMP*. Overall, this handbook advocates the use of the *IMS* primarily as a management tool versus a reporting tool.

It is a recommended practice to use EVM-like measurements for all P/p, regardless of LCC value, whenever possible. EVM techniques will likely require the designation of specific milestones within the baseline *IMS* as "EVM milestones" to which a portion of the PMB costs will be assigned, as described in Section 5.5.2. The PMB consists of the budget or budgeted cost for work scheduled (BCWS) for all control accounts. For in-house P/ps, or P/ps with major elements of in-house work, the schedule baseline supports the PMB. However, for many of NASA P/ps, the P/p's prime and non-prime contractors will have contractual EVM requirements. Therefore, some reconciliation between the P/p-level *IMS* and the contractors' IMSs will be necessary.

For P/ps requiring EVM, the complete set of EVM milestones comprises the PMB from an *IMS* perspective. The P/S, EVM Analysts, Resource Analysts, and Technical Leads should work together during Schedule Planning to define how the BCWS will be time-phased and how the earned value, or the budgeted cost of work performed (BCWP), will be taken. The exact approach for determining BCWS and taking BCWP may vary among P/ps based upon which Performance Measurement Technique (PMT) is utilized. Generally, the performance measurement of work packages is derived directly from the objectively determined status of the time-phased tasks/milestones composing the work packages. Work packages containing deliverable products, or work associated with deliverable products, are deemed "discrete effort." Discrete effort work packages are assigned an appropriate PMT considering duration, value, and nature of the effort. The same PMT method used for planning purposes and documented in the *SMP* should also be used for claiming earned value. Future activities, requiring further definition, are assigned to planning packages and are reflected in the *IMS* at a summary level of detail. As planning package tasks reach the near-term window, they are divided into discrete work packages, and assigned appropriate PMTs, prior to beginning work. It is important to note that LOE activities, which represent only support efforts (e.g., P/p management, administration, safety), generally have no discrete products that are produced making the quantification of accomplishment difficult or impossible. Examples of PMT's include the following:

- Weighted milestone – significant events represented by a milestone assigned a percentage of the total value of the task/activity.
- 50/50 and 0/100 – used for short duration effort that are planned to complete within one to two reporting periods.
- Percent complete – is either an objective (e.g., based on physical quantities) or subjective (personal judgment) determination of the percent of the task/activity that has been completed. It is strongly recommended that as each task percent complete is determined and incorporated that the task's remaining duration is also determined and accurately reflected in the *IMS*.

  Note: When updating an in-progress schedule task, it is the remaining duration that becomes the determining factor in reflecting the task's accurate forecasted completion date.
- Apportioned – is determined to be the same percent complete as the related task or tasks (e.g., safety/quality inspector support for fabrication of hardware).

PMTs are individually selected for each work package to enable the most accurate evaluation of performance possible. Future activities, requiring further definition, are assigned to planning packages and are reflected in the *IMS* at a summary level of detail. As planning package tasks reach the near-term window, they are divided into discrete work packages, and assigned appropriate PMT, prior to beginning work.

Caution. Schedule execution techniques measure schedule performance in different ways, using different assumptions and data sets. Using a single metric or a small set of metrics run the risk of the P/p drawing false conclusions. To mitigate this risk, the P/p should utilize a suite of complimentary schedule metrics to corroborate potential schedule execution concerns. Avoid manipulating the *IMS* with the intent of producing favorable metrics for reporting purposes as this severely impacts the value of the *IMS* as a management tool. The objective of using schedule execution metrics is to identify potential issues, propose and implement solutions, and assess the effectiveness of those solutions and not to simply have a report card. It is also important to note that frequent baseline changes (i.e. replanning, re-baselining) can also alter the effectiveness of the *IMS* as a management tool, as it may give false representations about how the P/p is truly executing to their plan.

7.3.3.1.1 Activity/Milestone Variances and Schedule Variance (SV)

Description. Schedule activity/milestone variances are indicators of whether the activities/milestones in question are ahead or behind schedule. It is very likely that the current schedule will at some point deviate from the schedule baseline. It is important to routinely compare the planned/baseline and current schedules to identify, measure, and monitor significant variances associated with key milestone events, as well as critical path and near-critical path activities. LOE activities are measured with the passage of time using a percent complete measurement technique based on the baseline duration of the task. Due to the nature of LOE tasks, they should never reflect a schedule variance. Understanding schedule execution performance for a given timeframe in the schedule may provide added insight, such as looking at the schedule variance metrics by year, quarter, month, or even phase. Schedule metrics that help to measure activity and milestone variances are identified in the table in Figure 7-9.

Key Indicator / Metric	Description
Planned Ahead	Activities/milestones that are currently planned to start before baseline start date.
Planned Delayed	Activities/milestones that are currently planned to start after baseline start date.
Planned on Schedule	Activities/milestones that are currently planned to start on time.
Started Ahead	Activities/milestones that started before the baseline start date (or planned start date if not yet baselined).
Started Behind	Activities/milestones that started after the planned baseline start date (or planned start date if not yet baselined).
Started On-time	Activities/milestones that are currently underway and started on time.
Completed Ahead	Activities/milestones that finished before baseline finish date (or planned finish date if not yet baselined).
Completed Delayed	Activities/milestones that finished after the baseline finish date (or planned finish date if not yet baselined).
Completed On-Schedule	Activities/milestones that completed on time.
Took Longer than Planned	Activities/milestones that took longer than forecasted by the schedule baseline.
Took Shorter than Planned	Activities/milestones that took less time than forecasted by the schedule baseline.
Actually Started	Activities/milestones that have actually started. Compare with Planned to Start to see how many activities started compared to how many were planned to start.
Expected to Finish	In progress activities that are 100% complete – erroneously statused, no Actual Date or vice versa)
Accelerated	Activities/milestones that started after planned start but finished before planned finish (or either or)
Actually Finished	Activities/milestones that have actually finished. Compare with Planned to Finish to see how many activities finished compared to how many were planned to finish.

Figure 7-9. The table provides a list of common schedule performance metrics that measure schedule variance.

Description. In general, schedule variance is a calculation of the difference between the baseline expected progress-to-date and the actual progress of an activity. Utilizing tools such as Acumen Fuse, schedule variance can be calculated for activities that are planned, in-progress, or complete.[148]

For P/ps requiring EVM, Schedule Variance (SV) is a standard EVM measurement. SV shows how the schedule is performing against the time-phased, budgeted PMB. In other words, it shows an ahead of schedule, on schedule, or behind schedule situation. SV measures the difference between the value of work accomplished and the value of work planned.

$$SV = BCWP - BCWS$$

Where:

- *BCWP is the Budgeted Cost of Work Performed to Time-Now*
- *BCWS is the Budgeted Cost of Work Scheduled to Time-Now*

SV Value	Interpretation	Stoplight
$SV > 0$	Value of work accomplished is greater than the value of work planned	GREEN
$SV = 0$	Value of work accomplished is equal to the value of work planned	YELLOW
$SV < 0$	Value of work accomplished is less than the value of work planned	RED

Figure 7-10. An example stoplight chart showing the interpretation of the SV.

SV_t is a time-based measure of whether the P/p is ahead of or behind plan. It is analogous to the cost indicator for Cost Variance (CV), as both are referenced to “actuals”.

$$SVt = ES - AT$$

Where:

- *ES is the Earned Schedule calculated by projecting BCWP onto BCWS and measuring the time units*
- *AT is the Actual Time (Time-Now status date)*

SV_t Value	Interpretation	Stoplight
$SV_t > 0$	P/p is completing work ahead of schedule	GREEN
$SV_t = 0$	P/p is on schedule	YELLOW
$SV_t < 0$	P/p is completing work behind schedule	RED

Figure 7-11. An example stoplight chart showing the interpretation of the SV_t.

The SV and SV_t are often presented with a trend plot as shown in Figure 7-12Figure 7-17. At “Time Now”, \$80 worth of work was planned to be completed, but only \$60 worth of work was actually completed, which results in a -\$20 value for the SV. Also, at “Time Now”, 15 months have passed but

---

[148] NASA has an Agency license agreement for Acumen Fuse, which is available on the NASA Software Center application. Instructions for installing Acumen Fuse can be found on the NASA SCoPe website, https://community.max.gov/x/9rjRYg.

the value of work accomplished is only equal to 12 months of planned work, resulting in a -3-month value for the SV_t.

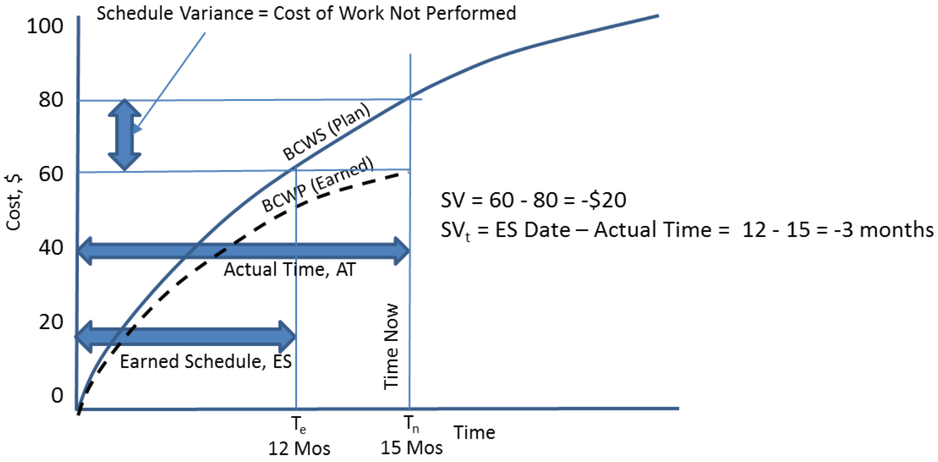


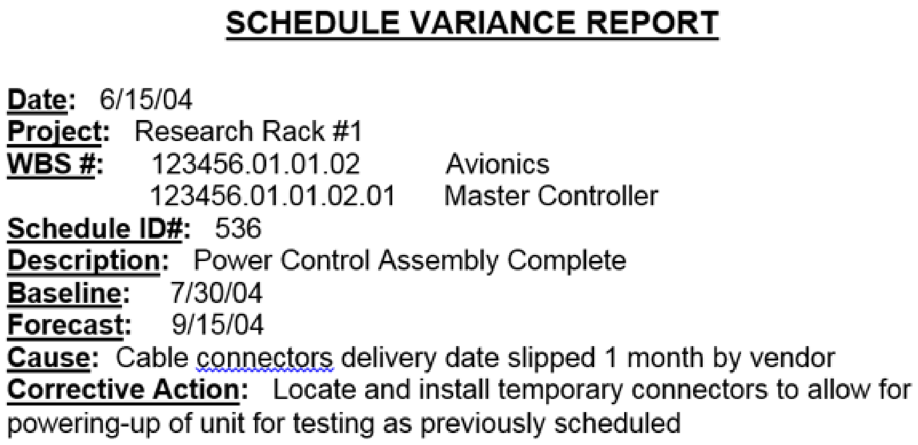
Figure 7-12. This figure illustrates an example of the SV and SV_t calculations.

Thresholds. Even before the schedule baseline has been set, the P/p can track schedule performance. Schedule thresholds should be established to aid in identifying and focusing on those variances that should be monitored and managed. Thresholds help to bound schedule variance questions, such as:

- How many days has the task/milestone changed from the schedule baseline?
- How many days of total slack are associated with those variances?
- Is the variance rationale from the responsible Technical Lead accurate and reasonable?

For some metrics, thresholds may vary due to the type, length, and complexity of the P/p being implemented. For other metrics, simple guidelines may exist. For instance, when using either the SV or SVt metric, a negative value is referred to as an unfavorable variance because the value of work planned is greater than the value of the work performed. Conversely, a positive value is referred to as a favorable variance because the value of work accomplished was greater than the value of work planned. SV is calculated in terms of dollars, whereas SV_t is calculated in terms of time.

Thresholds agreed upon and established by the P/p management team should be documented in the *SMP* along with the added requirement to provide appropriate variance rationale from the responsible Technical Lead or CAM. A typical example of a schedule variance report is shown below in Figure 7-13.



SCHEDULE VARIANCE REPORT

Date: 6/15/04
Project: Research Rack #1
WBS #: 123456.01.01.02 Avionics
123456.01.01.02.01 Master Controller
Schedule ID#: 536
Description: Power Control Assembly Complete
Baseline: 7/30/04
Forecast: 9/15/04
Cause: Cable connectors delivery date slipped 1 month by vendor
Corrective Action: Locate and install temporary connectors to allow for powering-up of unit for testing as previously scheduled

Figure 7-13. Example of a schedule variance report.

It is important to understand why variances occurred (i.e., the root cause) and what the impacts are to P/p completion so that appropriate corrective action can be planned. This involves asking a series of questions related to the performance metrics that show variances:

- What caused the schedule variance? (fix the problem before additional time is lost)
- Does the schedule variance involve tasks that are on the critical path or secondary paths close to being critical? (if so, every day slip means a day slip to the end date, or very close to moving the end date)
- Can the work process or task sequence be modified to enable gaining the lost time back? (identify any work that can be done in parallel instead of series)
- Are inadequate resources causing the variance? (make sure the right number and right skills are working the job)
- Are additional work shifts needed to make up lost time? (if variance is not on the CP (or close), then it may not be practical or cost effective to add more shifts)

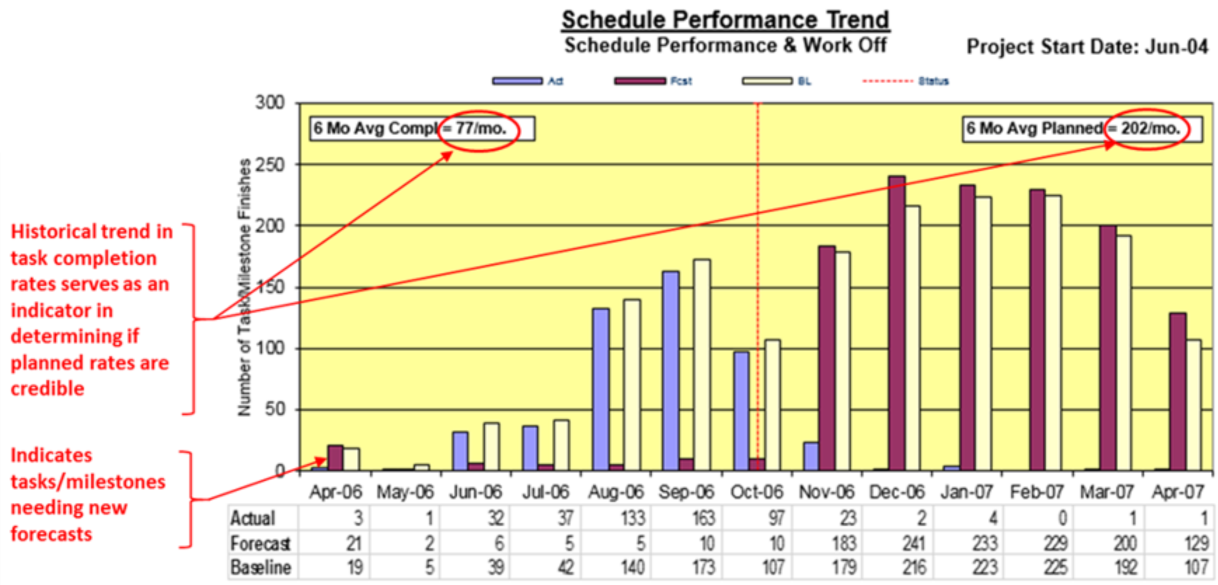
Uncontrolled schedule variances may impact the schedule in any one of the following ways:

- May cause a slip to the P/p completion
- May cause a new primary critical path or a near secondary path
- May result in the need for resources to be adjusted
- May result in the need for a work around plan to be developed
- May cause conflicts in facility usage
- May impact internal handoffs between departments, or external deliveries to P/p partners

Caveat. As the P/p nears completion, SV and SV_t converge to 0.0, gradually losing their value as a performance indicator. Hence, other performance metrics need to be included in routine Schedule Control.

7.3.3.1.2 Activity/Milestone Performance Trends

Description Task/Milestone Completion Rates. Figure 7-14 reflects analysis data that compares monthly average performance rates for accomplishing tasks in the past to the average quantity of planned tasks required in future months to stay on schedule.



Historical trend in task completion rates serves as an indicator in determining if planned rates are credible

Indicates tasks/milestones needing new forecasts

	Apr-06	May-06	Jun-06	Jul-06	Aug-06	Sep-06	Oct-06	Nov-06	Dec-06	Jan-07	Feb-07	Mar-07	Apr-07
Actual	3	1	32	37	133	163	97	23	2	4	0	1	1
Forecast	21	2	6	5	5	10	10	183	241	233	229	200	129
Baseline	19	5	39	42	140	173	107	179	216	223	225	192	107

Figure 7-14. The example shows schedule milestone finishes over time.

Thresholds. Thresholds are predetermined and documented in the *SMP*. Caution should be taken if this analysis reflects an unrealistic bow-wave of tasks scheduled to occur with higher required completion rates than the P/p has been able to accomplish previously. This situation is indicative of an unrealistic schedule. In this type of trend analysis, if the completion rates projected for tasks scheduled for the next six months are much higher than actual completions accomplished during the past six months, a closer look should be taken at the type of tasks that are scheduled, to evaluate the need for replanning in order to keep the schedule realistic.

Description Cumulative Task/Milestone Completion Rates. Figure 7-15 illustrates schedule performance trend data for cumulative task and milestone "finishes". This is a basic performance metric that compares the baseline plan, the current forecasted plan, and to-date actual finish data. This metric not only provides management insight into how well the P/p baseline plan is being met, but also serves as a means a communicating schedule performance to P/p stakeholders.

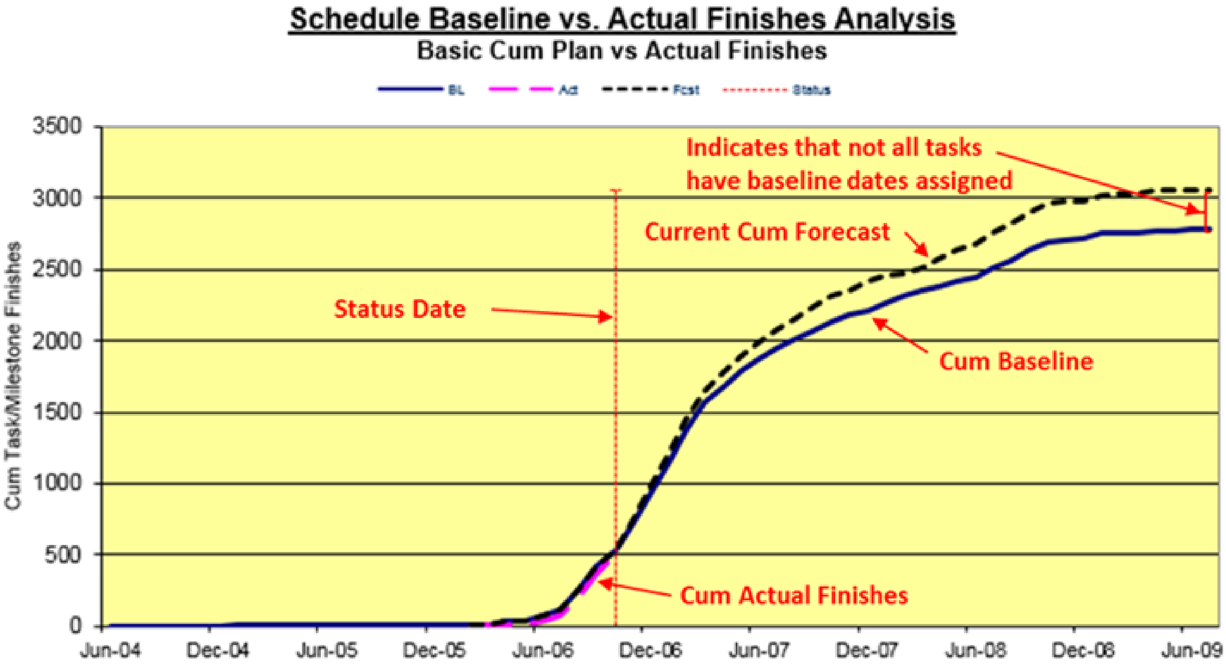


Figure 7-15. The example shows Cumulative Baseline Activity/Milestone Finishes, Actual Activity/Milestone Finishes, and Forecasted Activity/Milestone Finishes.

Thresholds. Thresholds are predetermined and documented in the *SMP*. If the cumulative baseline and cumulative forecast lines do not match, it is an indication that not all activities have baseline dates. The Cumulative Actual Finishes line is above the Cumulative Baseline line, it means that schedule performance is ahead of plan; if under, it means that schedule performance is behind plan.

Additional examples of trend reports can be found in Section 8.3.2.4.2.

7.3.3.1.3 Baseline Execution Index, Current Execution Index, and Hit or Miss Index

Description BEI. The Baseline Execution Index (BEI) answers the question: *"Is work getting done?"* BEI is simply the ratio of activities actually completed to activities planned to be completed. In other words, the BEI us an actual-to-baseline comparison. The BEI value indicates the current cumulative performance for how well the P/p has actually accomplished baseline tasks during the months of actual implementation. Typically, LOE activities and milestones are excluded from the calculation. LOE activities tend to have long durations as they are support activities for the entire P/p and would skew the BEI calculation. Milestones are excluded since they are not actual work activities. Figure 7-16 shows the BEI calculation and a standard stoplight chart to help interpret the BEI values.

$$BEI = \frac{Activities\ Actually\ Completed}{Activities\ Planned\ to\ be\ Completed}$$

BEI Value	Interpretation	Stoplight
BEI > 1.05	P/p has completed more activities than planned	GREEN
1.05 > BEI > 0.95	P/p is close to completing activities on time	YELLOW
BEI < 0.95	P/p has completed fewer activities than planned	RED

Figure 7-16. An example stoplight chart showing the interpretation of the BEI values.

The BEI is often presented with a trend plot as shown in Figure 7-17. At "Time Now", 80 activities were planned to be completed, but only 60 were actually completed and results in a 0.75 value for the BEI.

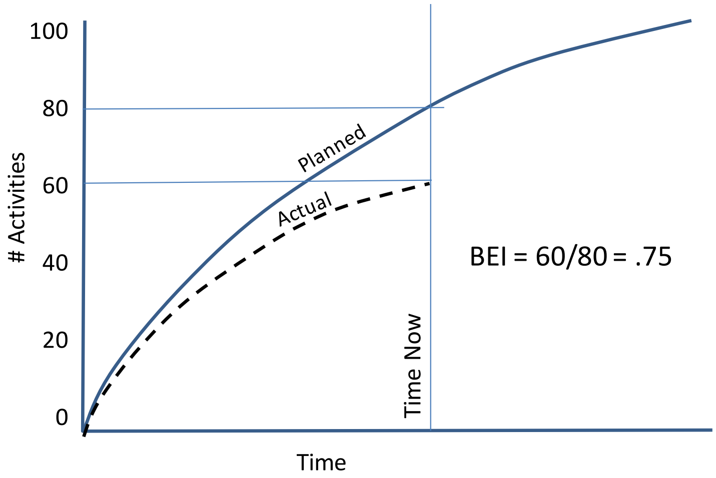
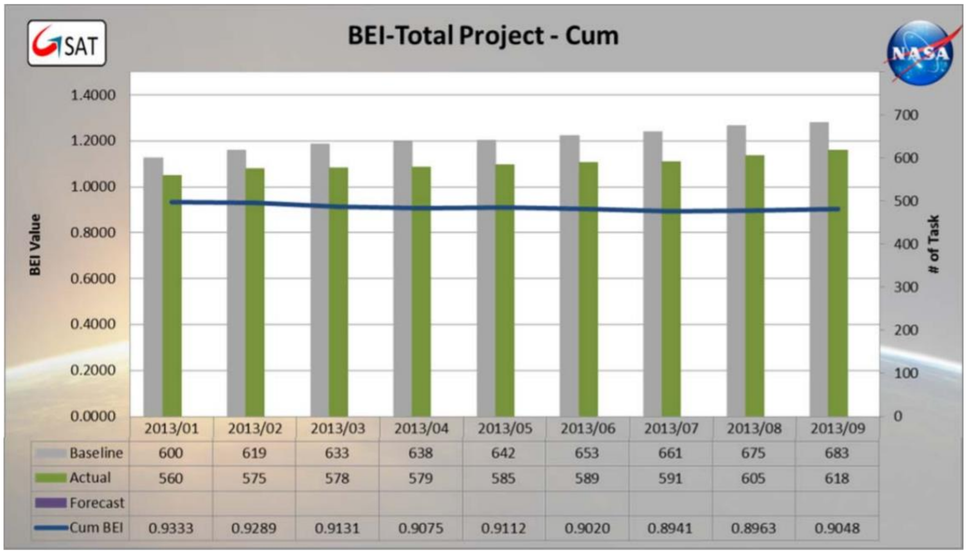


Figure 7-17. This figure illustrates an example BEI calculation.

An example BEI trend chart is shown in Figure 7-18.



	2013/01	2013/02	2013/03	2013/04	2013/05	2013/06	2013/07	2013/08	2013/09
Baseline	600	619	633	638	642	653	661	675	683
Actual	560	575	578	579	585	589	591	605	618
Forecast									
Cum BEI	0.9333	0.9289	0.9131	0.9075	0.9112	0.9020	0.8941	0.8963	0.9048

Figure 7-18. This figure illustrates an example BEI trend chart for a NASA project.

Description CEI. Current Execution Index (CEI) provides an alternate technique for monitoring schedule performance. CEI answers the question: *"Is work getting done in the forecasted time frame?"* CEI compares forecast dates from one status period to the next. The goal of the CEI metric is to determine or measure how well the near-term schedule represents what actually takes place through execution. It represents the fidelity of the forecast schedule and a P/p's ability to execute tasks as projected each month. The CEI is designed to encourage a forward-looking perspective on the schedule. This results in a more accurate predictive model and increases the P/p's ability to meet its obligations on schedule.

The CEI reflects an index value, which is determined by dividing the number of tasks/milestones that actually finished during the current reporting period by the number of tasks that were forecasted to finish during the reporting period. The CEI is similar to the BEI except that a near term window is set by the P/p for the calculation; thus, CEI is not an actual-to-baseline comparison, but an actual-to-forecast comparison. This is done to avoid the dilution that is caused by performance early in the P/p life cycle. Often corrective actions will be initiated to correct poor performance and it is important for the P/p to examine the effect of the corrective action without the dilution caused by the early performance. On the other hand, if no action was taken, the P/p needs to measure the current performance to determine performance trend.

$$CEI = \frac{Activities\ Actually\ Completed\ in\ the\ Window}{Activities\ Planned\ for\ Completion\ in\ the\ Window}$$

In the equation, "Window" is defined by the P/p to be the relevant time frame to be used for the calculation. It is important to note that the value of CEI cannot be over 1.

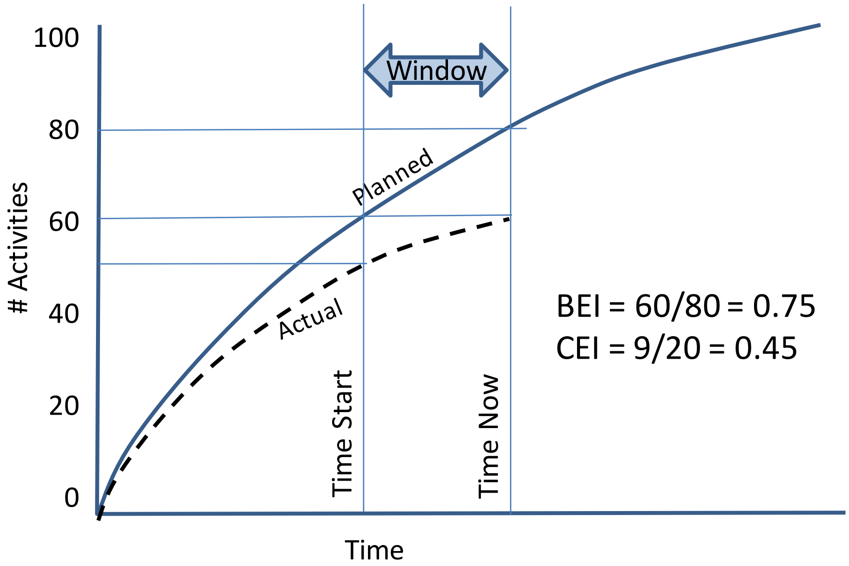
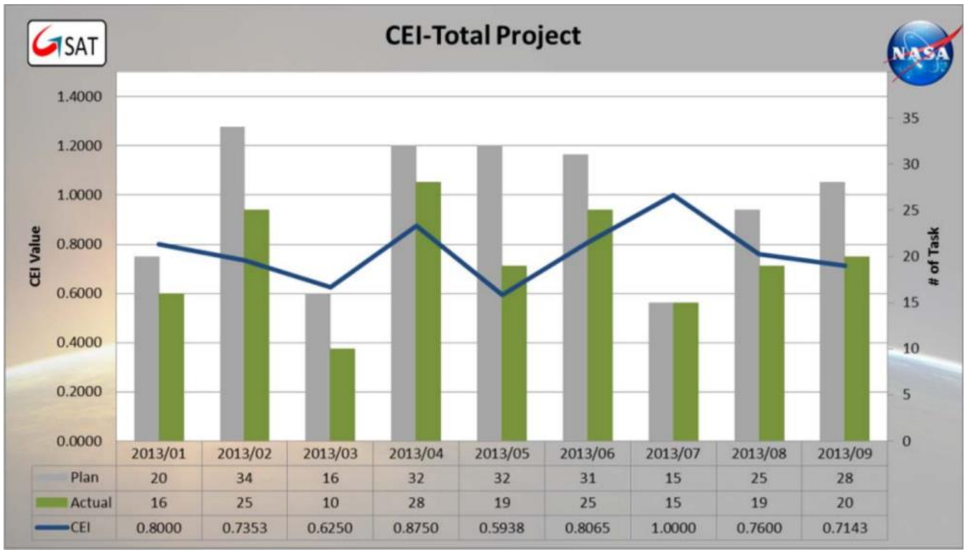


Figure 7-19. The figure shows the Current Execution Index is indicating a downward trend of deteriorating performance.

An example CEI trend chart is shown in Figure 7-20.



	2013/01	2013/02	2013/03	2013/04	2013/05	2013/06	2013/07	2013/08	2013/09
Plan	20	34	16	32	32	31	15	25	28
Actual	16	25	10	28	19	25	15	19	20
CEI	0.8000	0.7353	0.6250	0.8750	0.5938	0.8065	1.0000	0.7600	0.7143

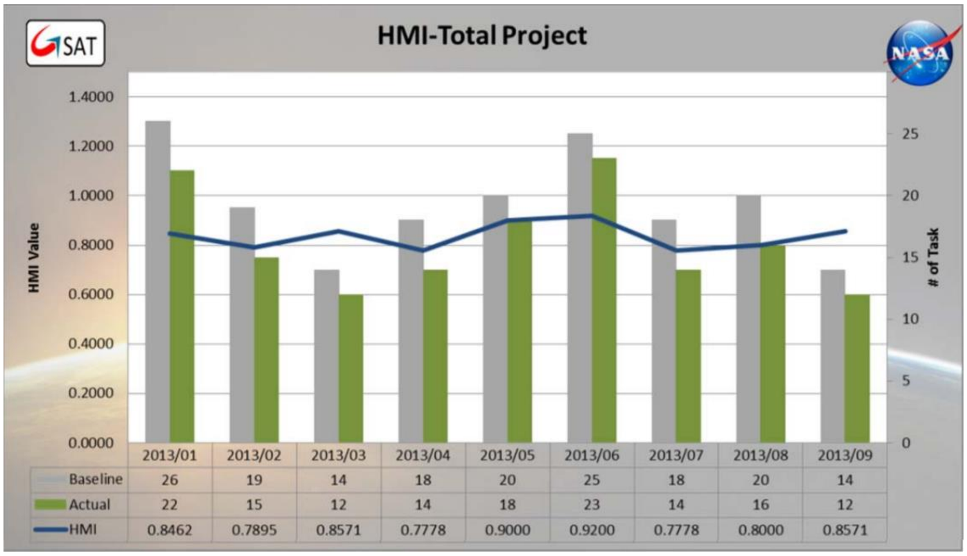
Figure 7-20. This figure illustrates an example CEI trend chart for a NASA project.

It is a good practice to use this technique along with the BEI when possible so that management can have insight into not only how well the P/p is performing against the baseline plan, but also how accurately the team is able to forecast their projected work from one period to the next. In Figure 7-19, above, the BEI was calculated to be 0.75 however the CEI is showing 0.45 indicating a worsening performance trend. In this case, the P/p should take action to correct the performance. However, caution is urged depending on the width of the window. In some cases, there may be a bow wave of completions just beyond the “Time Now” window boundary. In other words, it is possible to pick a window such that a number of completions are planned near the closing of the window and just a few days late would move them beyond the window and cause an exaggerated indication of poor performance.

Description HMI. HMI answers the question: *“Is the right work getting done?”* The HMI measures the number of baseline tasks completed early or on time to the number of tasks with a baseline finish within a given month. It is used to inform the P/p management the ratio of activities actually completed in a monthly reporting period to the number of activities planned for that month. Similar to CEI, the value of HMI cannot be over 1.

$$HMI = \frac{Activities\ Actually\ Completed\ this\ Month}{Activities\ Planned\ to\ Complete\ this\ Month} = CEI\ (Window = Current\ Month)$$

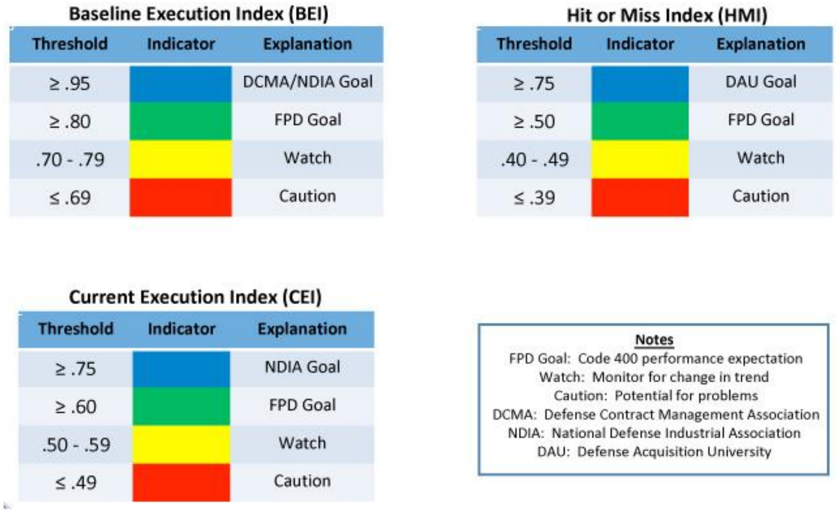
An example of trend charts showing the BEI, CEI, and HMI metrics is shown in Figure 7-21.



	2013/01	2013/02	2013/03	2013/04	2013/05	2013/06	2013/07	2013/08	2013/09
Baseline	26	19	14	18	20	25	18	20	14
Actual	22	15	12	14	18	23	14	16	12
HMI	0.8462	0.7895	0.8571	0.7778	0.9000	0.9200	0.7778	0.8000	0.8571

Figure 7-21. This figure illustrates an example HMI trend chart for a NASA project.

Thresholds. A typical example of BEI, CEI and HMI monthly reports ad thresholds is shown in Figure 7-22.[149] Blue indicates excellent performance; no further oversight penetration is required. For green stoplight a typical action may be to research the P/p for efficiencies to save money. In the yellow stoplight, the prescribed action may be "Watch" and direct the activity owners to seek improvements internally. The red stoplight will require corrective actions formally tracked by the P/p. Whatever the prescribed actions, they were determined during the Schedule Planning Process and are documented in the *SMP*.



Baseline Execution Index (BEI)

Threshold	Indicator	Explanation
≥ .95	🟦	DCMA/NDIA Goal
≥ .80	🟩	FPD Goal
.70 - .79	🟨	Watch
≤ .69	🟥	Caution

Hit or Miss Index (HMI)

Threshold	Indicator	Explanation
≥ .75	🟦	DAU Goal
≥ .50	🟩	FPD Goal
.40 - .49	🟨	Watch
≤ .39	🟥	Caution

Current Execution Index (CEI)

Threshold	Indicator	Explanation
≥ .75	🟦	NDIA Goal
≥ .60	🟩	FPD Goal
.50 - .59	🟨	Watch
≤ .49	🟥	Caution

Notes
FPD Goal: Code 400 performance expectation
Watch: Monitor for change in trend
Caution: Potential for problems
DCMA: Defense Contract Management Association
NDIA: National Defense Industrial Association
DAU: Defense Acquisition University

Figure 7-22. An example set of stoplight charts showing the interpretation of the BEI, CEI and HMI values.

---

[149] Shinn, S. and W. Majerowicz. "A Metrics-Based Approach to Enhancing Schedule Performance Insight." NASA Cost Symposium 2016. Slide 25. https://www.nasa.gov/sites/default/files/atoms/files/40_metrics-based_approach_to_enhancing_schedule_performance_insight_shinn_and_majerowicz_10aug_16v2_tagged.pdf

Trending of CEI and HMI over time can provide early warning signs:

- **Unstable Baseline.** An HMI trend ≤ .40 is an early warning sign of an unsustainable baseline. Once an unfavorable HMI trend of .40 or less is established, float (or margin) erosion and baseline completion delays are likely.
- **"Bow Wave".** A CEI trend ≤ .55 is an early warning sign of a "Bow Wave". A sustained .55 or less CEI trend indicates a bow wave of unfinished work that will erode the remaining margin and threaten P/p completion.

Caveat. The BEI and the CEI do not distinguish between activities, they only count completions. Thus, the BEI and CEI may not indicate whether the "right" work is getting done. There is no adjustment for simple, low-cost activities versus complex, high-cost activities. The P/p management staff will need to be careful about taking corrective actions when a large number of low-cost activities may have disproportionally diluted the BEI and/or CEI. The HMI can be very misleading should a number of activities finish on the first day of the subsequent month. In addition, high latency baseline control practices distort BEI and HMI.

7.3.3.1.4 Schedule Performance Index (SPI), Time-based SPI (SPI_t), and Earned Schedule (ES)

Description SPI, SPI_t and ES. In general, a schedule performance index is a ratio of the performance of an activity relative to the baseline. Utilizing tools such as Acumen Fuse, the schedule performance index can be calculated for activities that are planned, in-progress, or complete.[150]

Schedule Performance Index (SPI) is a standard EVM measurement. The SPI measures the budgeted cost of work performed up to the "Time Now" date, divided by the budgeted cost of work scheduled to be performed. It provides the ratio of P/p dollars earned-to-date to the dollars the P/p should have earned. Thus, SPI is a measure of schedule in terms of cost, or in other words, unspent time-phased money. Therefore, it is often useful to convert to a time-based measurement, such as SPI_t. This is done by calculating the Earned Schedule (ES), which is the time that equates the budgeted cost of work performed (BCWP) to the budgeted cost of work scheduled (BCWS), and the dividing the ES by the actual P/p duration up to "Time Now" (AT). It is analogous to the cost indicator for Cost Performance Index (CPI), as both are referenced to "actuals". It provides the ratio of the P/p time earned-to-date to the time the P/p should have earned. [151] These measurements are illustrated in Figure 7-23.

---

[150] NASA has an Agency license agreement for Acumen Fuse, which is available on the NASA Software Center application. Instructions for installing Acumen Fuse can be found on the NASA SCoPe website, https://community.max.gov/x/9rjRYg.

[151] Additional information on schedule-based EVM metrics can be found in a presentation by Andrea K. Gilstrap, PMP, EVP, entitled, "Earned Schedule in Empower." Empower User's Group. August 28, 2019.

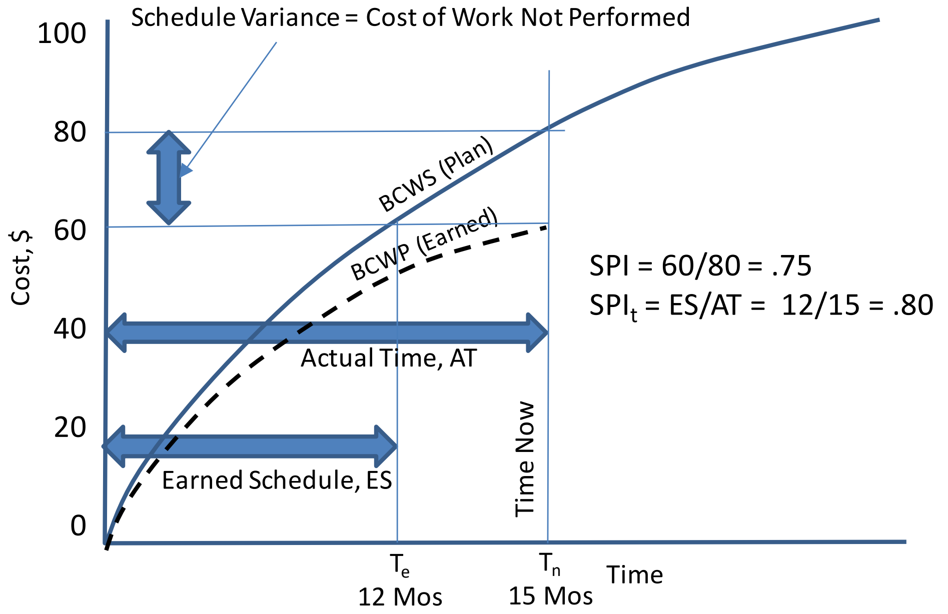


Figure 7-23. The figure illustrates SPI, SPI$_t$, and Earned Schedule.

$$SPI = \frac{BCWP}{BCWS}$$

$$SPI_t = \frac{Earned\ Schedule}{Actual\ Duration}$$

Where:

- *BCWP is the Budgeted Cost of Work Performed to Time-Now*
- *BCWS is the Budgeted Cost of Work Scheduled to Time-Now*
- *Earned Schedule (ES) is the schedule date where the BCWP equals the BCWS*
- *Actual Time (AT) is the schedule duration up to Time-Now*

SPI Value	Interpretation	Stoplight
SPI > 1.05	P/p is completing work faster than planned	GREEN
1.05 > SPI > 0.95	P/p is close to completing activities on plan	YELLOW
SPI < 0.95	P/p is completing work slower than planned	RED

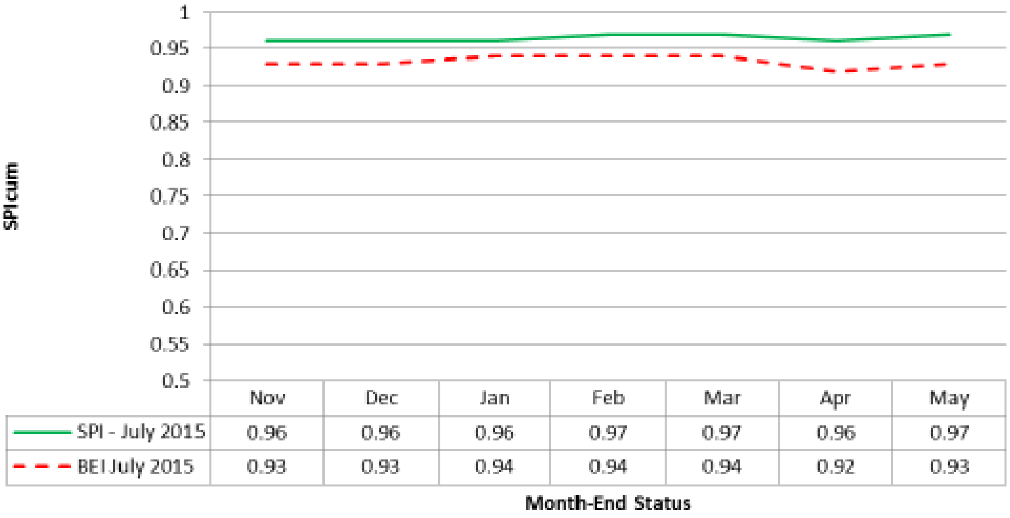
Figure 7-24. An example Stoplight Chart showing the interpretation of the SPI.

Evaluating cost-based EVM measurements alongside schedule-based metrics often provides additional insight as to P/p progress. For instance, using Total Float (TF) values (also called Total Slack) and Schedule Performance Index (SPI) values provides a comprehensive performance view of the status of a P/p from an integrated cost and schedule perspective, as shown in Figure 7-25.

SPI Value	TF Value	Interpretation
> 1.0	> 0	P/p is ahead of schedule
< 1.0	< 0	P/p is behind schedule
> 1.0	< 0	Critical tasks behind schedule; total work ahead of schedule (priority issue)
< 1.0	> 0	Critical tasks ahead of schedule; total work behind schedule (priority issue)

Figure 7-25. The relationship between SPI and Total Float.

In addition, when cost and schedule integration is sound, BEI and the cumulative SPI (SPI$_{cum}$) should trend in a similar pattern, as shown in Figure 7-26.



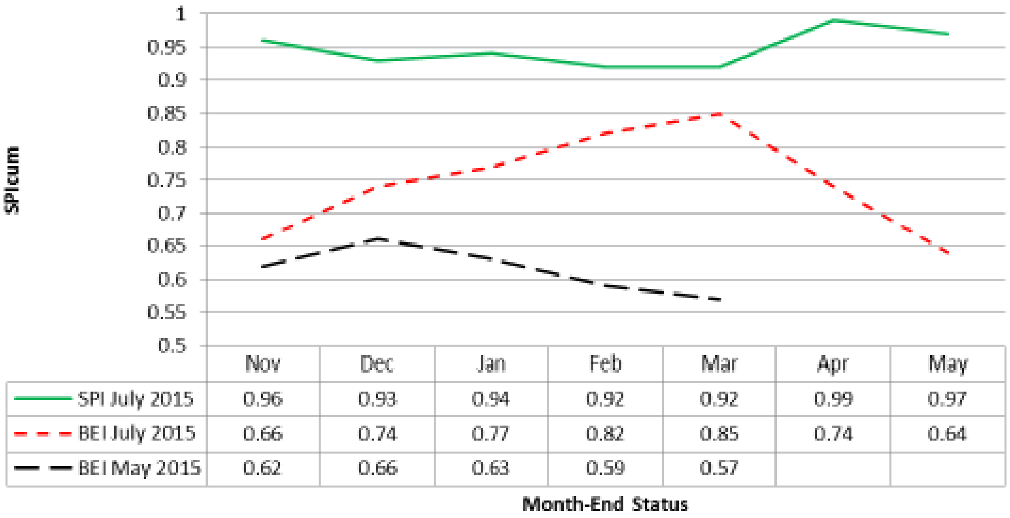
	Nov	Dec	Jan	Feb	Mar	Apr	May
SPI - July 2015	0.96	0.96	0.96	0.97	0.97	0.96	0.97
BEI July 2015	0.93	0.93	0.94	0.94	0.94	0.92	0.93

Figure 7-26. An example showing consistent BEI and SPI trending.

Figure 7-27 shows an example of a NASA project, where the BEI and SPI$_{cum}$ were inconsistent in their trending. The SPI indicated good performance (green), while the BEI indicated deterioration (black). Retroactive BCRs added already completed work to the baseline (red), but performance erosion continued as measured by the BEI. The project eventually slipped its launch date.[152]

---

[152] Shinn, S. and W. Majerowicz. "A Metrics-Based Approach to Enhancing Schedule Performance Insight." NASA Cost Symposium 2016. Slide 36. https://www.nasa.gov/sites/default/files/atoms/files/40_metrics-based_approach_to_enhancing_schedule_performance_insight_shinn_and_majerowicz_10aug_16v2_tagged.pdf



	Nov	Dec	Jan	Feb	Mar	Apr	May
SPI July 2015	0.96	0.93	0.94	0.92	0.92	0.99	0.97
BEI July 2015	0.66	0.74	0.77	0.82	0.85	0.74	0.64
BEI May 2015	0.62	0.66	0.63	0.59	0.57		

Figure 7-27. An example showing inconsistent BEI and SPI trending.

Thresholds. For the P/ps required to perform EVM, those thresholds are established by P/p management at the WBS element or control account level and should be captured in the P/p Plan and/or Technical, Cost, and Schedule Control Plan.[153] SPIs greater than ~ 1.1 – 1.2 indicate poor planning and the P/p should have prescribed actions in the *SMP* to search for efficiencies to reduce costs or to contract the schedule.

Caveat. SPI is not a precise measure of schedule variance in days but is rather a measure of unspent money. When the P/p completes, the SPI will equal 1.0 regardless of actual completion time because all money will be spent. Likewise, as the P/p nears the end of the scheduled duration, the percent of total money spent is large and begins to dilute the SPI to a point where it is no longer a useful indicator of schedule performance. It is a recommended practice that when the P/p has spent 2/3 of the P/p budget, greater emphasis needs to be placed on other *Schedule Performance Measures*. Earned Schedule describes schedule variance in time units and typically retains utility until P/p completion and does not automatically converge towards 1.0 near P/p completion.

7.3.3.1.5 Critical Path Length Index (CPLI)

Description CPLI. The CPLI is a measure of the efficiency required to complete a schedule milestone on time. The CPLI measures the ratio of the remaining critical path length plus the total float to the remaining critical path length. For example, if there is a long critical path with low total float, then the index will be a number close to 1.0 and will indicate that there is not a lot of “wiggle-room” to accommodate unknown problems or poor schedule performance. A CPLI of 1.0 indicates that the P/p must execute perfectly for the remainder of the P/p time. CPLI can be less than 1.0 indicating that the P/p is accumulating negative float due to inability to perform to plan. Figure 7-28 shows the CPLI calculation and a standard stoplight chart to help interpret the CPLI values.

---

[153] NASA/SP-2013-3704. NASA EVM Systems Description. March 2016. https://nen.nasa.gov/web/pm/evm

$$CPLI = \frac{Critical\ Path\ Length + Total\ Float}{Critical\ Path\ Length}$$

CPLI Value	Interpretation	Stoplight
CPLI > 1.05	P/p likely to be able to complete on time	GREEN
1.05 > CPLI > 0.95	P/p schedule performance needs careful monitoring	YELLOW
CPLI < 0.95	P/p unlikely to complete on time without corrective action	RED

Figure 7-28. An example Stoplight Chart showing the interpretation of the CPLI values.

The CPLI is often plotted over time to show trends. Trend charts are useful in giving the P/p management team early warnings as shown in Figure 7-29. Clearly in the February-April time-frame, the trend chart is showing urgent corrective action is going to be needed.

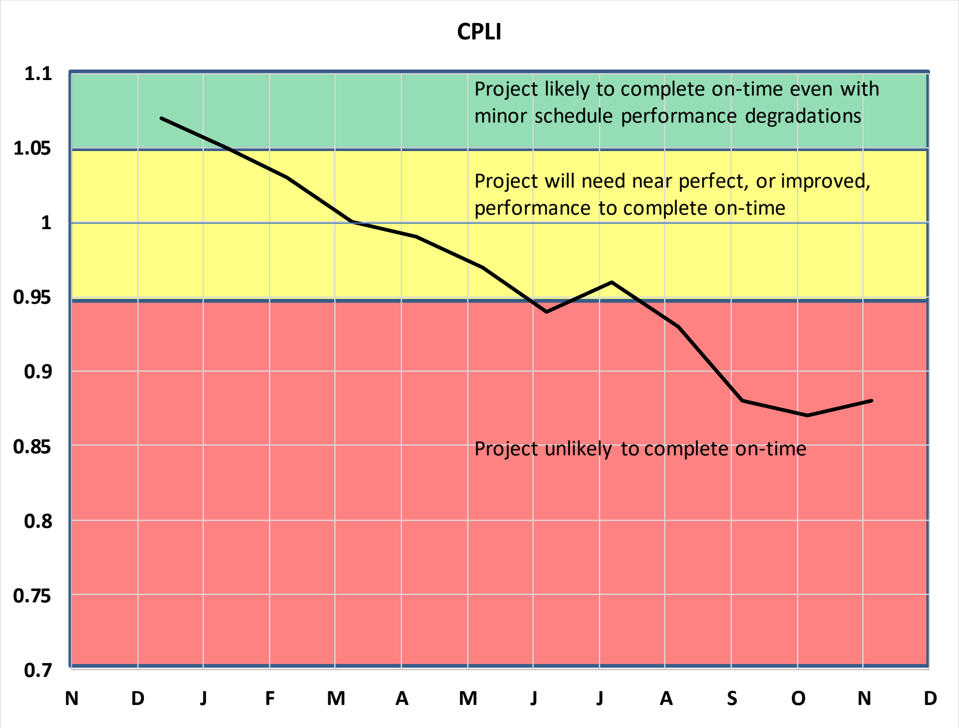


Figure 7-29. An example of a CPLI trend chart.

Thresholds. The P/p has established thresholds for prescribed actions in the *SMP* for all selected *Schedule Performance Measures*. In the examples in the figures above, the P/p has established color bands for the prescribed actions. For green stoplight or the green shaded area in the Trend Chart a typical action may be to research the P/p for efficiencies to save money. In the yellow coded areas, the prescribed action may be "Watch" and direct the activity owners to seek improvements internally. The red coded areas will require corrective actions formally tracked by the P/p. Whatever the prescribed actions, they were determined during the Schedule Management Planning Process and are documented in the *SMP*.

Caveat. CPLI is a "global" measure and does not provide details needed to actually target the individual tasks that may be causing the problems. Also note that the CPLI is only measures performance along the critical path and cannot show other paths that may be failing and soon to be on the critical path. Hence, other performance metrics need to be included in the monthly reviews.

7.3.3.1.6 Margin Consumption

Description Margin Consumption. Careful tracking of schedule margin consumption or reallocation and comparison to critical path total float provides an indication of how realistic the schedule completion date is. ***It is a best practice to track and monitor schedule margin throughout the P/p life cycle.***

Margin is planned according to the guidelines and techniques specified in the *SMP* and established within the schedule during Schedule Development, as described in Section 5.5.11. It is likely that a relatively small number of activities or groups of activities (e.g., a subsystem) will be determined by the P/p to be critical enough that the schedule should be protected by the assignment of a margin activity. On the other hand, float, which is number of days an activity can slip before it hits the critical path, is not assigned but is calculated by the scheduling tool. Every activity will have a float calculation.

Schedule margin is a control parameter owned by the PM and can only be released through a formal process. The amount of schedule margin needed is greater early in the P/p and decreases with time as P/p uncertainty decreases. Because of that decreasing need, P/ps will create a margin burndown curve and track against that burndown curve. This control process is typically performed against the deterministic schedule, tracking month-end margin at each schedule update.

Being able to identify where margin activities are housed in the schedule are critical elements in tracking margin. In other words, margin activities should be clearly identifiable when included within the P/p schedule. It is also important to understand the difference between available margin days and other non-working calendar days when calculating "effective margin". Effective margin is defined as margin on the critical path and can be determined by zeroing out the margin tasks and calculating the number of days that the P/p end-item date or finish milestone moves to the left. **Note:** The cumulative margin may not equal the sum of the individual margin durations.

Margin should be allocated according to working days in the schedule. It is worth noting the distinction between the available "working days" (i.e., margin days) and any "non-working" days, such as weekends or holidays (i.e., contingency days). Whereas margin days are defined as "working days" available in a schedule (where the P/p does not already have work defined/planned) to mitigate or absorb schedule risk, contingency days or "non-working days" should only be used as a resource to the PM to recoup delays due to poor schedule performance so as to not utilize schedule margin. P/p management should keep in mind that contingency days will likely cost the P/p more money than using available float, but if there is no float available, contingency days should be the next option prior to the consideration of margin.

A tracking issue may arise when a P/p distributes the margin and includes weekends and/or holidays into its margin totals (e.g., if the margin activities are initially tied to non-working days and are later reallocated to risk changes, the P/p's effective margin totals could change without any adjustment to the actual duration on the margin tasks, which would create a margin tracking problem). If the P/p monitors schedule margin in working days and contingency days separately, the P/p management will have a better understanding of the time resources available to the P/p at any given point in time. Figure 7-30 illustrates how a P/p can track schedule margin (and contingency) depletion/erosion (and restoration) over time against the planned depletion.

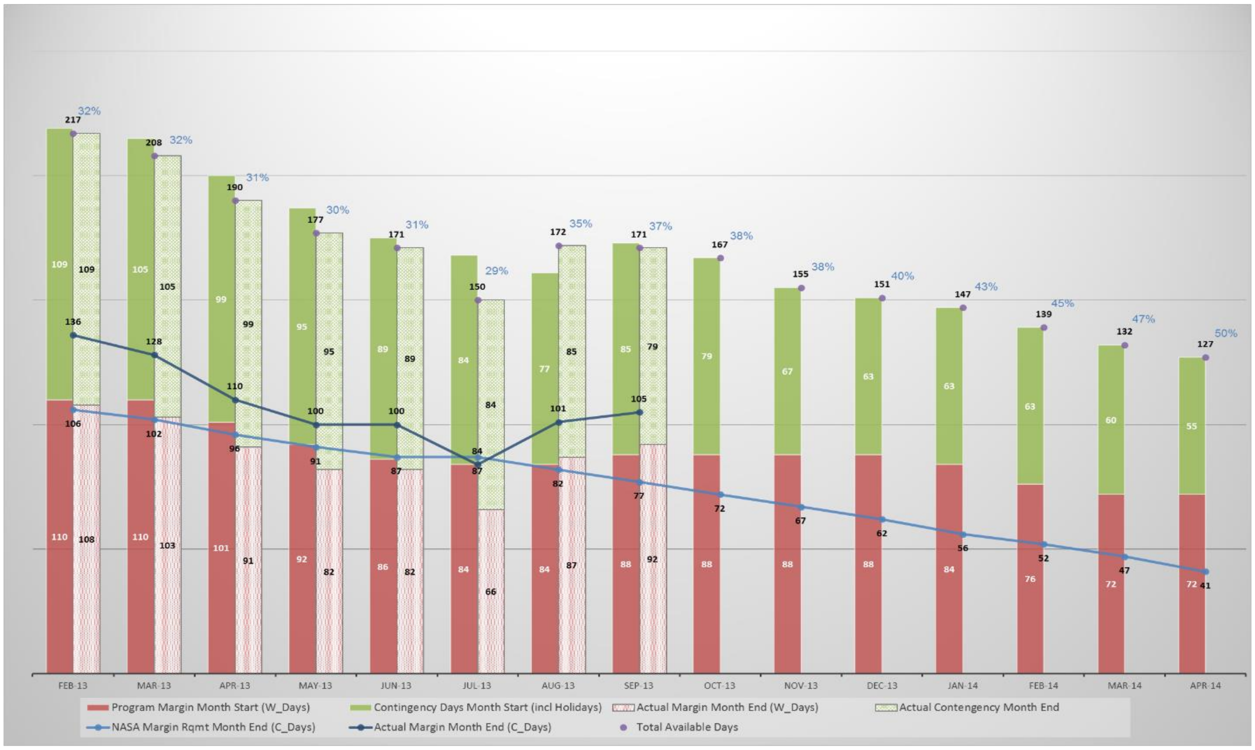


Figure 7-30. The figure illustrates an example of a tracking margin and contingency days as they relate to the total number of calendar days.

The chart in Figure 7-30 distinguishes between margin (i.e., working days) as "W", contingency days (weekends or holidays) as "Contingency", and calendar days as "C." The solid red (margin) and green bars (contingency) are stacked to show the number of days available at a particular month's start that are not planned work days. The crosshatched red (margin) and green (contingency) bars show the actual month-end days available. The point at the top of the bars showing the total number of month-end days available (i.e., margin + contingency), while the percentage shows the total days (i.e., margin + contingency) available as a percentage of the days-to-go in the schedule. The lower blue line indicates the planned margin burndown; whereas the upper blue line indicates the actual month-end margin remaining over time.

When tracking margin, it is helpful to understand that margin can be consumed by risks and uncertainties in several ways: risks become realized and slow down current work or require additional, new work; risk mitigations are developed and incorporated into the P/p plan/schedule; or uncertainties become realized, slow down current work or require additional, new work. For each of these instances the margin is essentially allocated, either as extended task durations, as mitigation activities, or as new tasks, thereby reducing the "effective margin" by an amount equal to the overall impact that would be incurred at the point of the margin task. For any zero-float paths, this may be an amount equal to the duration of the wait time, new work, or mitigation activities. For any non-zero-float paths, the margin may not need to be reduced by an amount equal to total duration of the wait time, new work, or mitigation activities, as there may be positive float on the path that will absorb some of the risk/uncertainty impact.

Keeping a record of how margin is utilized is an important aspect of understanding and communicating margin consumption. As margin is consumed or reallocated and critical paths change, “non-effective” margin activities that were once on less-critical paths may end up on the new, primary critical path, now as “effective margin” activities. It is important to recalculate the total amount of effective margin as these changes occur. It is a recommended practice to maintain a Margin Log indicating the changes in schedule margin and the reason for margin consumption.

Depending on the where the P/p is in its life cycle, margin and float erosion tracking may need to be performed at different levels (e.g., P/p level vs. subsystem level) for adequate insight into schedule performance. A few specific examples of margin and float erosion tracking follow.

Subsystem Margin Consumption Tracking

During the design, development, and fabrication phase of a P/p, systems and subsystems are usually parallel activities that feed into the I&T phase, while the I&T phase is usually serial; thus, the tracking charts will be different. Figure 7-31 shows a typical tracking charts for subsystem (SS) margin prior to delivery into I&T. The upper right corner shows an example of prescribed action based on the current forecast for completion. If the forecast delivery date is on-time or within the calculated float, then no action is required. See the “Green” forecast dates indicated for SS1, SS2, and SS3 in the figure. If the current forecast is showing all float consumed and margin beginning to be threatened, then the forecast is shown as “Yellow” as with SS6 and requires a watch action. SS4 and SS5 have consumed most or all of the float and/or margin and corrective action is required.

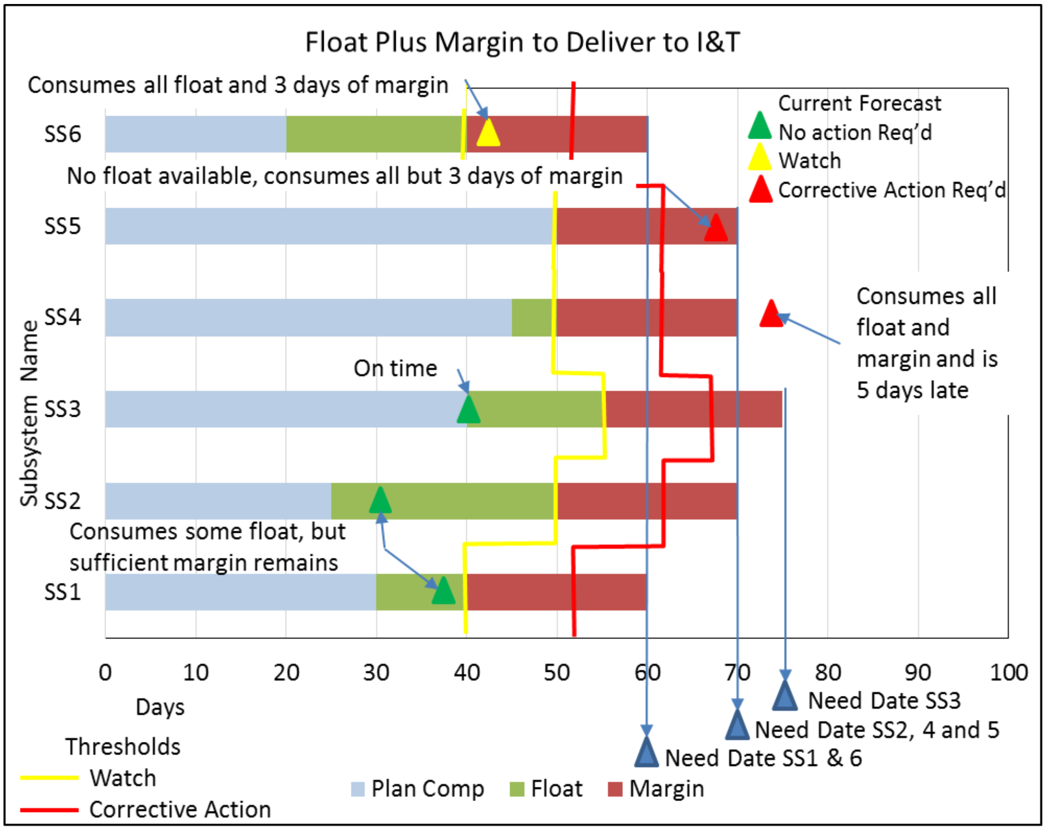
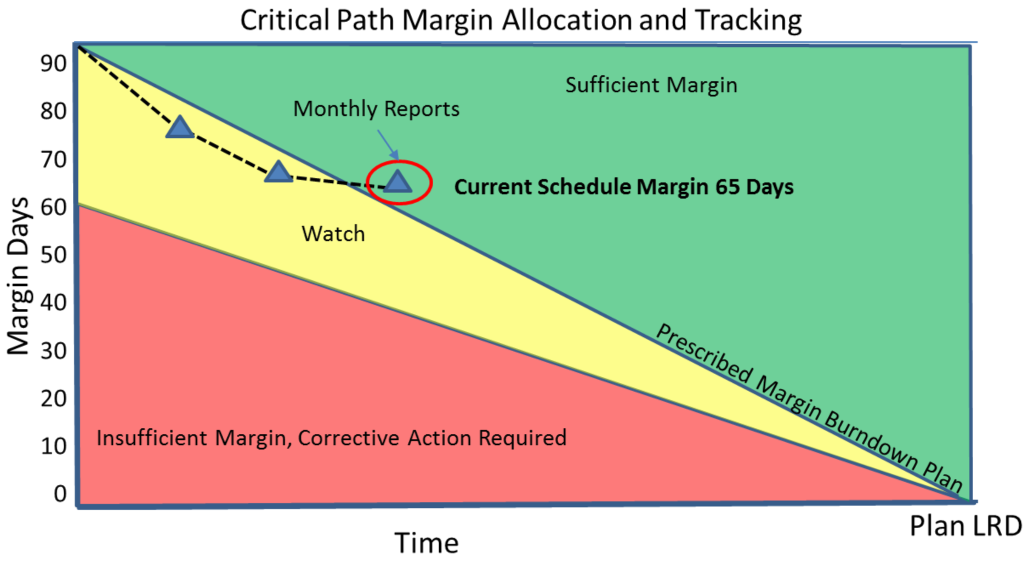


Figure 7-31. The figure shows an example of margin tracking for subsystems (SS) being delivered into I&T.

Critical Path Margin Tracking

Often P/ps will track the margin along the critical path. The previous showed margin tracking for several critical subsystems as they feed into I&T. However, it is likely that only one of these is on the critical path and there may be margin activities distributed prior to delivery to I&T (e.g., delivery of an EDU into a test lab). Figure 7-32 is a generic example of typical margin tracking charts used by P/ps. The figure shows the required margin at the start of the P/p (usually the Confirmation Review) and a prescribed margin burndown over the life of the P/p. Shown is a linear burndown but stepped burndowns that mimic the margin guidelines over time are sometimes used as well. The margin remaining is calculated routinely usually monthly or quarterly. The figure shows thresholds for specific actions such as Watch or Corrective Action required. Such charts are used by the P/p management to make decisions regarding margin release. As shown in the figure, there should be a method of tracking and archiving the use of margin, in this case a “Margin Use Log”.



Margin Log

Date	Reason for Margin release by P/p
Apr-06	Project schedule margin was established by PM at 90 Days
Jul-06	PM approved use of 10 days due to late design changes
Sep-06	PM approved use of 5 days due to fab tool failure
Nov-06	PM approves overtime – activity finishes early, added back to margin

Figure 7-32. Example of a Margin Trend Report and Margin Log for the critical path showing the trends from the monthly reports.

I&T and Launch Operations Margin Tracking

The I&T and Launch Operations flow normally has margin activities strategically placed to protect the start, the major test facility schedules and the delivery to launch operations. In launch operations there will normally be a margin activity inserted to protect launch. Figure 7-33 shows a generic margin tracking chart for a typical I&T and Launch Operations flow. There are prescribed thresholds shown in the figure for “Watch” and “Corrective Action”.

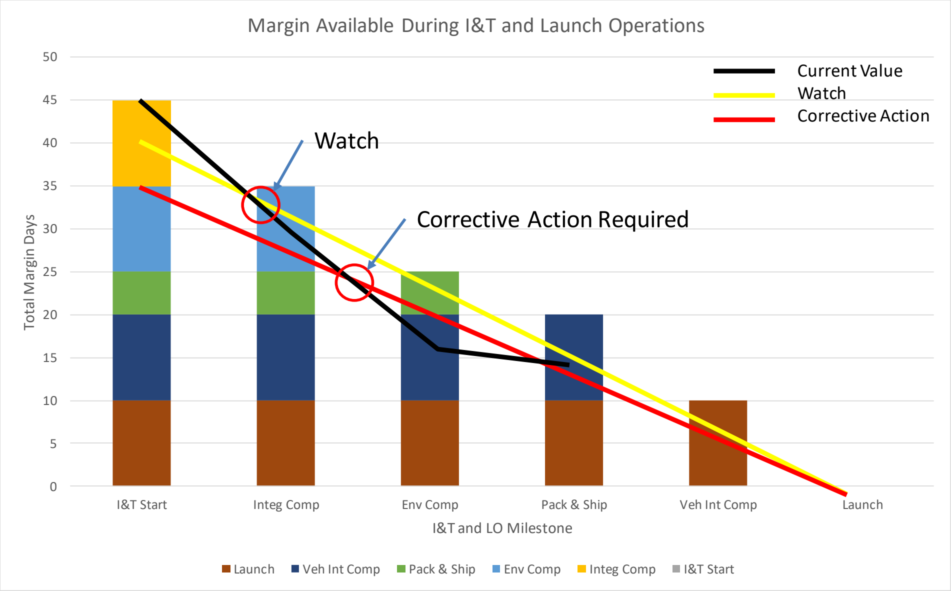


Figure 7-33. The figure shows an example of margin tracking for I&T and Launch Operations

Thresholds. The P/p sets the thresholds during the Schedule Management Planning Process and documents them in the SMP. Once the P/p is in Implementation, the expenditure of schedule margin is tracked and reported at regularly scheduled P/p reviews. Deviations from the guidelines trigger a requirement for either an explanation about why the deviation is acceptable or for the initiation of activities to mitigate the trend. For these example cases, thresholds are selected to set a “Watch” flag when the margin is threatened, and corrective action is required when significant margin is consumed.

7.3.3.1.7 Float Erosion, Total Float Consumption Index (TFCI), Predicted Critical Path Total Float (CPTF)

Description Float Erosion. An important key to achieving the desired schedule completion date is being able to identify and evaluate what tasks are directly driving the P/p end date. Total float provides this capability and knowing the total float for every task and milestone in the schedule will provide management with the necessary insight into how each task impacts the P/p end date. The Float Erosion metric is presented in tabular form showing float by WBS. It is typically reviewed monthly.

A Float Erosion table, as shown in Figure 7-34, is helpful in that provides performance measurement at lower levels in the IMS and more likely to catch performance issues before the margin activity is threatened. Total float for the “Time Now” date is shown for each WBS item in the “Current Float” column. The P/p can track the data down to the lowest level in the IMS if necessary. In the figure, the structures subsystem is decomposed to the next level WBS in order to bring P/p management attention to the erosion of total float for the *Pyros*. Management will likely request that the *Avionics* subsystem be further decomposed at the next review period so that the stressed component can be identified and targeted for corrective action.

Activity	Comment	Plan Date	Need Date	Forecast Date	Plan Float	Current Float	Stoplight
C&DH	None	6/1/20	7/1/20	6/15/20	30	16	🟩
Avionics	Attitude controllers failed qual tests, design change pending	5/15/20	7/1/20	6/28/20	47	3	🟥
Structures							
Primary Structure	Late delivery of sidewall panels	6/1/20	6/15/20	6/17/20	14	-2	🟥
Secondary Structure	None	6/20/20	7/1/20	6/25/20	11	6	🟨
Mechanisms	Early delivery of hatches.	7/1/20	7/5/20	6/20/20	4	15	🟩
Pyros	GUIDEP notice of bad lots, batch testing underway	7/1/20	7/10/20	7/15/20	9	-5	🟥
Thermal Control	None	7/10/20	7/20/20	7/10/20	10	10	🟩
----		----	----	----	----	----	
----		----	----	----	----	----	

Figure 7-34. The figure illustrates a typical Float Erosion Table.

Total float is often presented as a trend chart by WBS. This is helpful in that the slope of the trend line can be an early warning indicator of the inability to perform according to schedule reducing the schedule resiliency. A typical trend chart is shown in Figure 7-35.

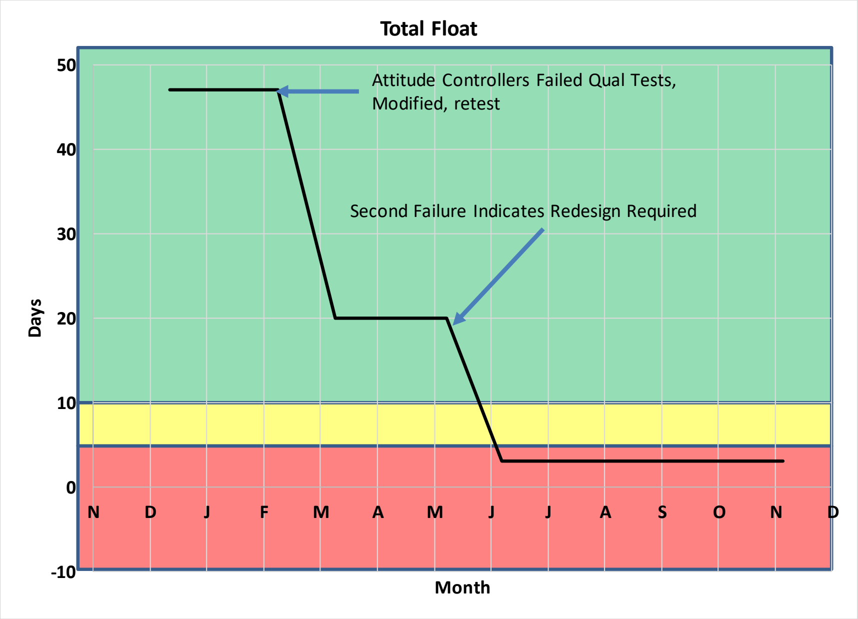


Figure 7-35. The figure illustrates a Float Trend Report for tracking the total float for a subsystem.

Sometimes a P/p will have a pre-planned float erosion to which actual float is tracked. A sudden, unexpected change in the slope may indicate that future milestones are threatened.

Figure 7-36 shows a typical stoplight chart for the Float Erosion metric with an interpretation and actions required. P/ps with higher risks might want more cushion and may set the thresholds higher.

Current Float (CF) Value	Interpretation	Stoplight
CF > 10	Float is sufficient to absorb unexpected schedule slips	GREEN
10 > CF > 5	Float is likely insufficient to absorb unexpected schedule slips	YELLOW
CF < 5	Float is insufficient; corrective action plan required	RED

Figure 7-36. An example stoplight chart showing the interpretation of the Current Float values.

Similar to the way in which total float is tracked, free float is valuable in analyzing scenarios involving schedule impacts and conflicts for a specific task/milestone or a set of tasks and also for prioritization of resource utilization. It should generally not be used as a primary means of monitoring and schedule analysis for the total P/p.

Thresholds. The P/p sets the thresholds during the Schedule Management Planning Process and documents them in the *SMP*. For the example case, thresholds were selected to set a warning flag when the float was between 5 and 10 days and corrective action is required when float is less than 5 days.

Caveat. As with most deterministic measures, total float is backwards-looking and does not consider any future risks that may occur. In our example case, 3 days of positive float is available and that may be sufficient if there is no exposure to a future risk. However, if the redesign approach relies on a new technology, then 3 days may not be enough. In addition, if the P/p completion task/milestone is assigned a fixed schedule constraint, then the critical path may reflect a negative float (slack) value. The schedule may also calculate negative float if there is an out-of-sequence relationship between activities (e.g. Activity B has started and has an FS predecessor link from Activity A, which has not yet finished). This is an error in the schedule baseline and should therefore be corrected.

Description TFCI and CPTF. Another metric that takes into consideration what would happen if a delinquent P/p continued at its current rate of total float erosion is the Total Float Consumption Index (TFCI).[154] TFCI calculates total float as an efficiency factor by applying the schedule's average rate of total float consumption to the remaining scope of work, thereby projecting a forecast finish date for the entire P/p.

$$TFCI = \frac{Project\ Actual\ Duration + Critical\ Path\ TotalFloat}{Project\ Actual\ Duration}$$

---

[154] PASEG, Version 4.0. National Defense Industrial Association (NDIA), Integrated Program Management Division (IPMD). March 9, 2016. Page 173.

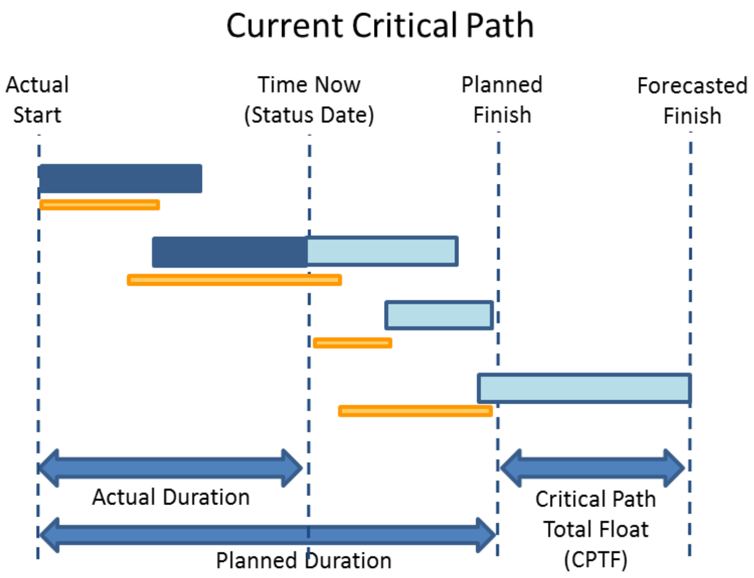


Figure 7-37. This figure illustrates an example TFCI chart.

Total Float Consumption Index (TFCI) Value	Interpretation	Stoplight
TFCI > 1.0	P/p is likely to complete early if float consumption trend continues	GREEN
TFCI = 1.0	P/p is likely to complete on time	YELLOW
TFCI < 1.0	P/p is not likely to complete on time if float consumption trend continues	RED

Figure 7-38. An example stoplight chart showing the interpretation of the TFCI values.

From the TFCI value, the amount of total float likely at the schedule baseline finish date, known as the Predicted Critical Path Total Float (CPTF), can be calculated.

$$Predicted\ CPTF = Planned\ Duration * (TFCI - 1)$$

Predicted Critical Path Total Float (CPTF)	Interpretation	Stoplight
CPTF > 0	If TFCI trend continues, P/p will be ahead of schedule by calculated # of days	GREEN
CPTF = 0	If TFCI trend continues, P/p will be on schedule	YELLOW
CPTF < 0	If TFCI trend continues, P/p will be behind schedule by calculated # of days	RED

Figure 7-39. An example stoplight chart showing the interpretation of the Predicted CPTF values.

Then using the P/p calendar, including non-working days, add (if negative) or subtract (if positive) the Predicted CPTF number of days to the baseline finish date to calculate a Forecast Finish Date.

$$Forecast\ Finish\ Date = Baseline\ Finish\ Date + Predicted\ CPTF$$

Thresholds. The P/p sets the thresholds during the Schedule Management Planning Process and documents them in the *SMP*. The P/p may choose to set tighter thresholds if the schedule has high uncertainty.

Caveat. As with most deterministic measures, TFCI is based on past performance and does not consider any future risks that may occur. TFCI should be used in conjunction with other risk-based techniques to forecast future performance estimates. TFCI is meant to be calculated for delinquent P/ps only. Also, the TFCI metric is sensitive to the Actual Duration (denominator) and should therefore not be used early in the P/p life cycle.

7.3.3.2 Step 2. Measure Stochastic Performance and Monitor Trends

It is a best practice for probabilistic risk-based techniques and metrics to be used to measure schedule performance and monitor trends. Although forecasts may be made by trending deterministic performance metrics and using EVM forecasting techniques, it is a recommended practice to use *SRA* tools and methods as described in Section 6.3.2 to generate risk-based schedule forecasts. For instance, probabilistic risk-based techniques can be used to forecast internally controlled schedule milestones, such as the Management Agreement (MA), and externally controlled milestones, such as the Agency Baseline Commitment (ABC). In this section, the performance tracking charts that can be generated from Schedule Analysis are discussed. The analysis and techniques for development of the data for those charts is reserved for Section 8.3.2.4.

The following sections introduce a set of forward-looking, risk-based, performance measurements intended to assist the P/p management in using the *IMS* to make sound programmatic decisions. These metrics include:

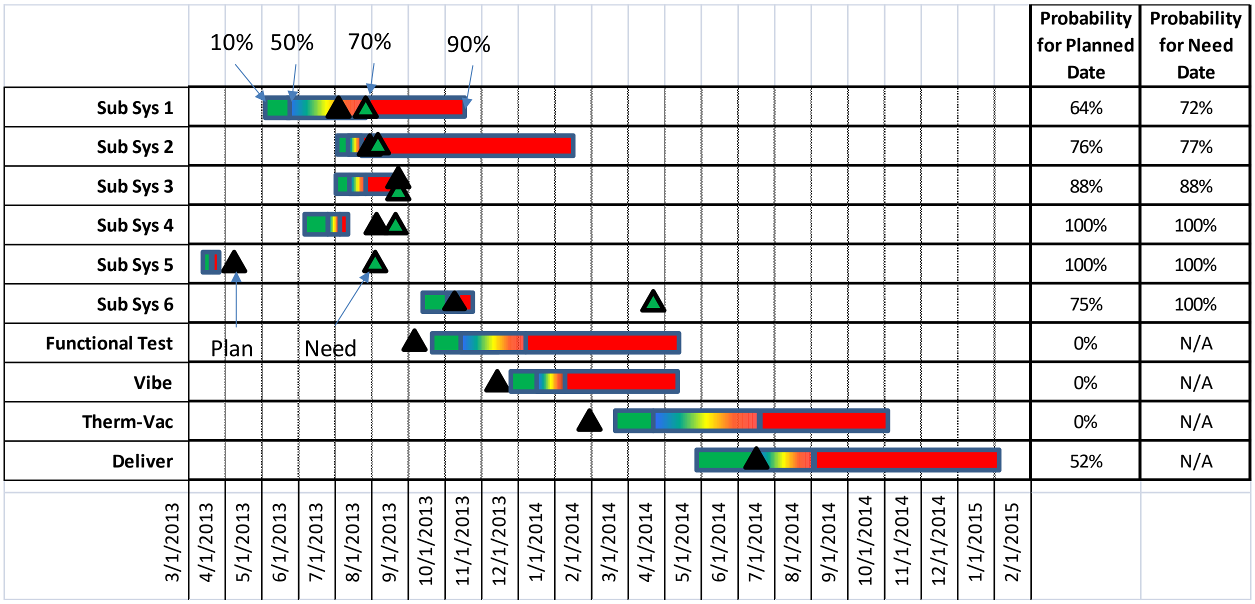
- Probability of On-time Delivery of Critical Items
- Risk-based Completion Trends
- Risk-based Sufficiency of Margin
- Risk-based Tracking against the MA and ABC

This list is not exhaustive and different techniques have been used by other NASA P/ps.

7.3.3.2.1 Probability of On-time Delivery of Critical Items

Description. *SRAs* can be performed routinely, considering the current risks and uncertainties at each status date, to show the probability of the on-time delivery of critical items. Each time the *SRA* is run, the completion-date probability distributions for each activity of interest are extracted from the *SRA* run and plotted with respect to both the current plan date and the need date. The resulting chart is commonly called a “BandAid” Chart because of its resemblance to its namesake.

The example shown in Figure 7-40 was developed for a NASA project. The left-most band is the range from the 10th percentile to the 50th percentile, the middle band is the range from the 50th percentile to the 70th percentile, and the right-most band is the range from the 70th percentile to the 90th percentile. The chart shows the probability for the Planned Date and the probability for the Need Date, with the difference representing the total float available. The chart shows where the P/p management needs to focus attention and exercise controls. For example, *Functional Test*, *Vibe*, *Therm-Vac*, and *Deliver* have virtually no chance of on-time completion and would require corrective action.



	Probability for Planned Date	Probability for Need Date
Sub Sys 1	64%	72%
Sub Sys 2	76%	77%
Sub Sys 3	88%	88%
Sub Sys 4	100%	100%
Sub Sys 5	100%	100%
Sub Sys 6	75%	100%
Functional Test	0%	N/A
Vibe	0%	N/A
Therm-Vac	0%	N/A
Deliver	52%	N/A

Figure 7-40. Example of a BandAid chart used in a recent NASA project.

Figure 7-41 below, is also from a NASA project and shows similar information but includes the available margin to show the threat to project-held margin. Due to SBU requirements, the actual subsystems have been renamed "SS-*x*". The chart shows the current best estimate for planned completion as the left-most edge of the band for each subsystem, then next follows slack to the edge of the project-held margin in each case. The project is holding 30 days between early integration and late integration into the I&T flow. Probability data from the *SRA* is indicated on the top of each band. To the right of each band is the probability of missing the late integration date. It is marked with the red arrow. For example, SS-2 shows a 79% probability of finishing on the early integration date, 90% probability of finishing on or before the late integration date and 10% chance of being late and delaying integration.

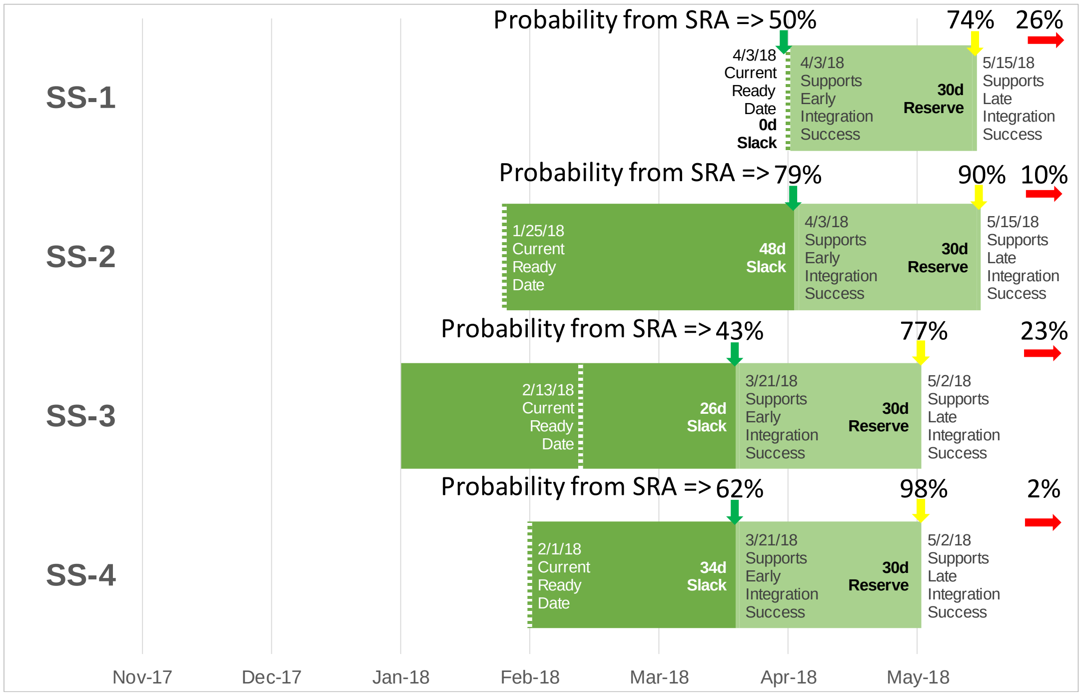


Figure 7-41. Probability of completion for critical items from a recent NASA project.

Thresholds. Although these projects had not established any prescribed thresholds, reasonable threshold recommendations would be to "Watch" when less than 70% on-time completion and Corrective Action required when less than 50% on-time completion. In the figure above, only SS-3 comes near the threshold for "Watch", having a probability of 77% completion before it will begin to delay I&T.

Caveat. The *SRA* results are very dependent on the quality of the inputs. The risk list and the *IMS* must be current and quality checked. These requirements can induce latency in the data if the P/p is not maintaining currency in the Maintenance sub-function.

7.3.3.2.2 Risk-based Completion Trend

Description. Risk-based Completion Trend is determined by repeating the *SRA* at routine intervals and tracking the trend of the probabilistic completion date over time. According to the NASA Risk Management Handbook, "initial performance measures establish initial risk tolerance levels (i.e., thresholds) for the achievement of performance requirements. Often, the expectation of improvement with time leads to a tightening of tolerance levels according to a risk burndown plan at key P/p milestones, which is combined with the objective of meeting the requirements per an associated verification standard. In other words, as the P/p evolves over time, mitigations are implemented; and as risk concerns are retired and the state of knowledge about the performance measures improves, uncertainty should decrease, with an attendant lowering of residual risk, as seen in Figure 7-42. The decrease may not be linear, as new risks may emerge during the P/p requiring new mitigations to be instituted."[155]

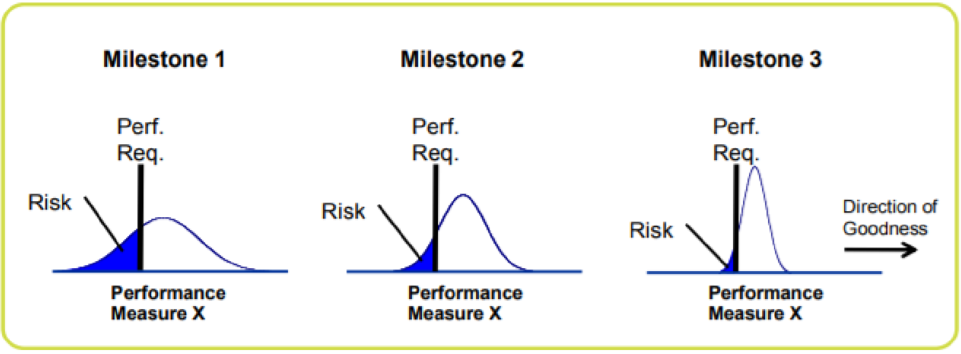


Figure 7-42. Decreasing uncertainty and risk over time.

To show the risk-based completion trend, the analysis is repeated at each pre-determined time using the latest risk data and the latest *IMS* (or *Analysis Schedule*). The mean value is plotted along with uncertainty bars indicating the range of the uncertainty of the output. This stochastic tracking technique was used by a NASA project and is illustrated in Figure 7-43. The date of the analysis is indicated on the vertical lines up to the data bars. This project repeated the analysis about every 6 months and at major reviews. The data bars show the mean and the 20th and 80th percentiles. The top line labeled "Deterministic" shows the planned completion date, margin excluded, and the downward trend as risks were realized. The lower line shows the trend of the stochastic results over time. The upward trend shows the effectiveness of risk mitigation and the uncertainty bars decrease with improved knowledge and retired risks. Everything looks good at the data point for "8/99;" after that point in time, the project was hit with a low probability, high impact risk which dropped the prediction down into the yellow banded area, but still with positive margin even at the 80th percentile at the lower end of the uncertainty bar.

---

[155] NASA/SP-2011-3422, NASA Risk Management Handbook. Version 1.0. November 2011. Page 96. https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20120000033.pdf

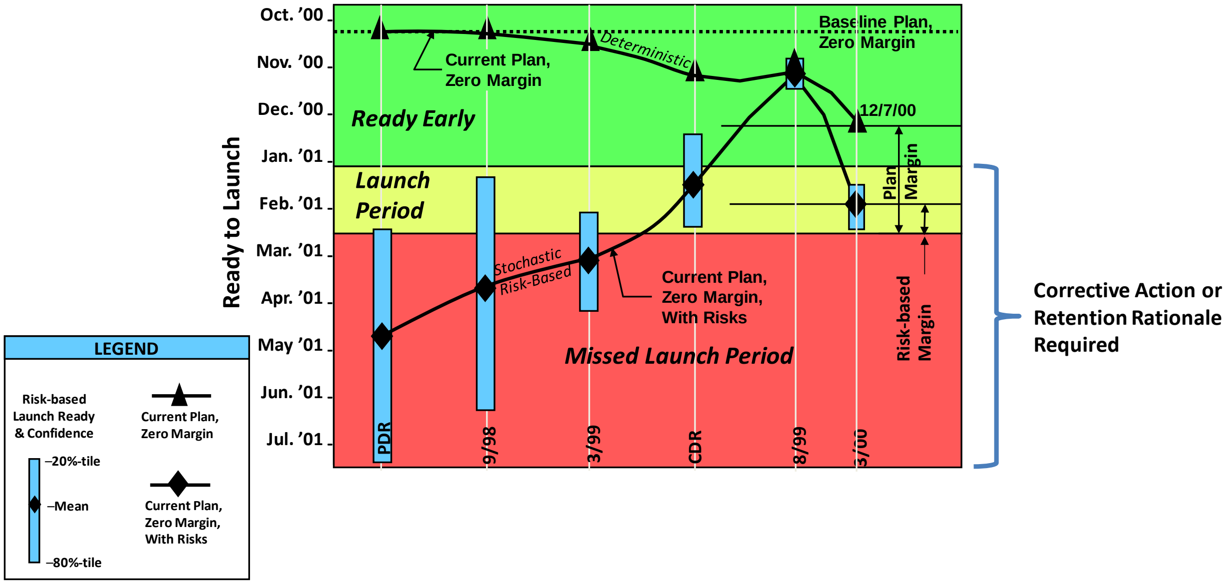


Figure 7-43. Example of a Risk-based Trend Chart for completion date used in a NASA project.

Thresholds. The P/p sets the thresholds during the Schedule Management Planning Process and documents them in the *SMP*. For the case discussed above in the figure, the project had selected everything above the launch window as "green", meaning no action required as long as the mean value was above the yellow banded region. The yellow band marked the launch window and any time the mean value was within that yellow band, the project action was "Watch". When the mean value was in the red-banded region, mitigation was required.

Caveat. The *SRA* results are very dependent on the quality of the inputs. The risk list and the *IMS* must be current and quality checked. These requirements can induce latency in the data if the project is not maintaining currency in the Maintenance sub-function.

7.3.3.2.3 Sufficiency of Margin

Description. It is typical for a P/p to track the consumption of margin against the deterministic schedule using a margin burndown curve, tracking month-end margin at each schedule update per Section 7.3.3.1.6. However, using a stochastic tracking curve takes the results from a routine *SRA* and plots the results against organizational margin requirements. Analyzing *SRA* results and comparing the *SRA*-based margin establishment/allocation to the predetermined guidelines can serve as a cross-check between the PM's initial expectations and the particular nuances of the P/p's risk posture. Deviations from the organization's planned depletion guidelines should be supported by the *SRA* results, with rationale clearly documented. This technique is very similar to risk-based completion trend chart shown above in Figure 7-43 which is a tracking against a launch period, whereas this technique is tracking against required margin. Two examples are shown in Figure 7-44 and Figure 7-45 below.

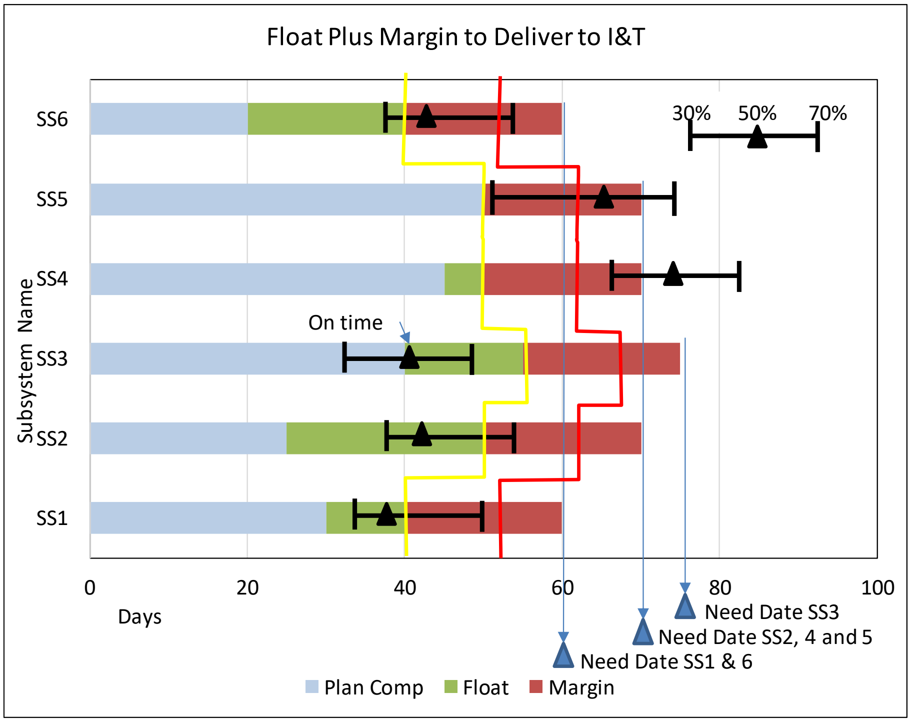


Figure 7-44. Using the SRA results to forecast the probability of subsystems (SS) completion for delivery to I&T.

Figure 7-44 is similar to Figure 7-31 with the exception of the probability bands added from the *SRA*. Using the 70th percentile, some of the subsystems (SS) change their status. SS1 and SS2 have now moved from “No Action” to “Watch”. SS6 has moved from “Watch” to “Corrective Action Required”. Furthermore, SS5 is now showing a probability of exceeding its available margin, and SS3 shows that it is very unlikely that any margin will be used.

Figure 7-45 shows an alternative method for showing the *SRA* results versus required margin. In this technique, the S-curves are plotted for each time the periodic *SRA* is performed and are compared against the current required margin. In this example case, Q1 and Q2 show no P/p action required. Q3 and Q4 indicate a “Watch” and “Corrective Action” respectively. This version of the tracking chart is more common, and it displays more information by showing probability values where the S-curves violate the margin boundaries. In this example case the “Watch” area is between the 70th and 50th percentiles with no action required above and corrective action required below.

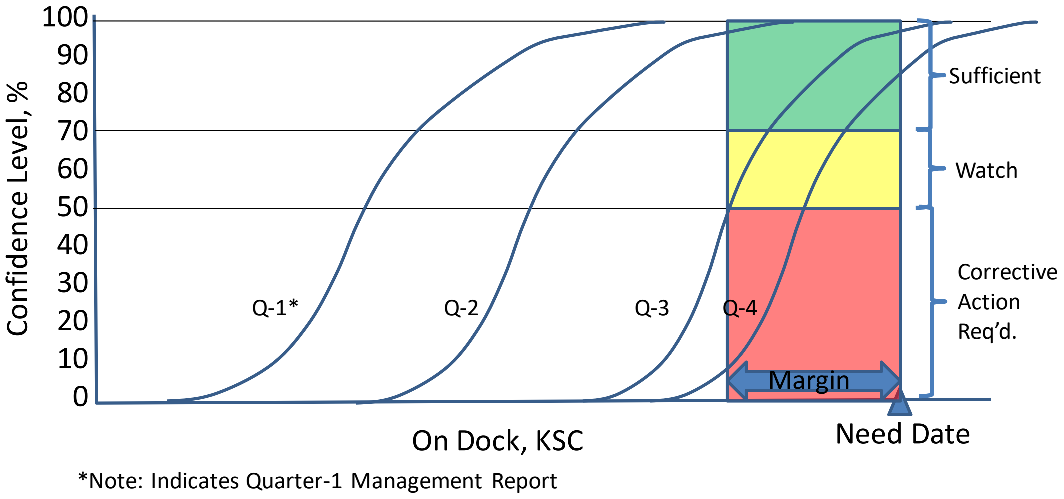


Figure 7-45. This figure shows a margin sufficiency tracking chart using the S-curves directly from the periodic SRA analyses.

Thresholds. The P/p sets the thresholds during the Schedule Management Planning Process and documents them in the *SMP*. In this example case, the P/p has chosen the "Watch" threshold to be where the total float is consumed, and the margin is the only cushion to delivery. The corrective action threshold is set where the margin is 50% consumed.

Caveat. The caveats are the same as the previous techniques.

7.3.3.2.4 Risk-based Tracking against the MA and ABC

Figure 7-46 shows the results from periodic *ICSRA* analyses as tracked against the MA and ABC. This technique was developed by a recent NASA program. The plot as shown here was generalized due to SBU constraints. It shows the trending for the probabilistic cost-at-completion and delivery date. The marker for each cross is the intersection of the values for the 50th percentile and the uncertainty bars are asymptotes for the 30th and 70th percentiles for cost and schedule respectively.

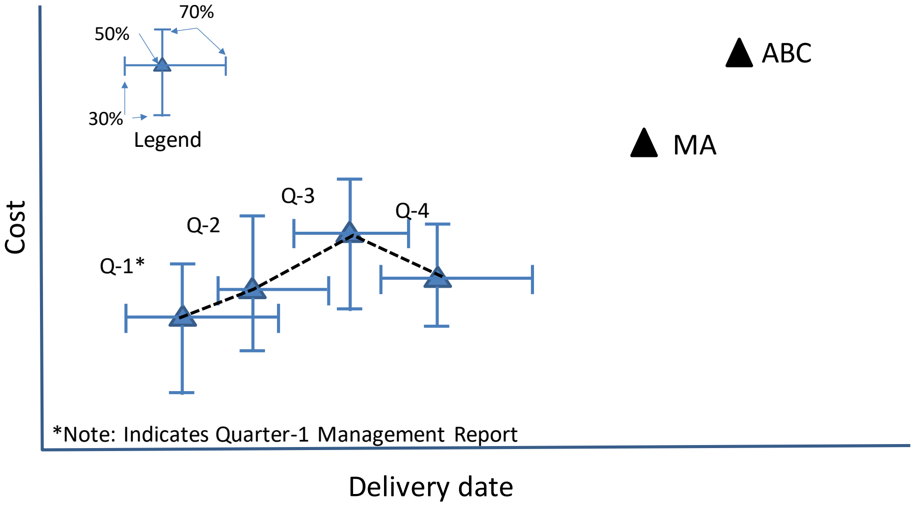


Figure 7-46. This figure shows both cost and schedule values from an ICSRA plotted against the MA and ABC.

Thresholds. No thresholds are shown here, nor did the specific P/p prescribe any. An example might be to define actions in specific quadrants surrounding the *ICSRA* plotted point and its uncertainties. Figure 7-47 illustrates the example.

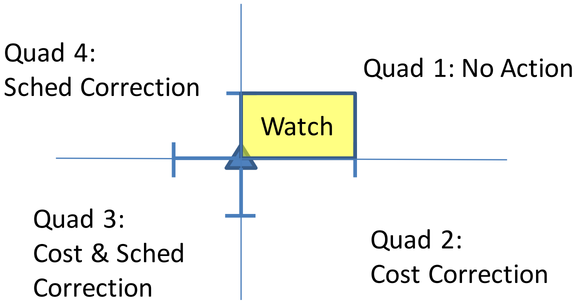


Figure 7-47. Example of recommended thresholds for risk-based tracking against the MA and ABC.

- **Quad 1.** If the MA or ABC is in Quad 1, no action is required with the exception of the small rectangular box bounded by the 70th percentiles and the 50th percentile *JCL* point. This rectangular region is labeled "Watch". Within this region there is between 30 and 50 percent chance that either the cost or schedule agreement will be violated.
- **Quad 2.** If the MA or ABC is in Quad 2, there is at least a 50 percent chance that the cost agreement will be violated and corrective action for cost performance improvement will be required. In this quadrant, the completion date agreement is at least 50 percent likely to be met.
- **Quad 3.** If the MA or ABC is in Quad 3, there is at least a 50 percent chance that both the cost and schedule agreements will be violated and corrective action for both cost and schedule performance improvement will be required.
- **Quad 4.** If the MA or ABC is in Quad 4, there is at least a 50 percent chance that the schedule agreement will be violated and corrective action for schedule performance improvement will be required. In this quadrant, the cost agreement is at least 50 percent likely to be met.

Caveat. In addition to the previously stated caveats for the schedule risk analyses, the same consideration needs to be observed here for the cost data as well. And since the current CPI will be used to estimate the cost uncertainties, the EVM data must be of suitable quality and should be current.

7.3.4 Procedure 4. Control – Determine Corrective Action or Retention Rationale

It is a best practice for corrective actions to be identified and tracked throughout the P/p life cycle to facilitate traceability to formal schedule changes. Changes to the schedule are expected throughout the life of the P/p. The PM must establish a schedule change control process to handle these changes (see section 8.3). The process and level of detail must be consistent with requirements levied on the P/p and also should be approved by the PM. Controlling the schedule baseline in response to changes, technical performance problems, or for other programmatic reasons assures an accurate plan going forward and a sound basis for continued performance measurement.

Knowing past schedule performance can provide much insight into future expectations. The findings are sorted into one of two categories as follows:

1. **Corrective Action**. It has been determined that a correction needs to be made to the baseline schedule. Corrective actions beget BCRs. Those corrections are managed through the P/p's Change Control process, as described in Section 7.3.1 and documented through the P/p's CM/DM function.
2. **Retention Rationale.** In some cases, the requirements or the best practice cannot be met. In those cases, if a corrective action is not taken, retention rationale must be documented along with any potential impacts to the schedule.

Performance metrics and trends that reflect poor activity and milestone completion rates may be an indicator that the P/p schedule is not realistic and corrective action is needed to control the schedule. The P/p has documented them in the *SMP* predetermined thresholds for when corrective actions are needed. This procedure utilizes a set of specific actions to be followed to bring schedule back into compliance when the prescribed thresholds are exceeded, as shown in Figure 7-48.

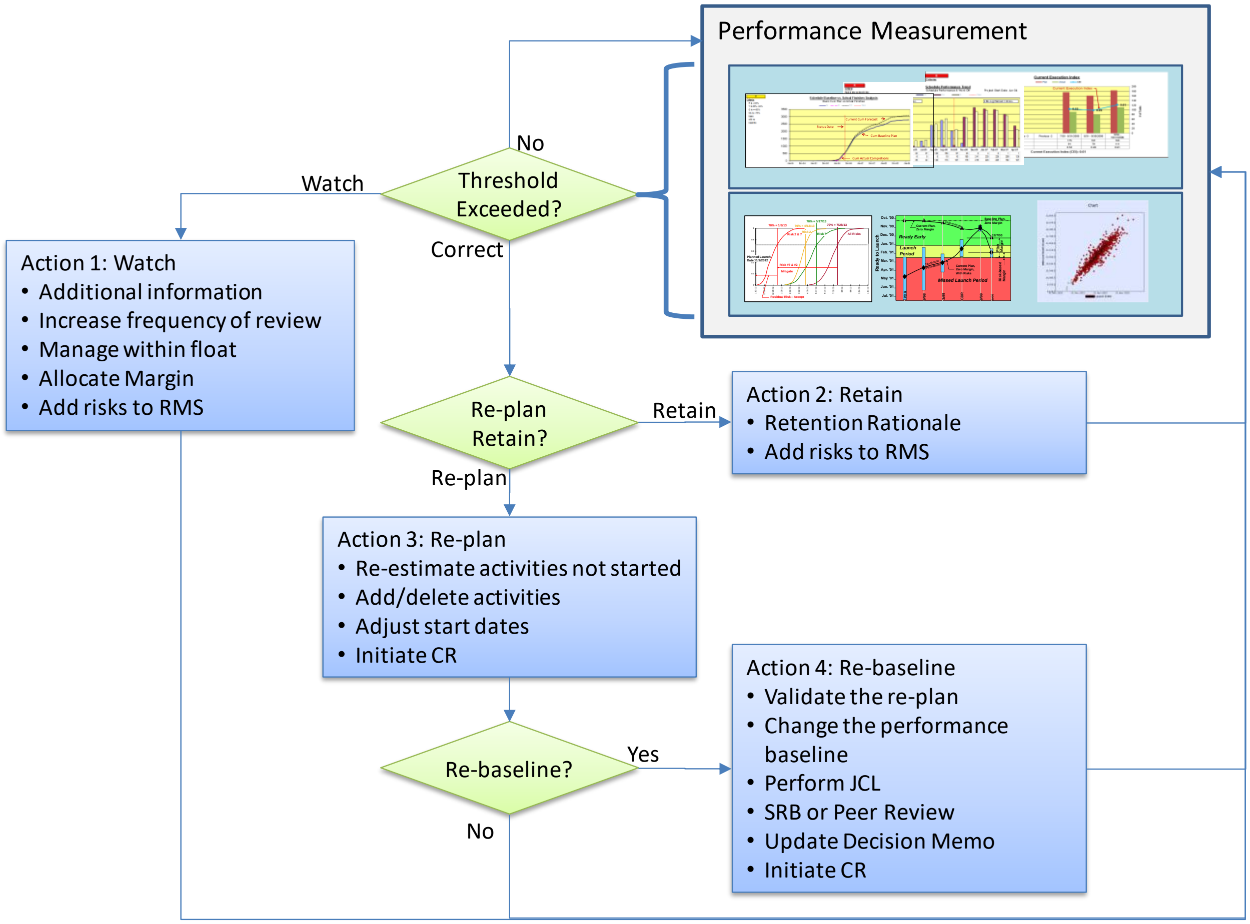


Figure 7-48. Shown here are the possible actions taken when performance measurement flags a threshold exceedance.

Corrective Actions

The schedule baseline (and PMB) should remain stable and only be modified due to authorized changes in work scope, reflected in authorized replans or authorized rebaselines. There are four specific corrective actions that can be taken through the P/p's change control process:

1. **Watch.** The PMB remains unchanged. Watch is always an action internal to the P/p. The P/p may release margin to protect against a replan. The Technical Lead may be directed to manage within available float. In such cases, additional risks may need to be added to the risk register.
2. **Retain.** Sometimes corrective actions are not feasible for reasons of complexity, cost, or other extenuating circumstances. In those cases, a rationale for retention is written and no corrective action is taken and the PMB remains unchanged.
3. **Replan.** A replan is internal to the P/p and occurs when there is a change in the original plan for accomplishing the previously authorized scope, typically involving the redistribution of budget for remaining work. The PM typically has the authority to replan within the approved MA, but must obtain the approval of the proper Decision Authority if the MA needs to be changed. The PMB, which is usually tied to the MA and P/p end-item or finish date (e.g., launch), may or may not be changed as the result of a replan. The EVM performance measurements, if applicable, are not reset unless the PMB changes.
4. **Rebaseline.** Rebaseline is generally external to the P/p. A rebaseline requires approval by the proper Decision Authority, as well as external stakeholders, including OMB and Congress. Rebaseline is a special case of a replan where the ABC is changed, and as a result, the MA and PMB are usually also changed. P/ps are required to rebaseline when: (1) the estimated development cost exceeds the ABC development cost by 30 percent or more (for projects over $250 million, also that Congress has reauthorized the project); (2) the NASA Associate Administrator judges that events external to the Agency make a rebaseline appropriate; or (3) the NASA Associate Administrator judges that the P/p scope defined in the ABC has been changed or the tightly coupled P/p has been interrupted.[156] ABCs for P/ps are not rebaselined to reflect cost or schedule growth that does not meet one or more of these criteria. When an ABC is rebaselined, the Decision Authority directs that a review of the new baseline be conducted by the Standing Review Board or as determined by the Decision Authority. After a rebaseline, EVM performance measurements are reset to 1.0 and a re-validation process is required for the changed content.

Figure 7-49 illustrates the flow of corrective actions and their impact on the schedule baseline.

---

[156] NPR 7120.5 rebaseline requirements reflect the requirements described in the, "NASA Authorization Act of 2005, Section 103 of Public Law 109-155."

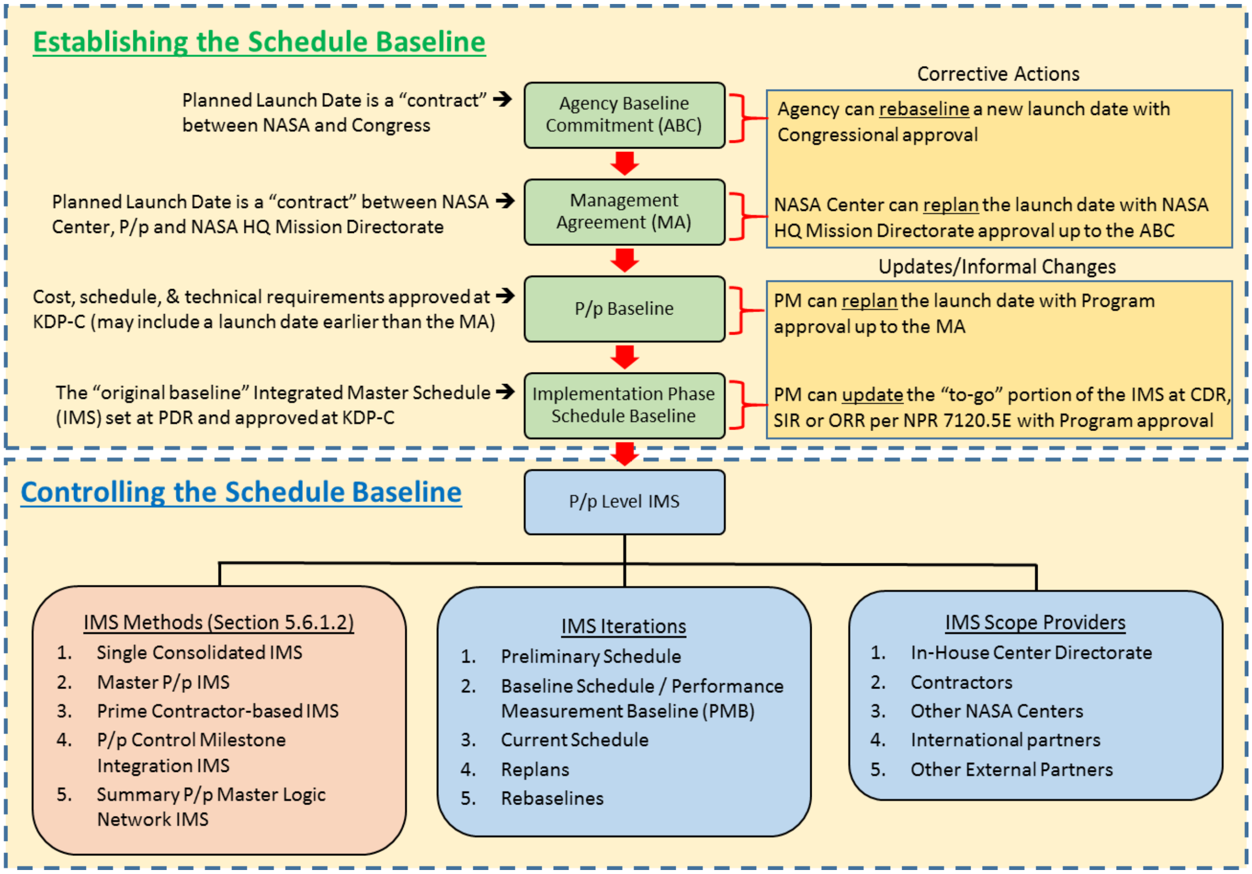


Figure 7-49. Flowchart illustrates how updates to the schedule baseline and corrective actions impact the schedule baseline.

As mentioned in the above sections, there exist conditions by which a replan and/or rebaseline may be directed by entities external to the P/p. The NASA Authorization Act of 2005, Section 103, "Baseline and Cost Controls" for major P/ps (>$250M) specifies conditions under which a replan and/or rebaseline must be performed. NPR 7120.5 has implemented the requirements specified in the NASA Authorization Act of 2005 as follows. For P/p whose LCC is greater than $250M:

- If the Estimate at Completion (EAC) for the Development costs or the LCC exceeds the ABC by 15%, a replan is required.
- If the EAC for the Development costs or the LCC exceeds the ABC by 30%, a rebaseline is required.
- If the estimated completion dates for the specified key schedule milestone(s) slips by more than six months, a replan is required.

Figure 7-50 illustrates the decision and actions required by NPR 7120.5 for externally imposed replan and/or rebaseline.

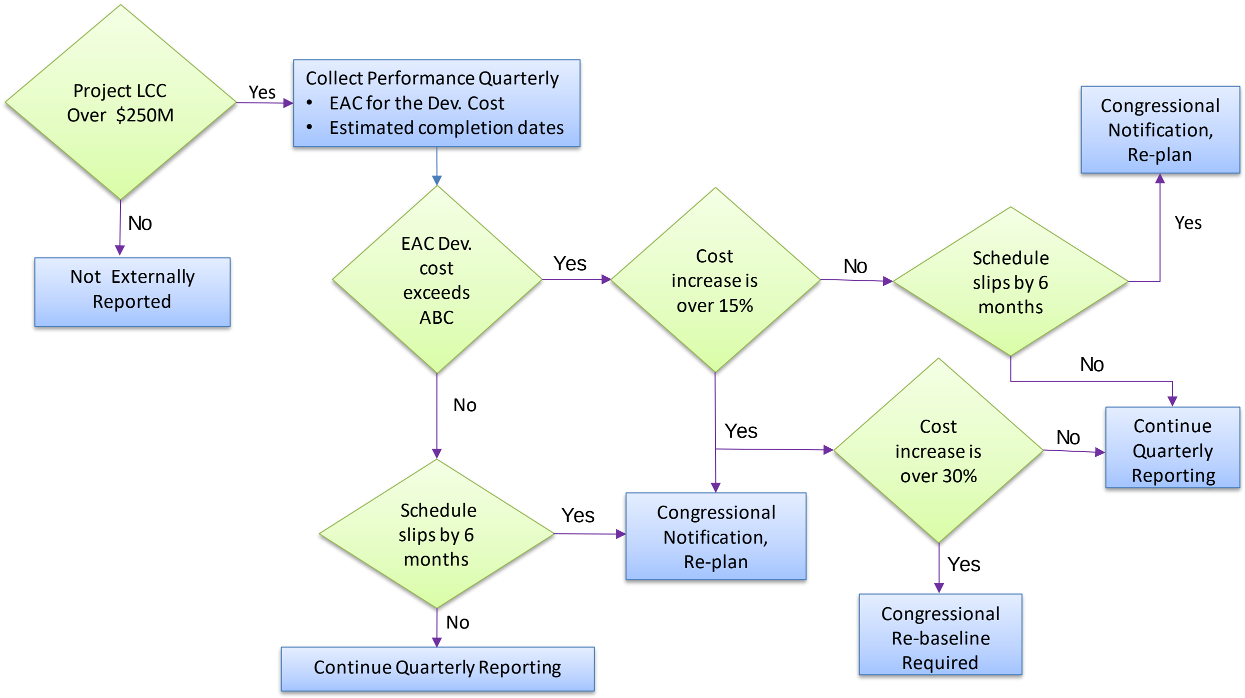


Figure 7-50. NPR 7120.5 implementation of NASA Authorization Act of 2005.

7.3.4.1 Decision 1. Threshold Exceeded?

The *SMP* has established thresholds for corrective actions. Those thresholds are limits for variations from the schedule baseline. Once a routine (e.g., monthly, quarterly, etc.) P/p review has been completed and all performance measurement data is available (Procedure 3), the P/S will look for threshold exceedances that may have been triggered by actuals or forecasts. Typically, the P/p will establish an early-warning threshold, "watch", which will focus P/p management attention to a poorly performing activity, and a "Corrective Action" threshold, which is exceeded if performance continues to deteriorate. As thresholds are breached, the prescribed watch action or a corrective action (e.g., retain, replan, or rebaseline) is initiated. In some instances, the PM may direct corrective action before a threshold has been exceeded due to a negative trend indicating that the threshold is threatened and very likely to be exceeded within a subsequent near-term reporting period.

Decision. (1) Watch, or (2) take Corrective Action.

7.3.4.2 Action 1. Watch

A watch action will be assigned by the P/p management team. It is important to note that the PMB remains unchanged for watch actions. The watch action typically consists of, but is not limited to, the following steps:

1. Request additional information to better understand the causes of low performance.
2. Increase the frequency of the performance reviews for the threatened activity.
3. Request analysis of available float and determine whether it is sufficient to absorb the low performance. Direct the Technical Lead to manage within available resources.

7.3.4.3 Decision 2. Retain or Replan?

Upon analyzing the performance data or gathering additional information from the watch action, the PM may choose to retain the schedule, leaving it as is, or implement a replan

Decision. (1) Retain (do not change) the schedule, or (2) Replan (and possibly change the MA and/or integrated performance baseline (or PMB), as appropriate). Document the corrective action or retention rationale in the schedule baseline change log as part of the *BoE*.

7.3.4.4 Action 2. Retain

Not every activity that violates a performance threshold needs to be replanned. Instead, revisions can be made to the schedule that do not impact key milestone dates. Some revisions can be accommodated at the WBS or CAM level. For example, the Technical Lead can move or otherwise adjust activities within the float that they are allowed to "manage". The PM may approve release of margin and reserve funds so that risk mitigation activities can be added to the schedule to avoid a replan.

Often no action is taken, and the poorly performing activity is unchanged. If no corrective action is assigned, the PMB is unchanged. The following list is a set of potential reasons no action is assigned:

1. Other activities may be causing the poor performance and the corrective actions assigned to them will resolve performance on the threatened activity. For example, an action assigned to activity X will increase the float available to activity Y.
2. There may exist external activities that the P/p cannot control that are causing the poor performance. For example, a component delivered from another P/p or from a foreign partner may be delayed.
3. It may not be cost-effective to replan; continue to track the performance.
4. Funding availability may be limited and priorities for correction assigned to other activities.
5. Timing may be inopportune. For example, a major review is in progress which may uncover additional performance issues and waiting until completion may provide consolidated correction actions.

Taking no action usually exposes the P/p to additional risks which should be entered into the RMS, since continuing on may threaten the MA and/or the ABC. Should this be the case, the P/p needs to review the current performance and risks with its stakeholders to determine whether a replan or rebaseline needs to be made instead.

7.3.4.5 Action 3. Replan

Replanning occurs when the schedule baseline is revised to reflect approved changes and involves rescheduling the remaining P/p work (or "to go" effort). Partial replans to selected portions of the baseline schedule can be implemented for the same reasons and using the same process as a full P/p replan. Replans typically require the redistribution of budget for remaining work. Thus, a replanned schedule may include revised activities/milestones, sequencing, durations, calendars, codes, constraints, and resources. There are two main types of replanning:

- **Internal Replanning.** Internal replanning refers to an action in which tasks for the remaining effort are rescheduled due to internal (to the P/p) scope changes, new technical approaches, resequencing of activities, recovery or workarounds from technical problems or risks, or to simply create more realistic schedules for the work remaining to be accomplished. With internal replanning, the external commitments remain unchanged (e.g., external control milestones, launch date, and the ABC date). The PM typically has the authority to replan within the approved Schedule MA (also within the existing schedule performance baseline, or PMB). However, it is possible that the replan will result in a necessary change to the MA and the integrated performance baseline (or PMB), in which case the PM must obtain the approval of the proper Decision Authority. In either of these scenarios, P/p notification and control milestones or receivable/deliverable dates may change to the extent that the changes do not impact external commitments. P/p-held schedule margin may be allocated in support of the internal replan. **Note:** An internal replan can be for the entire P/p schedule, or for a specific element, such as a subsystem. A contractor will not typically implement an internal replan for its contractual effort without concurrence of NASA's P/p office.

- **External Replanning.** External replanning differs from internal replanning because it is driven by changes outside of the P/p's control such as a launch date change, budget cut, or other event. For example, an in-house instrument project could be impacted by a facility conflict with a higher-priority in-house project, necessitating a replan. In other instances, if P/p performance shows that the MA is being threatened, the P/p may receive direction from above the PM's level to perform a replan to bring the P/p back into compliance with the MA. Alternatively, external events could require P/p sponsors or stakeholders to move the MA and likewise require a replan.

A replan may be necessary for many different reasons, which may include, but are not limited to:

- To bring the schedule performance back into compliance with requirements
- To utilize schedule margin for risk mitigation activities or the realization of risks
- To address a situation whereby the time-phasing of the schedule shows overutilization of available budget
- To incorporate a scope change affecting one or more subsystems,
- To address unplanned budget impacts through the PPBE process

Typical approaches for updating the schedule due to a replan are described in Procedure 5.

7.3.4.6 Decision 3. Rebaseline?

Upon analyzing the performance data, it may become apparent that the existing baseline is no longer achievable and measuring performance against it is of little or no practical value. The PM may request a rebaseline or may be directed to perform a rebaseline.

Decision. (1) Do not rebaseline and return to the performance measurement procedure, or (2) Rebaseline and change the ABC and document with an update to the DM. Document the corrective action in the schedule baseline change log as part of the *BoE*. **Note:** If/when a P/p undergoes a formal rebaseline, the P/p may work to a "new" schedule baseline; however, the original schedule baseline should be preserved for traceability and future planning.

7.3.4.7 Action 4. Rebaseline

Rebaselining is a special case of replanning that results from the need to change the P/p's external commitment, or ABC, in addition to the internal commitment, or MA. Rebaselining occurs when the existing baseline is no longer achievable and measuring performance against it is of little or no practical value. The need for a rebaseline may occur due to poor performance or other external factors, such as budget cuts or other P/p launch priorities. It may also occur when a rebaseline is directed per the NASA Authorization Act of 2005, Section 103. Partial rebaselines to selected portions of the baseline schedule can be implemented for the same reasons and using the same process as a full P/p rebaseline.

Typical approaches for updating the schedule due to a rebaseline are described in Procedure 5.

When a rebaseline is complete:

1. The P/p is required to validate the rebaseline. A review of the new baseline is conducted by the SRB or appropriate independent assessment team as determine by the Decision Authority.[157]
2. The risk list needs to be updated to reflect the changes.
3. The DM needs to be revised to record the change to the MA and ABC.
4. The performance measurement baseline is reset as appropriate.
5. For P/ps required to perform EVM, the PMB is modified to accommodate the schedule changes. A decision may need to be made to reset the variances to zero. This is not advised unless the measurements become useless to P/p management.
6. Then the flow goes back to the Performance Measurement Procedure.

7.3.5 Procedure 5. Maintenance – Update Schedule Database with Corrective Actions

It is a best practice for the schedule baseline to be updated according to corrective actions (replanning or rebaselining), as needed, as part of the P/p's change control process. Changes to the schedule are expected throughout the life of the P/p, although, not all require official corrective actions. For instance, updating the *Schedule Database* with current progress as described in Procedure 2, does not always result in a change the baseline. However, Procedure 5 captures all changes that impact the schedule baseline and schedule performance baseline, or PMB, through corrective actions.

Since the *IMS* is a dynamic network, in that the forecasted dates are automatically recalculated when activities change, significant changes to the *Schedule Database* that result from a corrective action must be processed through the P/p's formal CM/DM process. All proposed changes to the baseline must be evaluated carefully to determine cost, schedule, and technical impacts, and then approved only by the appropriate PM or P/p management designee. *IMS* milestones controlled by the Program Office, for example, may only be changed after receiving approval from the Program Manager. Corrective actions imposed on the baseline schedule may also result in changes to the cost estimate, and therefore the integrated performance baseline, or PMB.

---

[157] NPR 7120.5E. NASA Space Flight Program and Project Management Requirements. Effective Date: August 14, 2012. Expiration Date: August 14, 2020. Page 37. https://nodis3.gsfc.nasa.gov/npg_img/N_PR_7120_005E_/N_PR_7120_005E_.pdf

Typical events can initiate a change to the schedule baseline. For instance:

- The annual PPBE guidance document may reduce the available budget which may cause either deletion of content via the descope plan, or postponement of some activities until later fiscal years. It is also possible that the PPBE guidance may increase budget and allow acceleration of activities.
- The risk management process may identify mitigation plans that will need to be added.
- Planning errors may be discovered that require changes that impact cost and schedule and therefore need to be processed through the P/p's CM/DM process.
- The normal design process will often identify additional activities that need to be added.
- Component testing, EDU testing may uncover non-compliances requiring redesign activities to be added.
- Rolling waves will need to be decomposed into lower-level activities.
- The performance measurement process may trigger corrective actions that will modify or add activities.

Performance-to-date is useful in understanding how a corrective action is implemented. For example, the past performance may show a consistent underestimate of the duration of specific collections of activities. The replan or rebaseline should consider those findings.

In general, any replanning or rebaselining due to a BCR, CCB-approved changes, or other internally or externally-generated changes may involve the addition, removal, or alteration of work scope. Examples include adding a new test, de-scoping a spare subassembly, or making a component in-house that was originally planned as a procured item. Proposed changes are assessed for impact against the schedule performance baseline.

Rebaselining is similar to replanning in that the early start dates, early finish dates, and durations of the tasks affected by the rebaseline are changed. New activities may be added, others deleted, and workflows may be revised. Calendar and resource assignments may also be modified. However, in the case of rebaselining, these things are done to establish a new ABC and demonstrate that they can be met with acceptable risk versus to maintain the current ABC.

The P/S should review proposed schedule changes with the responsible P/p resource analysts to ensure proper integration of the schedule changes to the P/p's integrated performance baseline, or PMB, if applicable. It is a recommended practice to conduct validation by an independent review team if the replan is significant. For example, a replan may be significant if it requires a change in the MA date (e.g., launch date), but not necessarily a change in the ABC date (i.e., rebaseline). A replan may also necessitate an independent review if it breaches Agency thresholds as discussed in Section 7.3.4. For a rebaseline, an independent review is required.

Once a Corrective Action is approved:

1. A BCR is initiated through the P/p's CM/DM process. When the *Schedule Database* is updated, the updates must be flagged in appropriate fields and the specific BCR noted.

2. The risk list is revised to reflect the changes.
3. Depending on the corrective action, a decision may need to be made to reset the schedule performance baseline, or integrated PMB. Sometimes the progress against the original schedule baseline can be so poor that the performance measurements are no longer useful. Resetting the cost and schedule variances should only be done to improve the validity and usefulness of the performance measurements, such as EVM performance data, to support performance evaluations, future planning, or other management needs. For instance, rebaselining the integrated performance baseline (or PMB) will reset EVMS *Performance Measures* back to 1.0.
4. If the MA and ABC do not need revision, then the flow goes back to Procedure 3.

Schedule baseline changes resulting from the approval of the corrective action are implemented through updates to the *Schedule Database*. If these changes are not documented in the *BoE*, reflected accurately in the revised baseline, and subsequently controlled, then P/p future *Schedule Performance Measures* may not be accurate and identification of the need for any additional corrective actions after the replan will be compromised. The impacts could potentially result in either a lack of variance reporting or additional, unnecessary variance reporting requirements, and more importantly, faulty schedule information for use in management decision making. By properly maintaining the configuration of the schedule baseline, P/ps will have a plan against which to measure performance and understand variances that correspond to the work that is intended to be accomplished.

When retaining the schedule, several alternative methods exist for controlling the schedule baseline as described in the following sections.

7.3.5.1 Complete Schedule Baseline Update Method

The Complete Schedule Baseline Method is the most detailed and rigorous method for maintaining the schedule baseline. It involves modifying or resetting the baseline at the task level of the *IMS* for all tasks affected as a result of internal replanning, external replanning, or rebaselining as described previously. Additionally, *IMS* changes are documented in the schedule baseline change log. **Note:** Unless otherwise negotiated with the P/p's prime and non-prime contractors, contractor schedule baseline control will be in accordance with their internal PP&C systems and practices.

Depending on the type of corrective action taken, a variety of approaches may be utilized as part of the Complete Schedule Baseline Method. Several of the workaround approaches detailed include schedule acceleration and optimization techniques, as well as margin management techniques.

Change Activity/Milestone Start/Finish Dates

This approach is often used to address unexpected budget cuts or the impact of continuing resolutions. It is the easiest option available because the change to the PMB is minimal. For both internal and external replanning, early start dates, and early finish dates of tasks affected by the replan should be reset as the schedule baseline going forward, using a new "baseline" field in the *IMS*. (The original schedule baseline dates should be preserved for traceability and future planning.) Early start dates and early finish dates of other tasks, including historic tasks not affected by the replan, should not be changed, reset, or modified. Tasks that have not yet started may be replanned (e.g., adjustments to durations, interdependencies, and budget) as necessary within the approved P/p boundaries established for scope, schedule, and budget. Careful coordination within the P/p between the responsible technical, resource, and schedule personnel is necessary to preserve the integrity of the *IMS*. In-progress tasks are typically not replanned unless there is significant work left to accomplish. In this scenario, it is recommended that:

a. The in-progress task be redefined (split) such that the work accomplished to date becomes the entire scope for that task with the remaining work scope becoming eligible for replan.

b. The original in-progress task is then recorded as complete. (check this next statement for accuracy) This essentially is setting BCWS and BCWP equal to ACWP.

c. The remaining work scope, with the corresponding budget and duration, is then transferred to a new task or tasks and replanned.

Change Activity Durations

Changing activity durations may be necessary when it becomes obvious that there is a consistent indication of underestimation. In most cases, schedule durations are lengthened based on forecasted performance measurements.

Increase Assigned Resources

Increasing assigned resources may be necessary when it becomes obvious that there is a consistent indication of underestimation.

- **Schedule Crashing.** Schedule crashing is a schedule acceleration technique that adds extra resources to perform the work in a shorter period of time. **Note:** This technique requires additional money to add resources, which may be obtained through UFE.

Adjust the Calendar

Adjusting the calendar may be appropriate when longer work days or additional shifting is a possibility. The PM can choose to spend more money per time unit to shorten the schedule. **Note:** This approach is only possible if resources (people, facilities, and money) exist without conflicts to support the increased work periods.

Add Activities

Adding activities may be necessary for the following reasons:

- Risk mitigation activities have been identified and approved
- A test or verification failure requires adding redesign and retest activities
- Engineering development unit swapped for flight unit to accommodate late delivery of flight unit
- Change of scope or poor planning requires additional activities

The P/S will need to work with the Technical Leads to determine the baseline start and finish dates for the new activities.

Delete Activities

Deleting activities may be necessary when the projected schedule delay is unacceptable and other techniques for accelerating the schedule are not viable options. Descope options are identified in the *SMP* and should be the last approach exercised in order to maintain completion dates and recover from poor performance. **Note:** Descopes often require contractual changes.

Alter Workflows/Activity Sequencing

Altering workflows through modifications in activity sequencing is often done to reduce the impact of poor performance.

- **Fast Tracking.** Fast tracking is a schedule acceleration technique where activities that would have been performed sequentially are performed in parallel.
- **Streamlining.** Streamlining is a schedule optimization technique depends on the P/p team's ability to find a more efficient and effective approach to completing the work. It is often dependent on a faster or simpler approach, requiring innovation and possibly including reuse or eliminating non-value-added work. **Note:** With this method, the P/p has to weigh the level of potential risk involved with each streamlining option.[158]

The P/S will need to work with the Technical Leads to determine the revised workflow.

7.3.5.2 Baseline Control Milestone Update Method

The Baseline Control Milestone Method provides some flexibility for P/ps in maintaining the schedule baseline. It involves modifying or resetting the baseline start dates, finish dates and durations for only the P/p's control milestones. The P/p control milestones are a subset of major deliverables, milestones including EVM milestones, and other key events identified by the P/p team for tracking and measuring progress. Using the Baseline Control Milestone Method, supporting detailed *IMS* tasks are not maintained from a baseline control standpoint and their baseline start/finish dates will always reflect the original schedule baseline. Additionally, *IMS* changes are documented in the schedule baseline change log. It is important to note that unless otherwise negotiated with the P/p's prime and non-prime contractors, contractor schedule baseline control will be in accordance with their own internal PP&C systems.

Caveat. A disadvantage of the Baseline Control Milestone Method is that certain performance metrics, such as the Baseline Execution Index (BEI) and Hit or Miss Index (HMI), will track performance against the original schedule baseline dates at the detailed task level – since these tasks' baseline dates will not be changed. This will not be the case with the Complete Schedule Baseline Method. A workaround to this limitation of the Baseline Control Milestone Method is to use it in conjunction with the Annual PPBE Schedule Baseline Reset Method described later. This approach provides a method for keeping the schedule baseline at the detailed level up to date for schedule performance monitoring and reporting using BEI, HMI, critical milestones, and cumulative milestones reports.

---

[158] PASEG, Version 4.0. National Defense Industrial Association (NDIA), Integrated Program Management Division (IPMD). March 9, 2016. Page 115.

7.3.5.3 P/p Element Baseline Method

The P/p Element Baseline Method essentially tracks the individual revision levels of the P/p' various element *IMSs* (i.e., spacecraft, instrument/payload, ground system, etc.). Typically, the P/p will maintain a set of major receivable and deliverable milestones between these various P/p elements. The element work may consist of effort performed in-house, at industry contractors, other NASA centers, or international partners. Typically, the P/p receives the "native" *IMS* files from these performing organizations, but schedule baseline control is maintained by the provider organizations. The P/p's key responsibility from a schedule baseline control standpoint is to assure the provider organizations are maintaining an adequate schedule baseline control process. Additionally, the P/p should document and track the various revisions of the individual provider schedule baselines using a schedule baseline change log.

7.3.5.4 Contractor's Schedule Baseline Control Process Update Method

Unless otherwise negotiated with the P/p, the contractor's schedule baseline control process is the method used for maintaining the contractor's schedule baseline. This may or may not include the P/p's approval of contractor internal schedule changes. The key responsibility of the P/S is to monitor the contractor's schedule baseline to ensure the schedule baseline is being assessed, maintained, and controlled in accordance with NASA best practices.

7.3.5.5 Annual PPBE Schedule Baseline Reset Method

An alternative schedule baseline control method is to reset the baseline for all remaining *IMS* tasks underway or to be completed consistent with the annual PPBE process. In short, the Annual PPE Schedule Baseline Reset Method essentially means creating a new baseline each year for the remaining or "to go" effort. The advantage of this method is that it synchs the schedule for the work to be accomplished with the annual operating budget for the work to be accomplished. The disadvantage is that, if not communicated correctly and without buy-in from affected stakeholders, this method could create the appearance of a "rubber baseline." Rubber baselining refers to gaming and data manipulation techniques resulting in the masking of cost and schedule variances, often with an intent to mislead. The annual PPBE schedule baseline reset method may only include those elements of the P/p schedule directly controlled by NASA since contractors will be following their own internal PP&C processes.

7.3.5.6 Schedule Margin Maintenance

Some changes to the schedule baseline may involve the utilization, reallocation, or replenishment of schedule margin. Schedule margin management guidelines and techniques are captured in the *SMP*, and include:

- Definition of who owns the margin and how it is distributed (i.e., transition of margin management from PMs to Technical Leads, contractors, etc.)
- Guidelines for planned margin requirements (i.e., organizational margin burn-down guidelines)
- Process for utilizing margin
- Process for reassigning unused margin
- Processes for monitoring/tracking margin

After the schedule baseline has been set and margin has been established in strategic locations throughout the schedule, the P/p will need to actively manage or “maintain” the margin. When those instances of schedule margin involve the schedule baseline, the change should be documented in the P/p’s schedule baseline change log. Procedure 3 details the approaches for monitoring and tracking margin, whereas this procedure provides guidance on how to manage the margin in the schedule baseline. The following sections describe the processes for utilizing and reassigning margin using *SRA*-based techniques, which are further described in Section 6.3.2.5.3 above.

Managing Margin When Margin Needs to Be Utilized

Schedule margin is used to absorb the impact due to risks and uncertainties. The P/p can effectively manage schedule margin by continually performing *SRAs* to understand and address potential risk impacts to the P/p throughout its life cycle.

Once an *SRA* is run, the P/p should be able to determine whether the potential impacts of the uncertainties and risks can be absorbed given the allotted margin. If the finish milestone estimate does not move past the planned P/p completion date, then the P/p likely has appropriate margin given its identified uncertainty/risk posture. However, rather than waiting for the risks impacts to occur, proactive management might include adding risk mitigation activities to the schedule through the approved use of margin. The P/p may be able to implement a process for this to be accomplished via routine risk management meetings with PM approval.

Technical Leads are usually the first to recognize potential areas for risk mitigation. The P/S should work with the Technical Leads to compare what is actually occurring on the P/p with the results of the *SRA* to ensure the right risks are prioritized for mitigation. Assuming P/p management will plan to mitigate the risks with the greatest impact first, the risk sensitivity chart can be used to help prioritize risk management efforts. The “top risk” can be removed and the simulation rerun to understand the effective impact generated from the risk. Risks should be backed out of the analysis one-at-a-time with a new sensitivity chart generated for each iteration to reveal the subsequent top risk. It is important to note that the order of top risks is dependent on the combination of risks applied to the simulation at any given time (i.e., some risks have greater overall impact on a schedule when combined with a particular set of other risks). Removing a risk may change the critical path, making other risks and activities more “critical,” which is why it is necessary to rerun the tornado chart after each simulation. If the P/p has identified some other order of risk mitigation due to funding, management priorities, or other constraints, risks can be worked-off the simulation according to the PM’s plan. Running different “what if” scenarios provides a good comparison of the impacts each mitigation approach has to “buy back” schedule through working off the risks in different orders to achieve the greatest and most realistic benefit.[159]

---

[159] The authors of this paper acknowledge that while risk tornado charts based on correlation coefficients are widely used and supported by probabilistic risk analysis tools, recent research has shown that “ranking risks by correlation coefficients is not a good sensitivity measure, especially for schedule.” (Kuo, Fred. “A Mathematical Approach for Cost and Schedule Risk Attribution.” NASA 2014 Cost Symposium.) Another alternative for determining “optimal” schedule margin allocation is the Ruhm-Mango-Kreps Algorithm. (Fussell, Louis. “Margin Allocation Using the Ruhm-Mango-Kreps Algorithm.” 2016 NASA Cost Symposium.)

When mitigation activities are added to the schedule, margin activity durations, or some portion of margin activity durations are converted to the risk mitigation activity or set of activities, and then linked to reflect an appropriate logic flow within the schedule. The mitigation activities become part of the P/p's plan, and the margin is accordingly reduced in duration to maintain the P/p's planned finish date. It is important to note that the duration and cost of a mitigation activity may not be the same as the duration and cost of the risk impact; in most cases, it should require less money to mitigate the risk ahead of time than to recover from the risk impact(s), which is why P/ps should aim to mitigate risks, when possible. Sometimes when a risk is mitigated, the impact is not completely reduced, or some level of threat remains. This net risk after controls or mitigations have been put in place is referred to as residual risk. If any residual risk exists that cannot be mitigated, it should be accounted for in the P/p's risk list and considered in future iterations of the *SRA* for the proper allocation of margin. There may be enough information about the residual risk (usually an "accepted" or "transferred" risk) to capture margin where the risk impact might occur, or the margin to cover the risk impact may need to be included in the lump sum of margin held near the end of the schedule.

Technical Leads in addition to the Schedule Analyst, will also usually be the first to recognize the need to use margin for risk impact purposes. Although *SRA* risk prioritization may show that a particular risk may significantly and adversely affect the P/p's critical path, sometimes risk mitigations are either too costly or do not provide the P/p significant time savings. The P/p may anticipate a possible need for technical rework but choose not to make changes until verifying the need for rework through testing. In this case, the margin held after testing can be translated into new work to manage the impact of the failed test. In other cases, the risks may result from external factors that are out of the P/p's control, such as an anticipated late delivery from a partner. These risks might be those that have already been "accepted" by the P/p. Thus, the P/p may allow these risks to occur and use margin to handle the impacts. Margin must be allocated to the associated activities in these instances so that status can be tracked. "Margin", however, is not a work activity and should never be statused.

Whether margin will be used for mitigation purposes or to manage risk impacts when risks are realized, the P/p should follow pre-determined processes, outlined in the *SMP*, for approving the use of margin. The P/p will need to determine the trigger point at which margin should be released to manage the risk. It will be important for the P/p team to understand whether certain margin is held/managed by the Program Office, the Project Management Office or PM, or the Technical Leads, and how it is "released" from one level to the next if/when necessary. Waiting too late to use margin may result in an inefficient use of the available time (i.e., the margin may not be as helpful as it could have been if released earlier). The P/p management team will need to incorporate any scheduling changes, such as the addition of mitigation activities or the transformation of margin into new work activities to address risk impacts. Only as risk mitigation activities are identified and approved, should they be incorporated into the P/p's plan as specific tasks in the schedule and budget made available to perform the new work. For tracking purposes, the margin task(s) and effective margin calculations should be reduced accordingly.

Managing Margin When Margin Does Not Need to Be Utilized

Sometimes expected risk impacts do not occur, work takes place as planned, and tasks finish on time. Schedule margin along these "on-time" paths should not simply be wasted or consumed through "waiting" for the next work activity to start. Margin tasks do not represent contract scope and cannot be statused, so it benefits the P/p to find a way to repurpose the margin and possibly start subsequent tasks earlier.

Technical Leads need to be aware of what others on the P/p are doing. There may be opportunities that the P/p can take advantage of by repurposing or redistributing the resources expected to be consumed during the margin period. The P/p should actively analyze the schedule to determine whether any subsequent activities can start earlier than planned (i.e., prior identification of early start dates may help facilitate this analysis). If tasks can start as soon as their predecessors are finished, this can save the P/p money by completing work sooner and perhaps gaining total slack later in the schedule to help with potential performance issues or unknown risks. The P/p may also consider re-shifting and using the “available resources” to offset delays in other areas of the schedule. This assumes that reserves/workforce would have been available during the original margin task duration. If there are no other areas of the schedule that need to effectively take advantage of the “available resources” to get back on track, the P/p may consider performing value engineering or additional testing for certain technical elements to enhance technical performance (e.g., reliability, supportability, maintainability, survivability, etc.), or simply returning the margin duration to the P/p as float (i.e., an earlier end date) if the risk associated with the margin task no longer exists.

If none of these are viable options, the margin may be able to be moved downstream in the P/p workflow. While the calculation should be the same for incorporating a margin task at any point along the critical path, it may not be feasible to move the entire duration margin task to the end of the schedule. Since margin is not always entirely, or even partially fungible, how the margin translates from one point in the schedule to a later point in the schedule may be dependent on how much total float is on the primary critical path versus the secondary critical path; this will dictate whether the original primary critical path remains as the primary critical path after the removal and subsequent reallocation of margin, or whether the original secondary critical path becomes the new primary critical path. The full margin duration that was available to a particular subsystem or instrument in the spacecraft schedule may not translate one-day-for-one-day as it moves toward the end of the schedule. For instance, if the margin activity had a larger duration than the difference in total float between the primary and secondary critical path, the secondary critical path may now become the primary critical path. Figure 7-51 shows how removing a margin activity from the original primary critical path of a “time now” schedule with the intent of reallocating margin to what was the secondary critical path may result in a smaller duration of effective margin on what is now the “new” critical path.

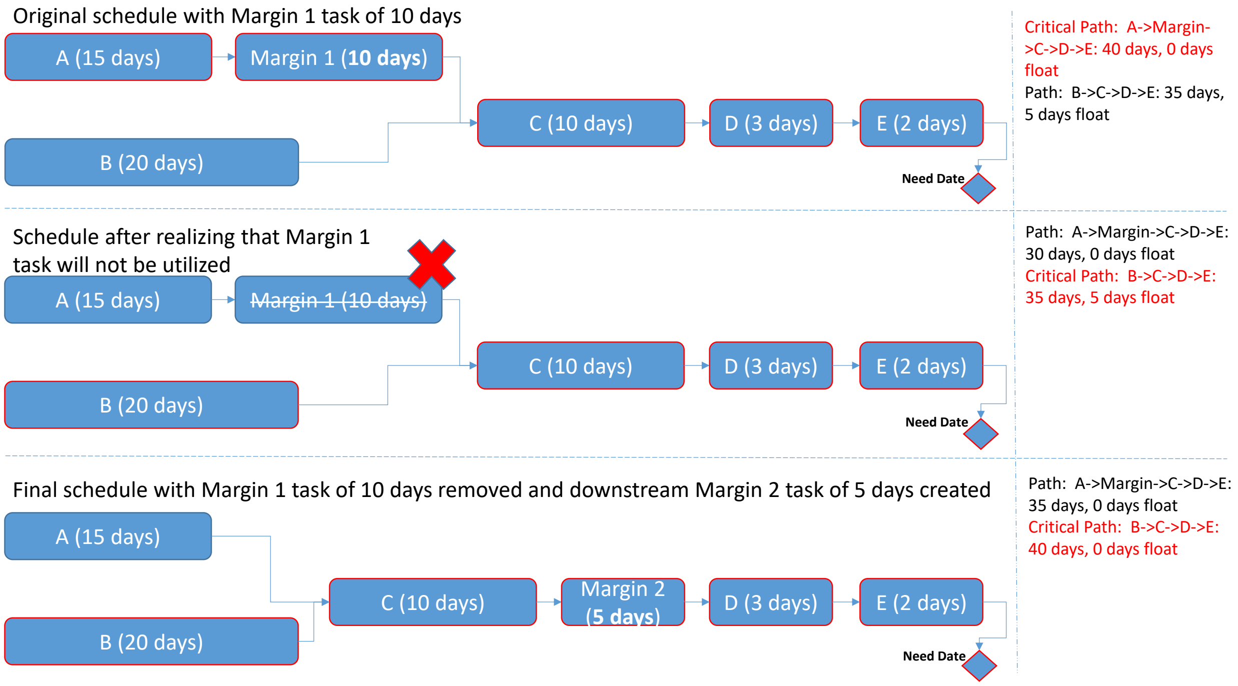


Figure 7-51. An example of unused schedule margin being moved downstream in the schedule.

With the margin removed, it is obvious that the path with Activity B was the deterministic critical path, pre-margin allocation. This suggests that Activity A might have been a new technology that was "inherently riskier" (i.e., had greater uncertainty) than Activity B, indicating that it appeared on the probabilistic critical path and necessitated some allocation of margin. However, the uncertainty did not manifest itself and therefore the margin was not used. The path with Activity A was no longer critical and management could redistribute the margin throughout the schedule. With careful analysis, it became apparent that the schedule would only be able to recoup 5 days of margin "activity" due to the next most-critical path having only 5 days of float to the P/p need date. In other words, the P/p only ever had 5 days of effective margin because while there were 10 days of margin on the probabilistic critical path, the pre-margin-allocation deterministic critical path had only 5 days of float to the P/p's need date. This simple example illustrates how critical path analysis on the deterministic and probabilistic critical paths aids in determining how much margin can be adequately accommodated at various points within the schedule, as well as how much effective margin the schedule is actually carrying with respect to the P/p end/need date.

If the P/p encounters a situation where margin near the end of the schedule will not be needed to address risks or uncertainties and reallocation of the margin at this point in single-flow activity is not viable, then P/p management may need to explore more creative options. While not likely an option for most Space Flight P/ps, some P/ps may be able to move up the finish milestone (i.e., deliver earlier, launch earlier, etc.). Another option may be for P/p teams to focus on completing any outstanding documentation (i.e., waivers, approvals, signatures). Still other P/ps may decide to allow personnel some down time prior to launch activities, for example. Depending on how much margin is remaining and the particular constraints on the P/p, the PM may be able to explore opportunities for utilizing margin for purposes other than to address risks, such as adding back in previously descoped work, for example. Again, this assumes that there were “available resources” associated with the margin duration (even though margin has no specified scope or budget). P/p management would likely need to go through an approval process to use management reserve (dollars) to add in new work.

Managing the Need for More Margin Than Is Available

At any point in the life cycle, a P/p may need to consider what to do when *SRAs* indicate the need for more margin than the P/p schedule has the capacity to incorporate. When performing an *SRA*, if the risk-impacted finish milestone estimate moves past the planned completion date, then the schedule “slip” has a greater overall impact than the allotted margin duration can accommodate. This is reflected in a “low” confidence level associated with the P/p finish milestone date. Confidence level thresholds for routine *SRAs* should be determined during Planning and documented in the *SMP*.

If a P/p encounters low confidence level results prior to establishing and allocating margin (i.e., prior to baselining the schedule), the indication might be that there is not enough float to accommodate the needed margin to account for the potential uncertainty and risk impacts. The P/p should consider viable options for modifying the preliminary schedule to regain appropriate total float, and ultimately establish adequate margin. Should any “time now” (post-baseline) *SRA* results indicate a low confidence level or the need for margin in excess of what is planned to meet a higher confidence level, the P/p may need to consider similar schedule workarounds to “buy back” schedule margin.

Possibilities for replanning primary critical path elements (and near-critical path elements, as needed) may include looking at restructuring workflows to include parallel paths or alternate logic, combining tests, adding resources, expediting procurements by paying a premium, etc. The goal should be to develop an achievable, risk-informed schedule that provides the needed margin. Schedule workarounds, as described in Section 7.3.5.1, may take into account viable schedule compression techniques for activities along the critical path, such as performing tasks in parallel (fast tracking), adding resources (crashing), or utilizing other replanning methods to capture recovery or new technical approaches. The P/p may be able to replan particular elements of the schedule to regain float (and ultimately margin), while still working to the planned end item finish date or P/p completion date, or rebaseline the entire schedule with a new P/p finish date to ensure a more realistic and achievable plan. However, the PM will need to weigh the potential addition of new risks to the P/p through these techniques. For example, performing work in parallel may add new risks to the P/p, whereas adding resources could be expensive. Taking these risks and uncertainties into account in an *SRA* on the hypothetical, “replanned” schedule and evaluating the resulting confidence level will help the PM to have a good grasp on whether the benefits outweigh the risks.

7.4 Exit Criteria

The Maintenance and Control sub-functions are continuous throughout the LCC for the P/p and is on a regularly scheduled cycle, often referenced as the “Business Rhythm.” A cycle is complete when:

- The performance review is complete
- If required, a replan event is initiated
- If required, a Rebaseline event is initiated
- If required, all schedule update Change Orders have been approved by the P/p management

7.5 Skills and Competencies Required for Schedule Maintenance and Control

The skills and competencies required for Schedule Maintenance and Control can be found on the SCoPe website.[160]

8 Schedule Documentation and Communication

It is a best practice for the schedule to be maintained and controlled according to the Schedule Management Plan and/or Schedule Control Plan. The *Schedule Documentation and Communication Plan* details how the P/p records and disseminates schedule information among team members, as well as other stakeholders, and helps decision makers determine whether the P/p's objectives and commitments are being met. Each Schedule Management sub-function discussed in previous chapters involves the generation of schedule information and required products at varying levels of maturity that must be properly documented and communicated throughout the P/p lifecycle.[161] This Documentation and Communication must take place with the appropriate personnel at the relevant time, using established CM/DM processes, as well as communication aids and tools that are consistent with the approach captured in the *SMP*.

Schedule Documentation and Communication ensure P/p schedule information is captured in such a way that it is useful for the management of a P/p and aids in decision making at all levels of the P/p, including stakeholder decisions. These two Schedule Management sub-functions, which are not only reliant upon the *Schedule Database* and the CM/DM processes, but also the baselining activity discussed in Chapter 7, facilitate subsequent management and control of content change. This rigor is necessary to ensure the intended meaning of P/p schedule information is not only steadfastly conveyed but also clearly received. Documentation and Communication are both an overarching linkage as well as a common thread woven into each sub-function of Schedule Management as reflected in Figure 8-1.

---

[160] SCoPe website, https://community.max.gov/x/9rjRYg

[161] NPR 7120.5 indicates specific states of maturity for documents and products per LCR requirements. Sections 3.5.2 (for Programs) and 4.5.2 (for projects) of the NASA Space Flight Program and Project Management Handbook discusses the varying levels of maturity for configuration-controlled documents/products by defining the following terms: preliminary, baseline, approve, and update.

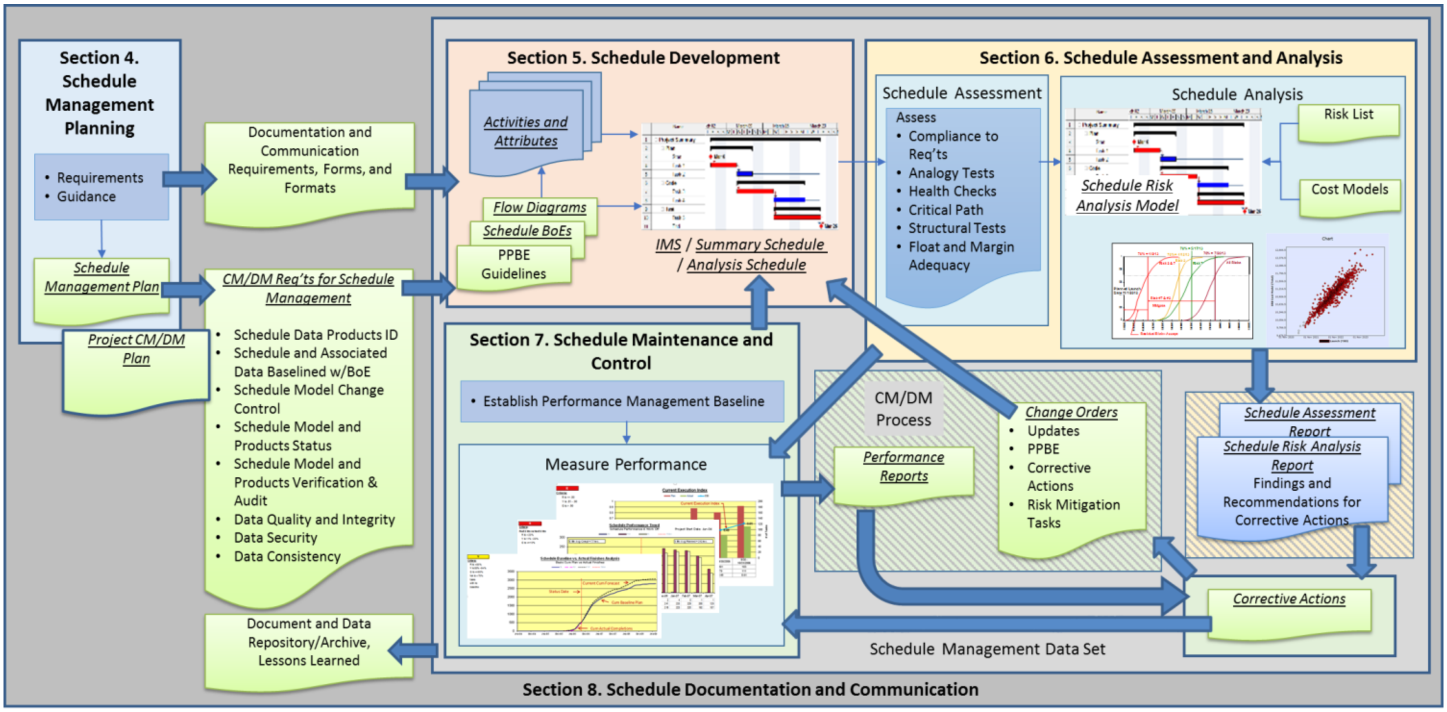


Figure 8-1. The Schedule Management Plan defines all of the forms, formats, templates and other figures used for communication, all of which must consistent and clearly marked, controlled and archived per the P/p's CM/DM plan.

Schedule Documentation and Communication are pillars of the overall Schedule Management function. Documentation and Communication begin at the onset of Schedule Management and continue throughout its life cycle. Well-defined tools, protocols, and formats for Schedule Management documented in the *Schedule Documentation and Communication Plan* must be established early in the P/p life cycle and developed in close coordination with the requirements of the *SMP* and *Schedule Database* to ensure processes, metrics, and data input/output are captured and conveyed in a manner that:

- Documents schedule information, including the *IMS* and *BoE* in a transparent and traceable manner
- Supports the evaluation of the baseline, changes, decisions, and the resulting impacts on the P/p and stakeholders
- Identifies, captures, and communicates impacts to multiple organizational units (i.e., cross-cutting decisions) enabling the coordination of Schedule Management efforts
- Enables consistent and repeatable reporting by each organizational unit to the sponsoring organization at the next higher level of the NASA hierarchy in a manner that allows the higher level organization to integrate that information into its own assessment to make informed decisions
- Ensures Schedule Management decisions and lessons learned, including their rationale, are captured as part of the organizational and institutional knowledge

8.1 Best Practices

Figure 6-5 details the best practices for Schedule Maintenance and Control.

SM.MC.1 Schedule Documentation and Communication Follows SMP	• The schedule is documented and communicated according to the Schedule Management Plan.
SM.DC.2 File Management System is Used for CM/DM of Schedule Information	• A systematic, structured, electronic file management system is used for configuration management/data management of schedule information.
SM.DC.3 Strategies, Plans, and Processes are Communicated to Stakeholders	• Schedule strategies, plans, and processes are routinely communicated with stakeholders.
SM.DC.4 Interface Tools Support the Schedule Information Delivery/Receipt	• Interface tools support the delivery/receipt of appropriate schedule information and data.
SM.DC.5 Reporting on Progress/Performance is Routinely Performed	• Reporting on schedule progress/performance is carried out on a routine basis, appropriate to the stakeholder's needs.
SM.DC.6 Plans/Products are Documented and Retrievable for LCRs	• All required plans and products are at the appropriate maturity and documented and retrievable in preparation for LCRs.
SM.DC.7 Formal Findings from LCRs and KDPs are Documented, with Progress Tracked and Products Updated	• Formal findings, recommendations, and actions from key P/p and life cycle reviews (LCRs) and Key Decision Points (KDPs) are documented, with progress against the recommendations and actions tracked, and products updated, as needed.
SM.DC.8 Reporting Formats and Templates are Developed	• Schedule reporting formats and templates are developed, which best align with and meet the needs of the P/p according to identified reporting forums.
SM.DC.9 Schedule is Routinely Backed Up	• The P/p schedule is routinely backed up throughout the P/p lifecycle, starting even before the schedule is baselined.
SM.DC.10 Schedule Performance, Assessment, and Analysis Data is Routinely Backed Up	• Schedule performance data, as well as assessment and analysis inputs, models, and results are routinely backed up for easy recovery, repeat analysis, and development of trends.
SM.DC.11 IMS Versions are Archived	• The original baseline IMS, any significant replan IMSs, all rebaseline IMSs, and as-built IMSs, along with schedule versions at each major life cycle review milestone are the minimum for P/p schedule archives.
SM.DC.12 Schedule Narrative is Archived	• The narrative associated with the original baseline IMS any significant replan IMSs, all rebaseline IMSs, and as-built IMSs, along with schedule

	versions at each major life cycle review milestone are the included in P/p schedule archives.
SM.DC.13 Final Schedule (and Cost) Package is Documented and Archived	• A schedule (and cost) data package associated with the original baseline IMS, any significant replan IMSs, all rebaseline IMSs, and as-built IMSs, along with schedule versions at each major life cycle review milestone are documented and archived.
SM.DC.14 Schedule Analysis is Archived	• Analysis input data, analysis models, and analysis results are formally archived throughout the P/p lifecycle for easy recovery, repeat analysis, and development of trends.
SM.DC.15 Schedule Lessons Learned are Routinely Developed and Archived	• P/p schedule management lessons learned are routinely developed and archived throughout the P/p life cycle, at a minimum at the end of each life cycle review milestone.

Figure 8-2. Schedule Documentation and Communication Best Practices.

8.2 Prerequisites

Schedule Documentation and Communication can be initiated when:

- P/p stakeholders are identified and understood
- P/p has identified P/p scope, including objectives, needs, and constraints
- The P/p WBS has been developed
- A P/p CM/DM process exists
- An initial draft of the *SMP* has been developed, including Schedule Communication and Documentation requirements
- For reporting, the *Schedule Database* is completely developed and populated with all initial (not necessarily 'baseline') data

8.3 Document and Communicate the Schedule

The Schedule Documentation sub-function details how the P/p records schedule information. Schedule Documentation utilizes the CM/DM process to ensure P/p events (intended and not), as well as decisions, are captured in such a way they are traceable, defensible, and repeatable. Schedule Documentation produces schedule information in a format that can be stored, catalogued, and accessed/retrieved when necessary.

The Schedule Communication sub-function details how the P/p disseminates schedule information among team members, as well as other stakeholders. Schedule Communication can be both written and oral. Schedule Communication allows for the information captured by the Schedule Documentation sub-function to be transferred in a useful format or variety of formats that aid in management and decision making. Communication strategies and reporting templates should be established very early in the P/p life cycle and structured to support various management briefings and decisions. Periodic schedule reporting is oftentimes a large component of Schedule Communication and is generated from the processes and procedures in Chapter 7.

Careful consideration should be taken to ensure P/p Schedule Documentation and Communication requirements are consistent with overall Schedule Management requirements levied by NPR 7120.5, NPR 7120.7, or NPR 7120.8, as appropriate, as well as the Schedule Management best practices defined in this handbook.

8.3.1 Configuration Management and Data Management (CM/DM) for Schedule Management

It is a best practice for a systematic, structured, electronic file management system to be used for configuration management/data management of schedule information. CM/DM is the PP&C function that is responsible for providing control of documentation, data, and technical characteristics of both configuration and non-configuration products for a P/p. As applied to programmatic work products, CM/DM is responsible for providing visibility into and controlling changes to performance, functionality, and physical characteristics and requirements. It is the backbone of Documentation and Communication and facilitates the capture, archive, and dissemination of information throughout the P/p life cycle, while maintaining the integrity and protection of data**.**

CM actually encompasses common naming conventions, data structure, consistent data coding, and change control to enhance the collection and analysis of data statistics. DM includes the control of data and information that is not usually identified within the configuration baseline and provides the control and release of data generated throughout the P/p's life cycle. Many proven CM/DM tactics involve creative file naming conventions that capture identifying attributes or recent changes made, not just version stamps. This allows for quick navigation through sets of similar files and enables straightforward "*time travel*" back to previous points from which the P/S or Schedule Analyst can retroactively depart. Regardless of the specific naming convention, file heredity should be apparent. An example used in many *ICSRA* analyses is shown in Figure 8-3.

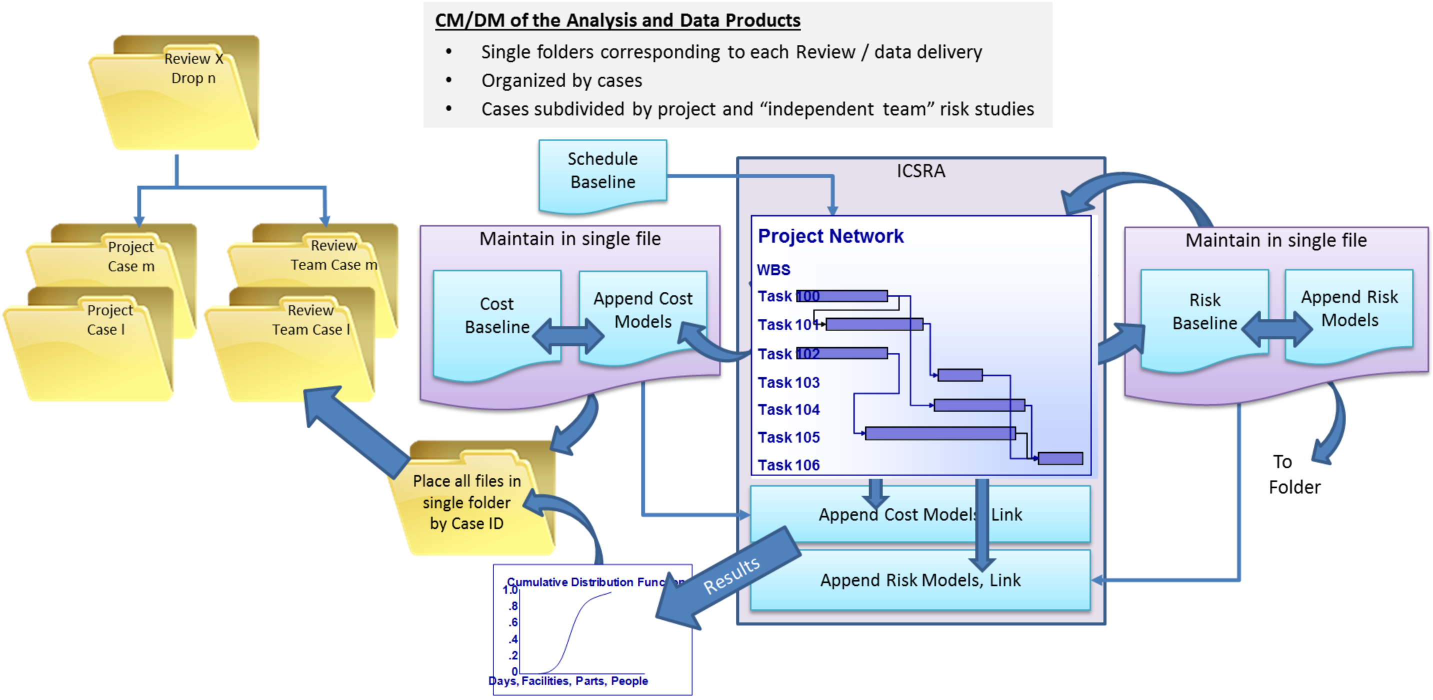


Figure 8-3. Schedule Documentation and Communication CM/DM.

By maintaining structure and discipline in the Schedule Management function, the quality of the data that can be mined and clearly understood will be improved, and the data will be more easily and quickly acquired thus supporting the consistent Schedule Documentation and Communication sub-functions. This includes data capture for all other Schedule Management sub-functions:

Schedule Management Planning. CM/DM helps to officially document the principles, processes, and best practices for how the schedule will be managed throughout the P/p life cycle, including the design, development, and implementation of all schedule management processes, tools, reporting forms, and formats, which are included in the *Schedule Management Plan* and Schedule Control Plan.

Schedule Development. CM/DM ensures the schedule is identified and documented in sufficient detail to support the P/p life cycle. Properly maintained records that detail the P/p *BoE*, initial logic, and major decision points of the P/p, as well as the thought process that went into creating the baselined schedule flow, are valuable not only to the P/S and P/p itself but also to the planning of future P/ps. Because the *BoE* is the backbone of the schedule data and information contained in the *Schedule Database*, its minimum standard calls for a collection of information necessary for an independent party to understand and reproduce the schedule estimate, according to the NASA Cost Estimating Handbook.[162] This can be accomplished by constructing an information packet (such as a file folder) that contains three critical ingredients: a primary narrative file, constituent data and information, and external references, all packaged together in a single location.

Schedule Assessment and Analysis. CM/DM applied over the life cycle of the schedule provides visibility and control of its performance, functional, and physical attributes. Perhaps the most important aspect of any schedule estimate's evolution is comprehensive documentation during the Assessment and Analysis sub-functions. *SRAs* and *ICSRAs*, which involve loading risk and/or cost into the *IMS* or *Analysis Schedule* are inherently iterative and can defy even the best Schedule Analyst's attempts at tracking the analysis maturation. Over the course of a P/p, as the Schedule Analyst modifies the preliminary or baseline models and creates what-if cases, an earnest configuration control effort is necessary for avoiding confusion, minimizing and tracing errors, and capturing key points of departure for P/p management and interested P/p staff (including the analyst him/herself upon revisiting the material in the near or long term). Ensuring the consistent capture of the models and associated data also facilitates the P/p's ability to develop and understand trending over time. Further, documentation of the *SRA/ICSRA* should always contain the actual model files themselves along with the schedule, risk, and cost baselines.

As an example, to fully explain a cost loading method associated with an *ICSRA* estimate, a Schedule Analyst may elect to maintain, alongside the models and baselines, an Excel workbook that illuminates the keywords included in each model version's file name within a change narrative, outlines a schematic of the cost-to-schedule mapping strategy, and if possible, contains the calculations themselves used to dissect the source cost estimate with the schedule in mind. The

---

[162] NASA Cost Estimating Handbook, Version 4.0. February 27, 2015. Appendix J. Page J-30. https://www.nasa.gov/sites/default/files/files/CEH_Appj.pdf

documentation can then be used as a contextual map that keeps an estimate cohesive and coherent throughout its initiation, maturation, and eventual finalization.

Schedule Maintenance and Control. Whereas change control addresses the management of the P/p, CM/DM addresses the management of the products. CM/DM is the practice of handling changes systematically so the schedule maintains its integrity over time, whether through routine status updates, internal or external replanning, or more formal rebaselining efforts. CM/DM implements the policies, procedures, techniques, and tools that evaluate and manage proposed changes, track the status of changes, and maintain an inventory of schedule support documents as the schedule changes. The CM/DM process facilitates orderly management of the schedule, including schedule changes for such beneficial purposes as to revise workflow logic, improve performance, or reduce risk. CM/DM allows P/p management to track requirements throughout the life cycle through acceptance and operations and maintenance. As changes inevitably occur in the requirements and design, they must be approved and documented, creating an accurate record of the system status and resulting changes to schedule tasks, durations, and logical linkages.

Another important factor in CM/DM is records retention. P/ps are required to comply with NPR 1441.1 and NASA Record Retention Schedule (NRRS) 1441, which describe NASA's records process and retention schedules, respectively.[163] Storage of the data needs to be compliant with the established procedures, and the appropriate level of security safeguards needs to be maintained. While the Configuration Manager is ultimately responsible for ensuring authoritative data is collected through a single authoritative source, the P/S should work with the Configuration Manager and the PM to help identify both the data required to be collected, as well as the authoritative source for each Schedule Management data product. The Configuration Manager should inform the PM and the P/S when authorized parties are provided access to Schedule Management data according to pre-determined plans and agreements.

8.3.2 Reporting

Clear communications build credibility with P/p stakeholders.[164] Schedule reporting is the dissemination of meaningful information about the schedule's overall status, progress to date, and forecast to complete. Schedule reporting helps determine if the P/p's objectives are being met. Various levels of schedule reporting may be required depending on specific stakeholder needs. It is important to note that all levels of schedule reporting should be provided from a single, integrated ***Schedule Database*** and not from separate schedule sources. The basic assertion that all WBS elements must report to the same depth or level of detail is not a valid assumption. Even at the P/p level, schedule reporting will vary based on the level of PM interest in the elements contained in the P/p schedule. Higher volume (dollars or hours) or critical/risk activities may require more granularity in detailed reporting, while lower volume, non-critical/risk, or level-of-effort tasks may require only summary-level reporting. In today's

---

[163] NASA Records Management is applicable to the Schedule Management Function per NPR 1441.1, NASA Records Management Program Requirements and NRRS 1441.1, NASA Records Retention Schedules. https://www.nasa.gov/content/nasa-records-management

[164] PMI. Practice Standard for Scheduling. Second Edition. Page 39.

P/ps, where resources are pushed to the limit, having appropriate flexibility in reporting requirements is a valid approach. P/p schedule reporting and communication requirements are captured in the *SMP*.

8.3.2.1 Communication Strategies

It is a best practice schedule strategies, plans, and processes to be routinely communicate with stakeholders (e.g., P/p management, technical leads/CAMs, other programmatic functions, contractors, and external partners). Schedule Communication helps determine if the P/p's objectives are being met from both the perspective of the P/S and/or Schedule Analyst (initial sender of the message) and of the P/p management and stakeholders (initial receiver of the message). Documentation should be a foundation of the communication (makes it repeatable, traceable, and defensible). Standardized communication aids should be developed with the information needs of the decisions they support in mind. If the method of communication is too wordy or too lengthy, it may be misunderstood or ignored. Clear, short, familiar and consistent words and phrases should be used. Reporting templates and processes should be structured to support various management communication (briefings, memos, presentations, etc.) and decisions.

Schedule Communication protocols should be negotiated among involved organizational levels and documented in the *SMP* as discussed in Section 4.3. This includes scheduled periodic reporting of schedule information, to various levels of stakeholders, as well as protocols for reporting in response to triggers such as the exceedance of a pre-determined threshold. The communication involved in Schedule Management may often have many potential dimensions that need to be considered, including but not limited to:

- Internal (within the P/p) vs. external (customers, vendors, contractors, other P/ps, organizations, the public);
- Formal (reports, minutes, briefings) vs. informal (emails, memos, ad-hoc discussions);
- Vertical (up and out, down and in) vs. horizontal (between teammates and peers);
- Official (newsletters, annual report) vs. unofficial (off-the-record communications); and
- Written vs. oral content, as well as verbal (voice inflections) and nonverbal (body language).[165]

Figure 8-4 is an example illustration of the *Schedule Documentation and Communication Plan* components that should be established during Schedule Management Planning. The P/p must decide which products flow in those channels and make plans to produce them. The following sections recommend various types of communication strategies and schedule reporting formats that will prove useful in managing a P/p.

---

[165] PMI. PMBOK, Fifth Edition. ANSI/PMI 99-001-2013. 2013. Page 287.

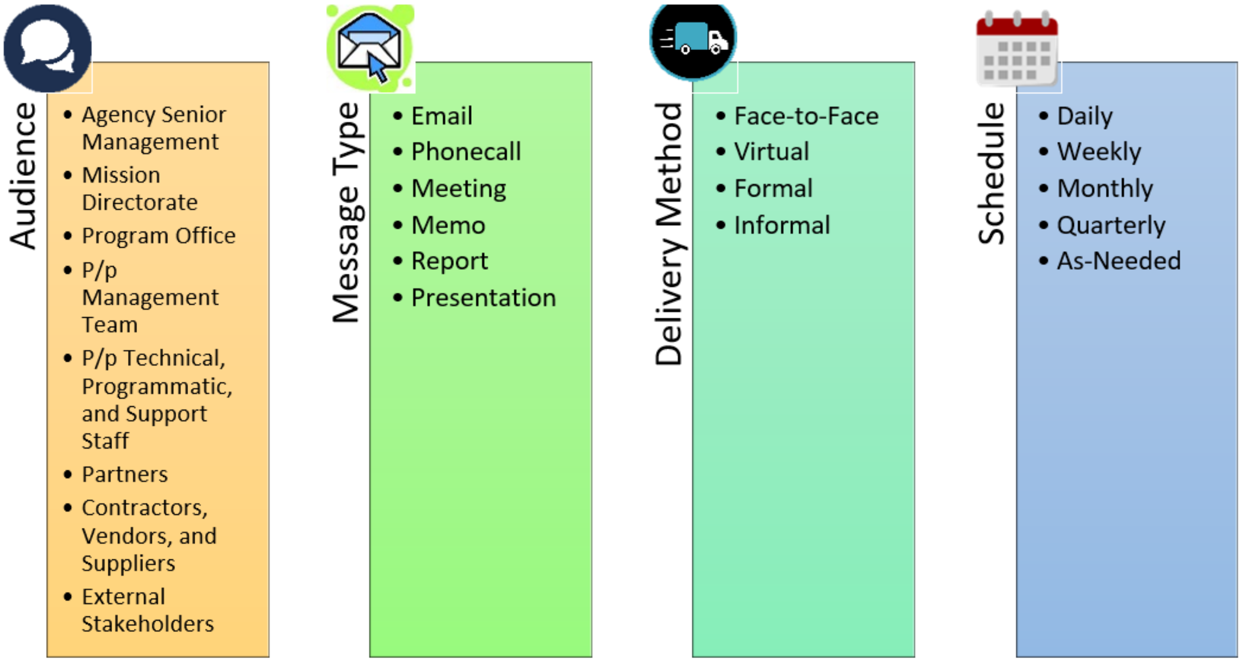


Figure 8-4. The Schedule Documentation and Communication Plan must consider the different needs of all interested parties.

8.3.2.2 Data Interface Tools and Techniques

It is a best practice for interface tools to support the delivery/receipt of appropriate schedule information and data. It is important that all selected Schedule Management tools and techniques properly function and interface with other selected P/p management and analysis tools and techniques in order to document and communicate the appropriate data and schedule outputs/reports. These outputs/reports must be consistent across the P/p and contain a clear, visible lexicon used within each report, as well as meet all P/p requirements for CM/DM. There are many different scheduling, schedule assessment, and schedule analysis tools in use across the Agency, each having different output, reporting, and communication capabilities. Whether these tools are imposed upon or selected by each P/p, the P/ps should establish schedule output formats and lexicon standards for use within their respective organizations to promote clear, uncomplicated communication. This is decided during Schedule Management Planning and documented in the *SMP*. A list of the more common tools used to support Schedule Management can be found on the SCoPe website.[166]

Contractor Reporting

To effectively integrate the contactor's schedule data into the P/p *IMS* It is imperative that a clear understanding exists between the government and contractors about the information necessary to be included as part of the baseline schedule, as described in Section 7.3.1.1. This includes details such as schedule content, level of detail, formats, reporting frequency, tools, thresholds, responsibilities, and controls. The P/S should coordinate with the responsible COTR to develop the schedule management and reporting requirements for applicable procurements. These requirements may be contained in the

---

[166] SCoPe website, https://community.max.gov/x/9rjRYg

contract SOW, the Contract Data Requirements List (CDRL), and/or the Data Requirements Document (DRD). The objective is to obtain the schedule information necessary to manage the *IMS* and enable informed decision making. This Handbook may be provided as guidance to contractors and subcontractors.

The SOW, CDRL, and DRD must provide clear requirements for contractors in the areas of scope content, deliverable expectations, and data requirements in order to avoid confusion during P/p implementation. The SOW, CDRL, and DRD should be structured in order to take maximum advantage of contractors' existing scheduling systems, capabilities, and formats, while still supporting NASA Schedule Management best practices. The contract SOW should clearly delineate the work and deliverables that are to be scheduled, the type of schedule products to be provided, the DRD to be followed, and any special considerations required for carrying out the contracted work. The CDRL is a listing of the technical information and reports required for a contract including submittal and approval criteria and instruction. The *IMS* DRD is a document that provides specific requirements for schedule content, level of detail, format, reporting frequency, applicable thresholds, and guidance for variance rationale. An example DRD for schedule deliverables can be found on the SCoPe website.[167]

External Partner Reporting

To effectively integrate the partner's schedule data into the P/p *IMS*, it is imperative that a clear understanding exists about the information necessary to be included as part of the baseline schedule, as described in Section 7.3.1.1. This includes details such as schedule content, level of detail, formats, reporting frequency, tools, thresholds, responsibilities, and controls. Just as NASA documents specify management and reporting requirements for prime contractors, the same must be established and agreed to with external partners. Schedule reporting requirements provided for partnerships between a P/p and other NASA Centers, research institutions, international partners, or other business arrangements not involving contracts or procurements should be incorporated into a Memorandum of Understanding (MOU), Space Act Agreement, Letter of Agreement (LOA), SOW, SMP, or other appropriate documents. This will enable the *IMS* to fulfill its intended function as an effective and efficient integrated P/p management tool.

MOU, LOA, and any other binding agreement with an external partner must provide clear specifics and/or guidance for the external partner in the areas of scope content, deliverable expectations, and data requirements so that minimal confusion arises during P/p implementation. Additionally, these documents must be structured in a manner that takes full advantage of their existing scheduling systems, capabilities, and formats, while still aligning with NASA Schedule Management best practices.

The external partner agreement should contain guidance for schedule management that clearly delineates what is to be scheduled, the type of schedules to be provided, the data requirements, and any special considerations required for carrying out the agreed to scope of work. The agreement should also document the specific P/p deliverables along with specific information on quantities, WBS relationship, due dates, delivery location, means of delivery, and any other pertinent guidance needed by the external partner. External partner agreements should also consider implications and impacts

---

[167] SCoPe website, https://community.max.gov/x/9rjRYg

resulting from regulations contained in the Federal Acquisition Regulations (FAR) and the International Traffic in Arms Regulations (ITAR). This approach will also serve to provide additional risk mitigation throughout the P/p life cycle.

8.3.2.3 P/p Reporting

P/ps are responsible for reporting the executability of all aspects of their P/p – programmatic and technical, along with major risks, mitigation strategies, and significant concerns – to the Decision Authority and other stakeholders through appropriate forums, such as P/p reviews. The processes for reporting on Schedule Management should be documented in the *SMP*. P/p reviews are essential elements of conducting, managing, evaluating, and approving P/ps, as well as an important part of NASA's system of checks and balances. These reviews are designed to provide the P/p with an opportunity to ensure that it has completed the work associated with the current phase. The P/p's approach for conducing reviews is documented in a P/p Review Plan.

Reporting should be performed consistent with the required products for a given P/p phase and the associated expected maturity of those products. Section 2.3 includes a table of required Schedule Management products throughout the P/p life cycle. For additional context on the expected maturity of the *IMS* in a given phase, see Section 5.5.6, Figure 5-15. Throughout the P/p life cycle, assumptions and status are routinely documented in the *BoE* for transparency and traceability of programmatic products to P/p requirements, including any approved changes.

8.3.2.3.1 Reporting for Internal Reviews

It is a best practice for reporting on schedule progress/performance to be performed on a routine basis, appropriate to the stakeholder's needs. Typically, the *IMS* is statused at least monthly to support routine P/p reporting, such as monthly status reviews and other internal reviews. However, the cadence of a P/p's routine reporting is dependent on the reporting level and may be P/p-specific. P/p's internal reviews help to establish and manage the progress against plans. Internal reviews can range from informal to formal, official to unofficial, and are often both written and oral. When necessary, P/p team members may also conduct informal "internal reviews" as a primary mechanism for internal P/p technical and programmatic control. The P/S should document any outcomes or changes in assumptions that arise from internal reviews.

For Space Flight P/ps, internal reviews are key components of the process used by P/ps to solidify their plans, technical approaches, and programmatic commitments and are part of the normal systems engineering work processes defined in NPR 7123.1, and are typically decisional meetings. These internal reviews are typically integrated discipline and mission phase reviews, which assess major technical and programmatic requirements along with the system design and other implementation plans. For both space flight and robotics P/ps, internal reviews are typically lower level system and subsystem reviews that precede LCRs. Major technical and programmatic performance metrics are reported and assessed against predictions.[168] The NASA Space Flight Program and Project Management Handbook provides extensive detail on the reporting needs of P/ps that adhere to NPR 7120.5 requirements.

---

[168] NASA/SP-2014-3705, NASA Space Flight Program and Project Management Handbook. Page 28, 35, 117.

For Research and Technology P/ps, PMs conduct internal P/p reviews as essential elements of conducting, managing, evaluating, and approving P/ps. These reviews help to establish and manage the progress against plans. These internal reviews are called Program Status Reviews (PSRs) for programs and Periodic Project Reviews (PPRs) for projects. More detail on PSRs and PPRs can be found in NPR 7120.8.[169]

8.3.2.3.2 Reporting in Preparation for LCRs/KDPs

It is a best practice for all required plans/products to be at the appropriate maturity and documented and retrievable in preparation for LCRs. P/p "life cycle" reviews are governed by NPR 7120.5 for Space Flight P/ps and NPR 7120.8 for Research and Technology P/ps. For Space Flight P/ps, these reviews generally include SRR, SDR/MDR, PDR, CDR, SIR, ORR, and PIR LCRs. For Research and Technology P/ps, these reviews generally include Authority to Proceed (ATP), Program Approval, Program Assessment Reviews (PARs) – *for Programs*, Continuation Assessments (CAs) – *for projects*, and Closeout.

Independent Assessments (IAs) are typically performed concurrent with the LCRs or other special reviews leading to KDPs. The appointed IA Team (e.g., Standing Review Board (SRB), Independent Review Team (IRT), etc.) provide a periodic assessment of the P/p's technical and programmatic status and health at key points in the life cycle using six criteria: alignment with and contribution to Agency strategic goals, adequacy of management approach, adequacy of technical approach, adequacy of the integrated cost and schedule estimates and funding strategy, adequacy and availability of resources other than budget, and adequacy of the risk management approach.

In order to provide the assessment, the IA Team will need access to variety of P/p documentation and data as defined in the corresponding NPRs (e.g., 7120.5, 7120.8, 7123.1, 8000.4, etc.) and handbooks (e.g., SRB Handbook, SOPI, etc.) that govern the review process and assessment criteria. For example, for Space Flight P/ps, NPR 7120.5 includes a list of P/p plans and products and associated maturity required by phase in support of each life cycle review milestone.[170] The SRB Handbook provides guidance on: what the maturity expectations are of the P/p data delivered to the SRB to support the life cycle review, including the programmatic assessment; when the P/p should deliver the data prior to the LCR; when the SRB will report its assessment after the LCR; and how to interface with Centers, Mission Directorates, and Management Councils for briefing the final results.[171]

Because the PM is responsible for planning and conducting the LCR, the P/S will likely be tasked with ensuring all required Schedule Management documentation and data products are up-to-date, consistent, and available to support the LCR. It is important that the P/S work with the programmatic assessors on the IA Team to ensure a streamlined data retrieval and communication process.

Per the Standard Operating Procedure Instruction (SOPI) 6.0 on the SRB Programmatic Process, "data drops" are defined to ensure the P/p programmatic products are available to the SRB's Programmatic

---

[169] NPR 7120.8A. NASA Research and Technology Program and Project Management Requirements. Effective Date: September 14, 2018. Expiration Date: September 14, 2023.

[170] NPR 7120.5E. NASA Space Flight Program and Project Management Requirements. Effective Date: August 14, 2012. Expiration Date: August 14, 2020. Appendix I.

[171] NASA Standing Review Board Handbook. Rev B. December 2016. https://nodis3.gsfc.nasa.gov/OCE_docs/OCE_5.pdf

Team in sufficient time to perform the programmatic portion of the IA prior to the LCR.[172] The Terms of Reference (ToR) document defines the scheduling of and content required for the data drops and is negotiated between the P/p, Program Office, and SRB prior to the initial data access milestone. To ensure adequate time for the SRB Programmatic Team to become familiar with the P/p's programmatic products, three programmatic data drops are defined:

- **Data Access:** P/p provides access to required repositories for the LCR and overview documentation (e.g., P/p Plan, WBS Dictionary, latest monthly status briefing) to assist the SRB Programmatic Team in understanding the P/p prior to the beginning of the LCR
- **Data Drop 1:** P/p provides preliminary required programmatic LCR products
- **Data Drop 2:** P/p provides final required programmatic LCR products

Reporting the results of any analysis necessary to support an LCR/KDP will always be specific to the P/p's requirements for the analysis. Furthermore, reporting will vary depending on the audience. For example, the P/p will want more information and details than an external reviewer or the stakeholders. However, it is a recommended practice for the Schedule Analyst to document the analysis results using the following outline. From that report, adjustments and extracts can be made for the different levels of reporting.

- Requirements for the analysis and date
- Overview of the analysis plan
- Brief or references to the technical baseline
- Specification of the technical, cost, schedule and risk products used in the analysis
- Overview of the models
- Test and verification of the models, results of any peer reviews
- Baseline results
- Sensitivity studies
- Conclusions
- Recommendations

8.3.2.3.3 Reporting Responses to Findings, Recommendations, and Actions from LCRs/KDPs

It is a best practice for formal findings, recommendations, and actions from key P/p and life cycle reviews (LCRs) and Key Decision Points (KDPs) to be documented, progress against the recommendations and actions tracked, and products updated, as needed. LCRs provide the P/p and NASA's senior management with a credible, objective assessment of the P/p's progress, issues, risks, and status. While participating in an LCR, the IA team may submit Requests for Action (RFAs). The P/p is

---

[172] OCFO-SID-0002. NASA Standard Operating Procedure Instruction (SOPI) 6.0. Release Date: May 23, 2017. https://www.nasa.gov/sites/default/files/atoms/files/sopi_6.0_final.pdf

responsible for the tracking, disposition, and closure of the RFAs. The IA team is also responsible for providing findings (strengths and weaknesses) and recommendations. The P/S will be involved in the response to and closure of any RFAs, findings, or recommendations that impact Schedule Management processes or the schedule baseline. An LCR is complete when the governing Decision Authority makes his or her decision to authorize a P/p to continue down the life cycle.

In some instances, LCRs are followed by KDPs. KDPs conclude the LCR at the end of the life cycle phase and serve as gates through which P/ps must pass to proceed to the next life cycle phase. The KDP occurs once the P/p and IA team report out to the governing Program Management Council (PMC), including the Decision Authority. The Decision Authority is the Agency individual who is responsible for making the KDP determination on whether or how a P/p proceeds through the life cycle and for authorizing the key P/p cost, schedule, and content parameters that govern the remaining life cycle activities.[173] The Decision Authority completes its assessment of the information presented during the applicable PMC (e.g., presentations by the P/p, Program Office, Mission Directorate, and IA Team, etc.), determines whether or how the P/p proceeds into the next phase and approves any caveats or additional actions (including responsible parties and due dates). These decisions are summarized and recorded in the Decision Memorandum (i.e., “Decision Memo”) signed at the conclusion of the governing PMC by all parties with supporting responsibilities.[174]

The purpose of the Decision Memo is to ensure that major decisions and their basis are clearly documented and become part of the retrievable records. Once signed, the Decision Memo is appended to the P/p FAD or P/p Plan, as appropriate. The programmatic content of the Decision Memo depends on whether the P/p is in Formulation or Implementation as follows:

- **Decision Memo during Formulation.** Documents key parameters related to work to be accomplished during each phase of Formulation. It also documents a target LCC range (and schedule range, if applicable) that the Decision Authority determines is reasonable to accomplish the P/p. For projects at KDP B, a more refined LCC range is developed.
- **Decision Memo during Implementation.** Documents the parameters for the entire P/p life cycle. At this point, the approved P/p LCC is no longer documented as a range but instead as a single number. The LCC includes all costs, including all Unallocated Future Expenses (UFE) and funded schedule margins, for development through prime mission operation to disposal, excluding extended operations. The ABC, which forms the official P/p baseline, is established as part of the KDP C approval and documented in the Decision Memo.

The Decision Memo also describes the constraints and parameters within which the Agency and the PM will operate (i.e., costs, schedules, or MA – *if applicable*, and key deliverables), the extent to which changes in plans may be made without additional approval, and any additional actions from the KDP. The MA forms the foundation for P/p execution and performance measurements. The MA is typically

---

[173] NASA/SP-2014-3705, NASA Space Flight Program and Project Management Handbook. Pages 9-11. https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20150000400.pdf

[174] NASA Space Flight Program and Project Management Requirements. Effective Date: August 14, 2012. Expiration Date: August 14, 2020. Page 39.

viewed as a contract between the Agency and the PM. The PM has the authority to manage within the MA and is accountable for compliance with the terms of the agreement. As the P/p matures, the need for any changes to the MA require renegotiation and approval from the Decision Authority. For instance, rebaseline reviews are conducted when the Decision Authority determines the ABC, and as a result the MA, needs to be changed. The MA and ABC are further defined in Section 7.3.4. At the Agency level, the Decision Memo is maintained by the OCFO's Strategic Investments Division (SID).

The potential outcomes at a KDP, as documented in the Decision Memo, include approval or disapproval to enter the next P/p phase, with or without actions for follow-up activities as follows:

- Approval to enter the next program phase, with or without actions
- Approval to enter the next phase, pending resolution of actions
- Disapproval for continuation to the next phase. In such cases, follow-up actions may include:
    - A request for more information and/or a follow-up review that addresses significant deficiencies identified as part of the life cycle review preceding the KDP
    - A request for a Termination Review
    - Direction to continue in the current phase
    - Redirection of the P/p

Working with P/p management, the P/S will use the decisions documented in the DM to facilitate any necessary revisions to the schedule baseline to support the ongoing maintenance and control of the schedule, as described in Section 7.3.

8.3.2.4 Report Types and Formats

It is a best practice for schedule reporting formats and templates to be developed, which best align with and meet the needs of the P/p according to identified reporting forums. Schedule Documentation should be easy to read and understand. Schedule Communication uses reporting formats and templates pre-determined from the *SMP* in the dissemination of meaningful information about the schedule's overall status, progress to date, and forecast to complete. Schedule reporting helps determine if the P/p's objectives are being met by communicating information in a structured way to ensure clear understanding by all stakeholders. It should also be noted the P/p schedule itself is a communication tool as well as a catalyst for communication. The following sections discuss the three types of schedule performance, as identified in Figure 8-5. These include: Status Reporting, Progress Reporting, and Forecasting. Each type of performance reporting includes different report formats and templates that will prove useful in managing a P/p schedule.

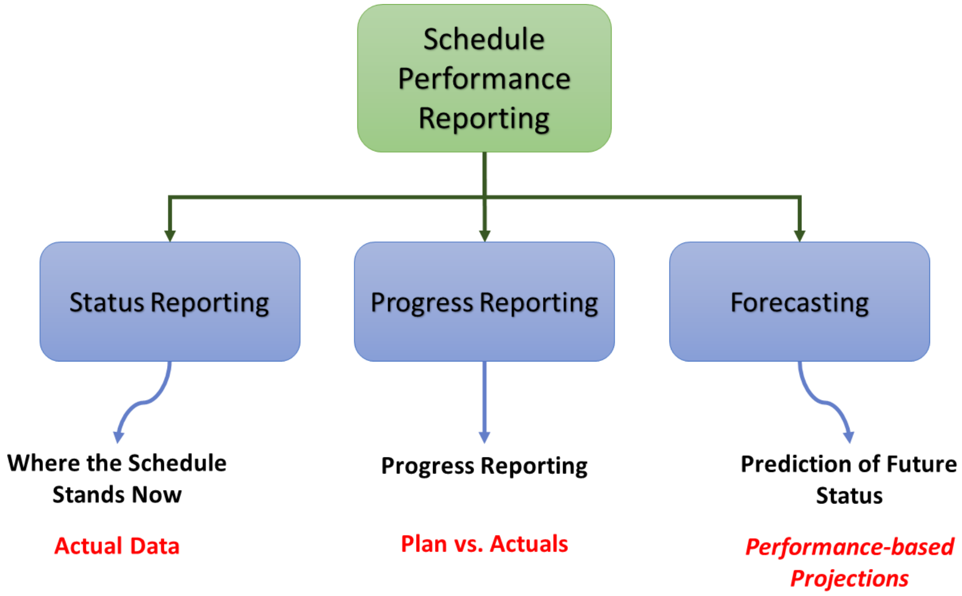


Figure 8-5. Schedule Performance Reporting can be broken down into three types: Status Reporting, Progress Reporting, and Forecasting.

8.3.2.4.1 Status Reporting: Where the Schedule Now Stands (Actual Data)

Schedule status reporting describes where the schedule now stands (i.e., actual data). This category of communication and reporting refers to a high-level snapshot in time and may include lists or graphical views of actual activity/milestone dates or activity/milestone counts, for example. It does not include any analysis of schedule metrics, trends, comparisons to previous versions, or forecast projections. Examples of status reports are described below.

Timeline Report

A *Timeline Report* is a high-level communication tool, primarily used within Programs because they can show a portfolio of project schedules according to a specified timeline. *Timeline Reports* are often accompanied by project-specific narrative to provide additional insight regarding the status of each project. Figure 8-6 and Figure 8-7 show examples of Program *Timeline Reports*.

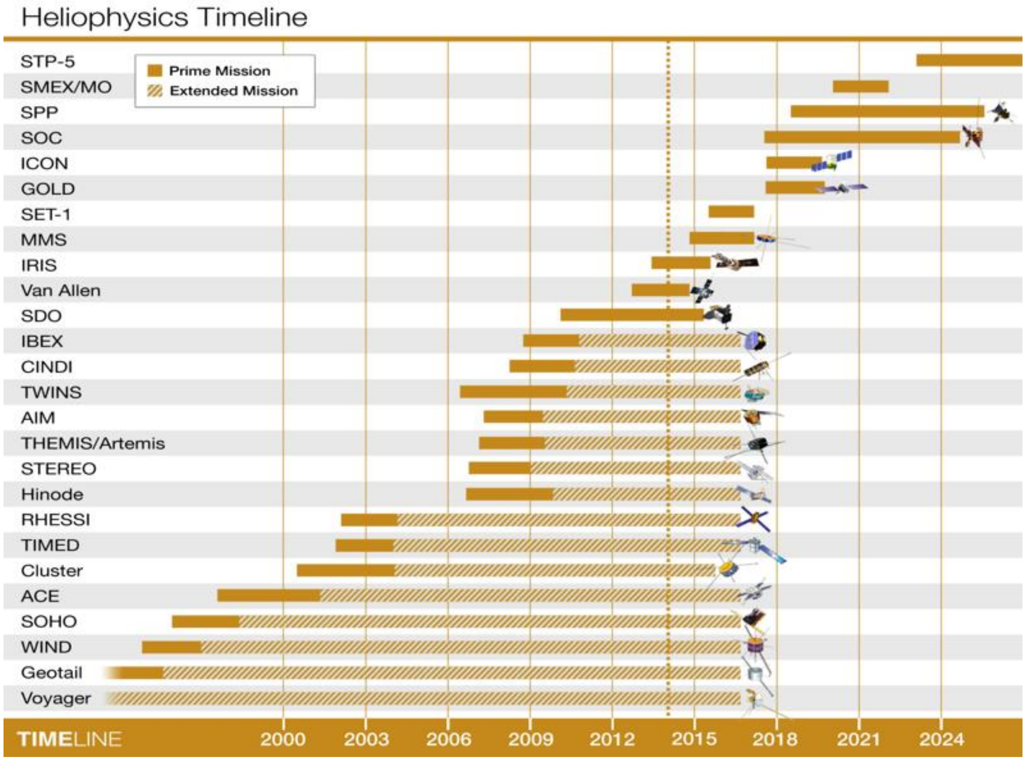


Figure 8-6. A Timeline Report showing the status of a Program's missions, including projects in development and operations.

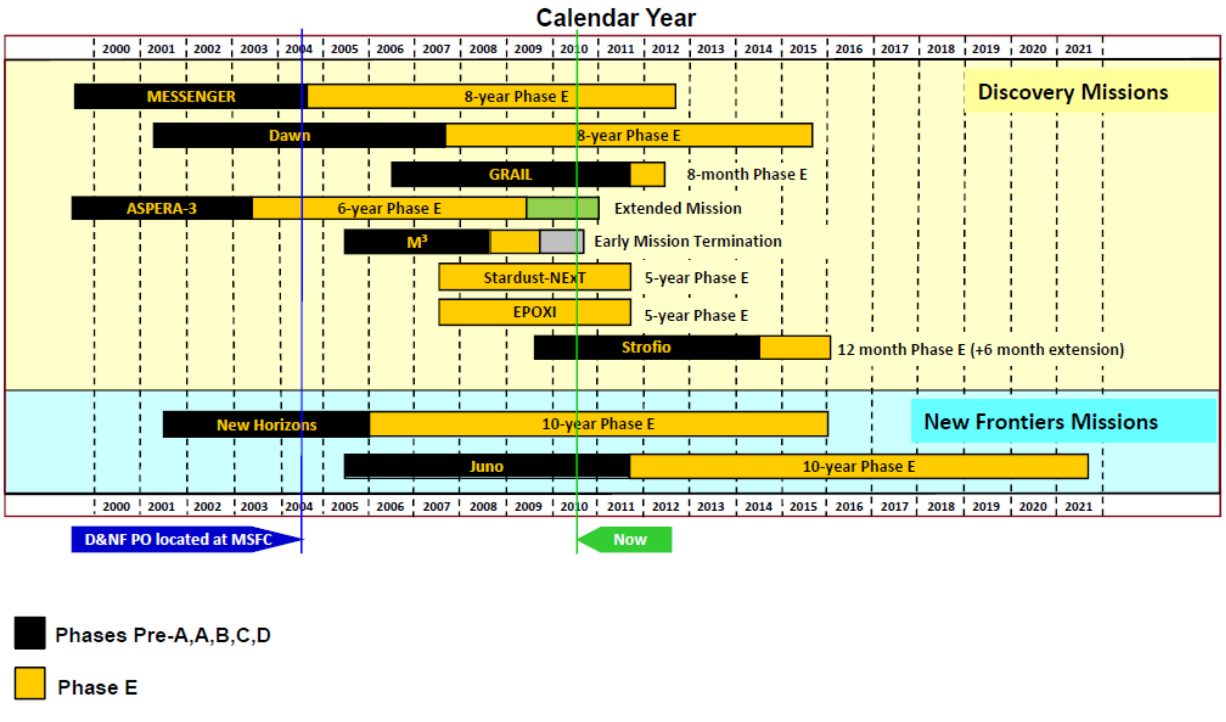
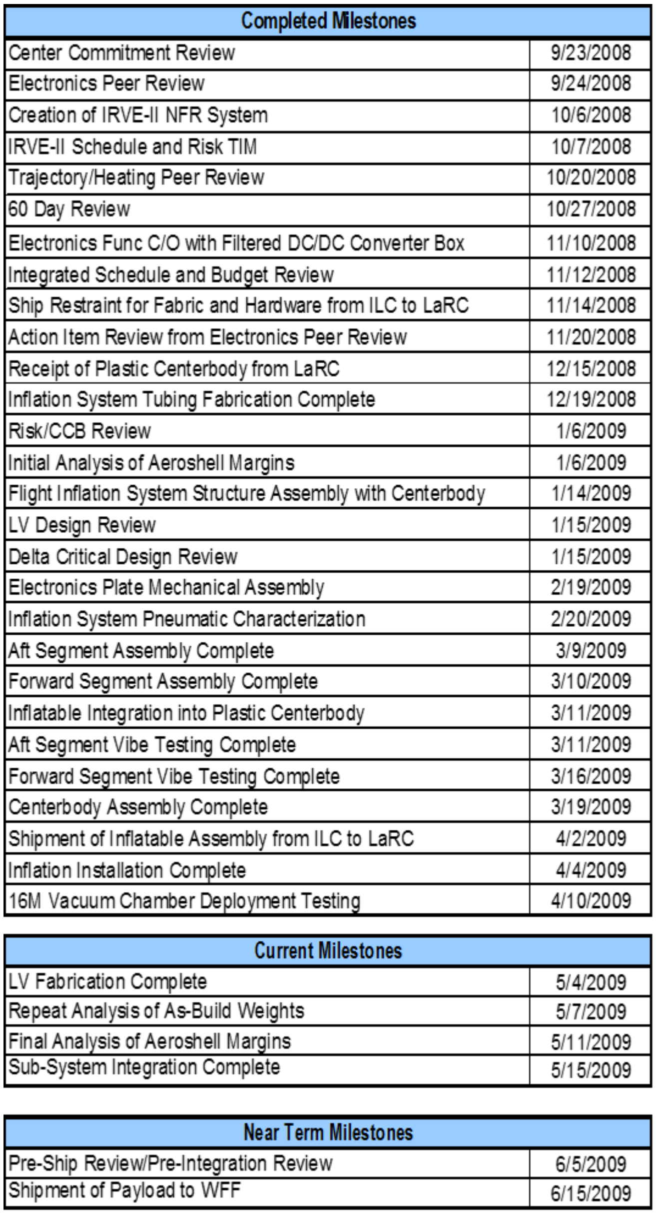


Figure 8-7. A Timeline Report showing the status of a Program's "current" missions.

Milestone Status Report

A *Milestone Status Report* focuses on significant events scheduled to occur at specific times in the P/p. Such events could be the initiation or completion of a particularly important or critical activity, equipment deliveries, reviews, or approval dates. A *Milestone Status Report* typically provides status on key milestones as identified in the schedule baseline. However, at any given point in the P/p life cycle, additional milestones from the schedule may be added to the report for better management insight. Charts used for milestone status reporting are often simply a table of milestones completed and/or milestones to-go illustrated in Figure 8-8, as a list shown in Figure 8-9, or as a Gantt chart-type capture of milestones shown in Figure 8-11. Figure 8-11 shows a Program *Milestone Status Report* showing key milestones for the projects that make up the Program.

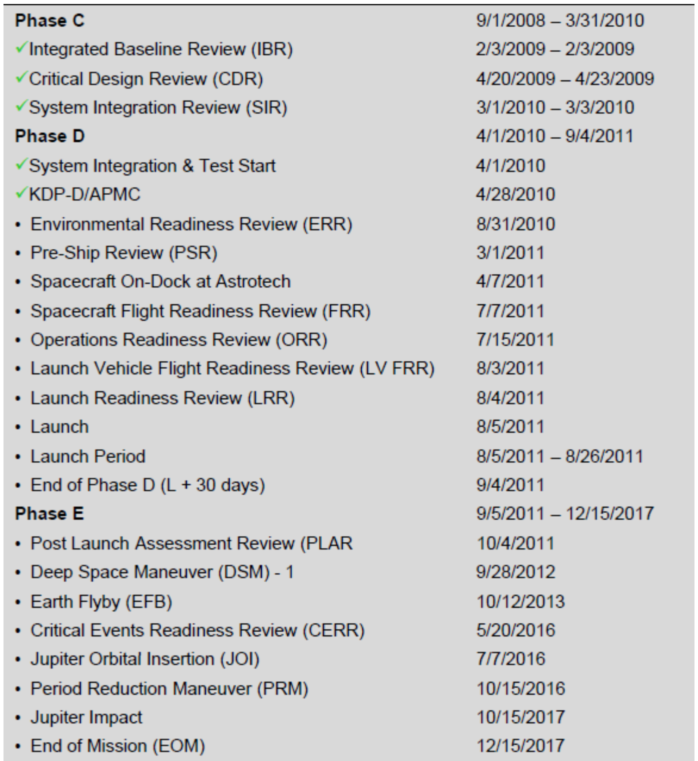


Completed Milestones	
Center Commitment Review	9/23/2008
Electronics Peer Review	9/24/2008
Creation of IRVE-II NFR System	10/6/2008
IRVE-II Schedule and Risk TIM	10/7/2008
Trajectory/Heating Peer Review	10/20/2008
60 Day Review	10/27/2008
Electronics Func C/O with Filtered DC/DC Converter Box	11/10/2008
Integrated Schedule and Budget Review	11/12/2008
Ship Restraint for Fabric and Hardware from ILC to LaRC	11/14/2008
Action Item Review from Electronics Peer Review	11/20/2008
Receipt of Plastic Centerbody from LaRC	12/15/2008
Inflation System Tubing Fabrication Complete	12/19/2008
Risk/CCB Review	1/6/2009
Initial Analysis of Aeroshell Margins	1/6/2009
Flight Inflation System Structure Assembly with Centerbody	1/14/2009
LV Design Review	1/15/2009
Delta Critical Design Review	1/15/2009
Electronics Plate Mechanical Assembly	2/19/2009
Inflation System Pneumatic Characterization	2/20/2009
Aft Segment Assembly Complete	3/9/2009
Forward Segment Assembly Complete	3/10/2009
Inflatable Integration into Plastic Centerbody	3/11/2009
Aft Segment Vibe Testing Complete	3/11/2009
Forward Segment Vibe Testing Complete	3/16/2009
Centerbody Assembly Complete	3/19/2009
Shipment of Inflatable Assembly from ILC to LaRC	4/2/2009
Inflation Installation Complete	4/4/2009
16M Vacuum Chamber Deployment Testing	4/10/2009

Current Milestones	
LV Fabrication Complete	5/4/2009
Repeat Analysis of As-Build Weights	5/7/2009
Final Analysis of Aeroshell Margins	5/11/2009
Sub-System Integration Complete	5/15/2009

Near Term Milestones	
Pre-Ship Review/Pre-Integration Review	6/5/2009
Shipment of Payload to WFF	6/15/2009

Figure 8-8. A Milestone Status Report, composed of a table showing completed, current, and near-term milestones.



Phase C	9/1/2008 – 3/31/2010
✓Integrated Baseline Review (IBR)	2/3/2009 – 2/3/2009
✓Critical Design Review (CDR)	4/20/2009 – 4/23/2009
✓System Integration Review (SIR)	3/1/2010 – 3/3/2010
Phase D	4/1/2010 – 9/4/2011
✓System Integration & Test Start	4/1/2010
✓KDP-D/APMC	4/28/2010
• Environmental Readiness Review (ERR)	8/31/2010
• Pre-Ship Review (PSR)	3/1/2011
• Spacecraft On-Dock at Astrotech	4/7/2011
• Spacecraft Flight Readiness Review (FRR)	7/7/2011
• Operations Readiness Review (ORR)	7/15/2011
• Launch Vehicle Flight Readiness Review (LV FRR)	8/3/2011
• Launch Readiness Review (LRR)	8/4/2011
• Launch	8/5/2011
• Launch Period	8/5/2011 – 8/26/2011
• End of Phase D (L + 30 days)	9/4/2011
Phase E	9/5/2011 – 12/15/2017
• Post Launch Assessment Review (PLAR	10/4/2011
• Deep Space Maneuver (DSM) - 1	9/28/2012
• Earth Flyby (EFB)	10/12/2013
• Critical Events Readiness Review (CERR)	5/20/2016
• Jupiter Orbital Insertion (JOI)	7/7/2016
• Period Reduction Maneuver (PRM)	10/15/2016
• Jupiter Impact	10/15/2017
• End of Mission (EOM)	12/15/2017

Figure 8-9. A Milestone Status Report composed of a list of completed and remaining milestones.

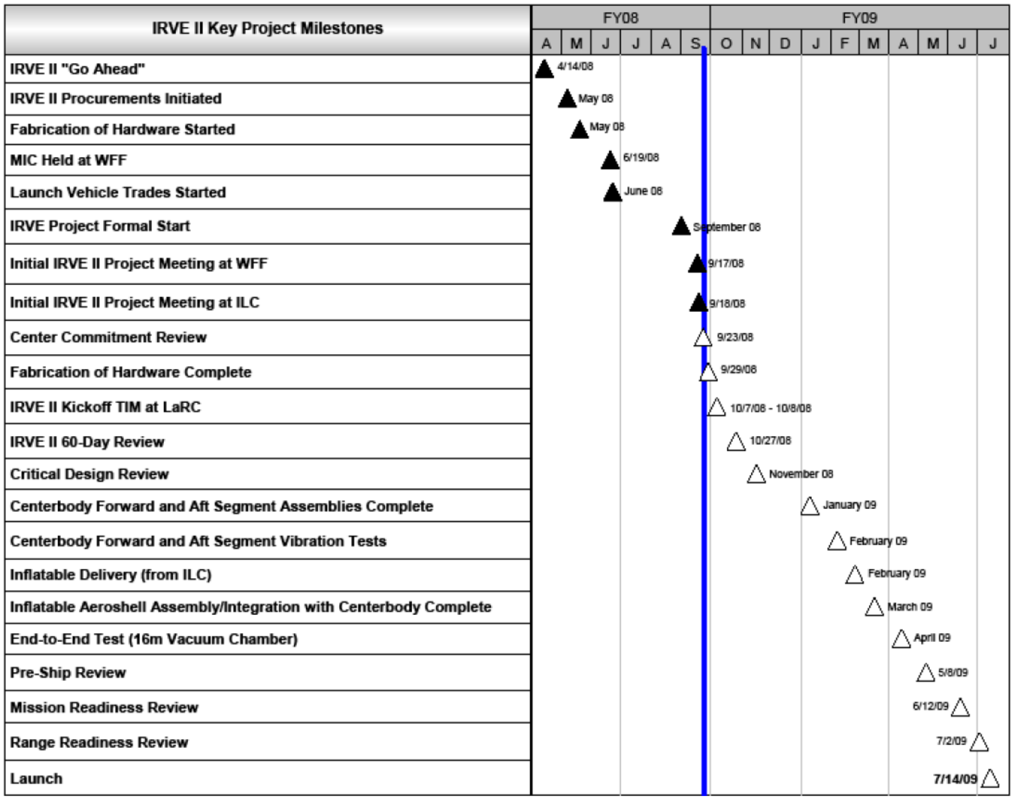


Figure 8-10. A Milestone Status Report composed of key project milestones.

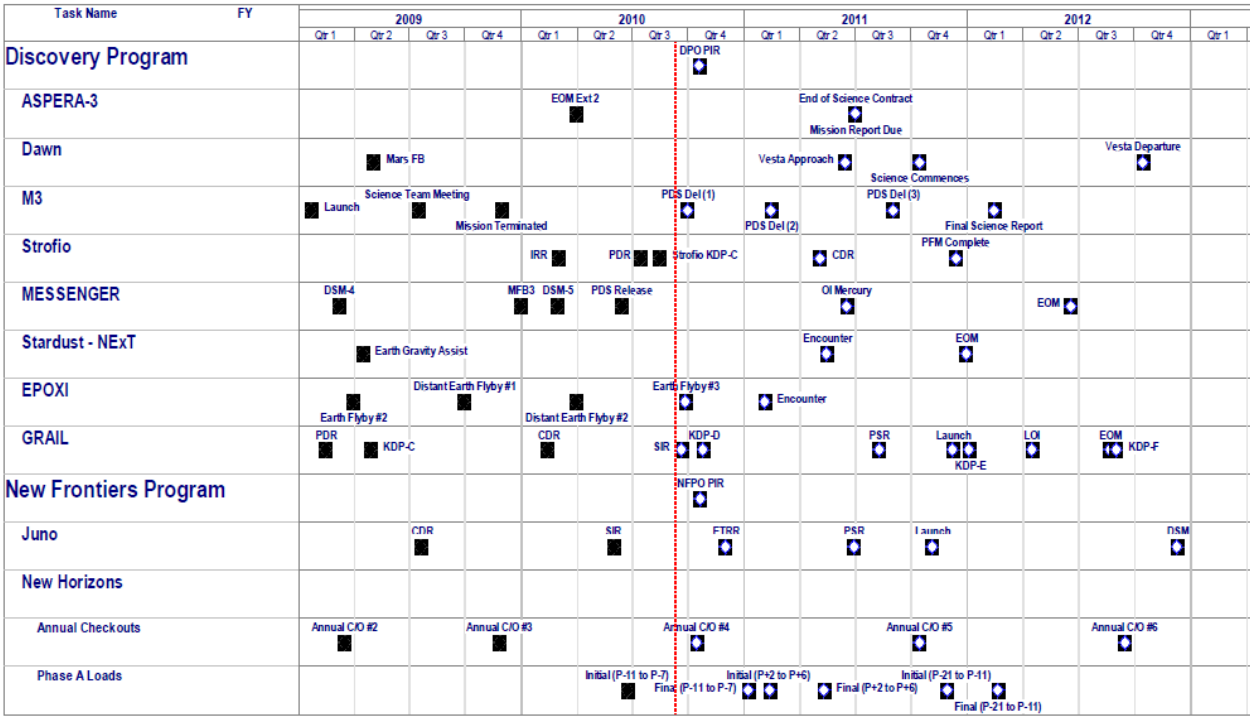


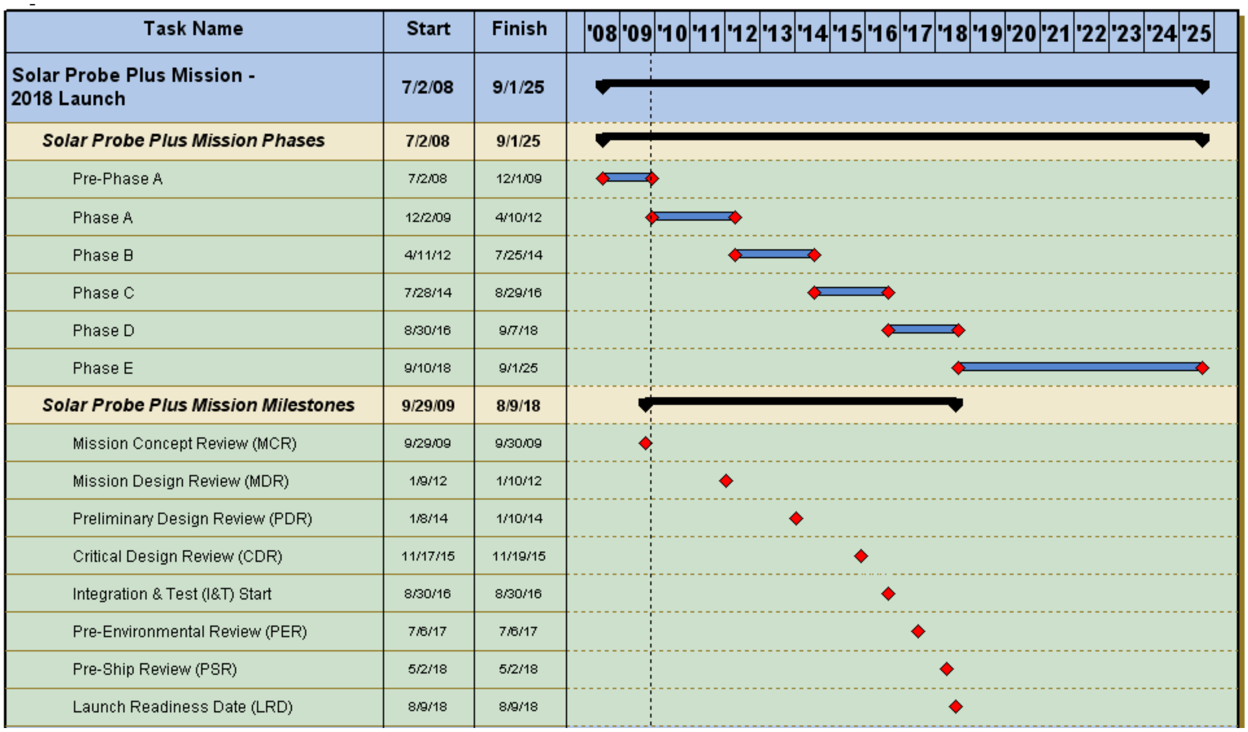
Figure 8-11. A Gantt-type Program-level Milestone Status Report showing the status of key milestones from each of the projects that make up the Program.

Summary Schedule Reports

A *Summary Schedule* is the most common type of P/p status report. This high-level report is typically used by management to keep informed on general P/p progress and issues and is typically utilized for a one-page slide in a management presentation. Since *Summary Schedules* provide a high-level summary view of the *IMS*, they are easier to communicate than other complicated charts made from long lists of tasks.

A *Summary Schedule* is composed of a Gantt chart, or horizontal bar chart, where the horizontal axis represents the total time span of the P/p broken down into increments of time (e.g., days, weeks, months, quarters, years, etc.), and horizontal bars of varying lengths represent the time span for each summary activity, which are placed along the axis to show the timing of events (i.e., start dates, end dates, and durations). Additional formatting of the bars may indicate summary activity progress. Key milestones are typically represented by diamonds (or triangles). A vertical line placed on the Gantt chart represents the report date. In its typical form, the Gantt chart does not show task dependencies, so it is impossible to tell how one task slipping may affect another task. Thus, it is not considered a forecasting report, but it instead shows a representation of the P/p's current status and current plan forward.

During Pre-Phase A, when not much detail is known about the P/p scope, a *Summary Schedule* may only include preliminary phase durations and estimated key milestone dates, as shown in Figure 8-12.



Task Name	Start	Finish
Solar Probe Plus Mission - 2018 Launch	**7/2/08**	**9/1/25**
Solar Probe Plus Mission Phases	**7/2/08**	**9/1/25**
Pre-Phase A	7/2/08	12/1/09
Phase A	12/2/09	4/10/12
Phase B	4/11/12	7/25/14
Phase C	7/28/14	8/29/16
Phase D	8/30/16	9/7/18
Phase E	9/10/18	9/1/25
Solar Probe Plus Mission Milestones	**9/29/09**	**8/9/18**
Mission Concept Review (MCR)	9/29/09	9/30/09
Mission Design Review (MDR)	1/9/12	1/10/12
Preliminary Design Review (PDR)	1/8/14	1/10/14
Critical Design Review (CDR)	11/17/15	11/19/15
Integration & Test (I&T) Start	8/30/16	8/30/16
Pre-Environmental Review (PER)	7/6/17	7/6/17
Pre-Ship Review (PSR)	5/2/18	5/2/18
Launch Readiness Date (LRD)	8/9/18	8/9/18

Figure 8-12. A Pre-Phase A Summary Schedule.

Once the P/p progresses past Pre-Phase A, the *Summary Schedule* should, at a minimum, identify all WBS elements and reflect all contract and controlled milestones, major development phases (i.e., design, fabrication, integration, assembly, etc.), clearly identifiable schedule margin, critical path(s) (at least primary, but recommended secondary and tertiary), and all end item deliveries. Figure 8-13 shows an example of a typical project *Summary Schedule*.

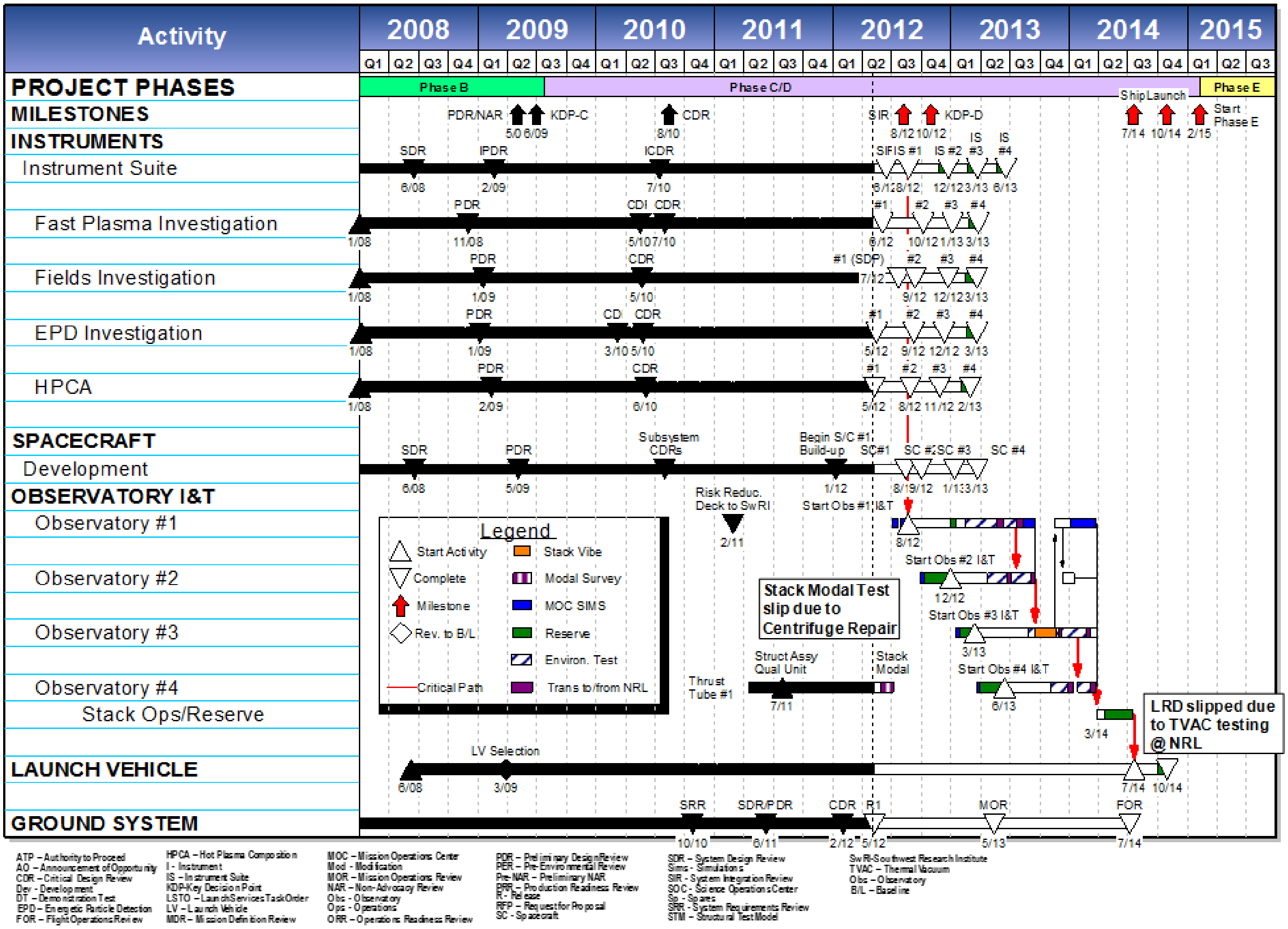


Figure 8-13. A typical Summary Schedule report with a legend, an acronym list, and callouts to highlight significant schedule slips.

As another example, Figure 8-14 shows a *Summary Schedule* with a separate "critical path margin" summary row, which allows for quicker identification of the margin along the critical path. A legend summarizing the total margin on each of the primary, secondary, and tertiary critical paths would also be a helpful addition to this report.

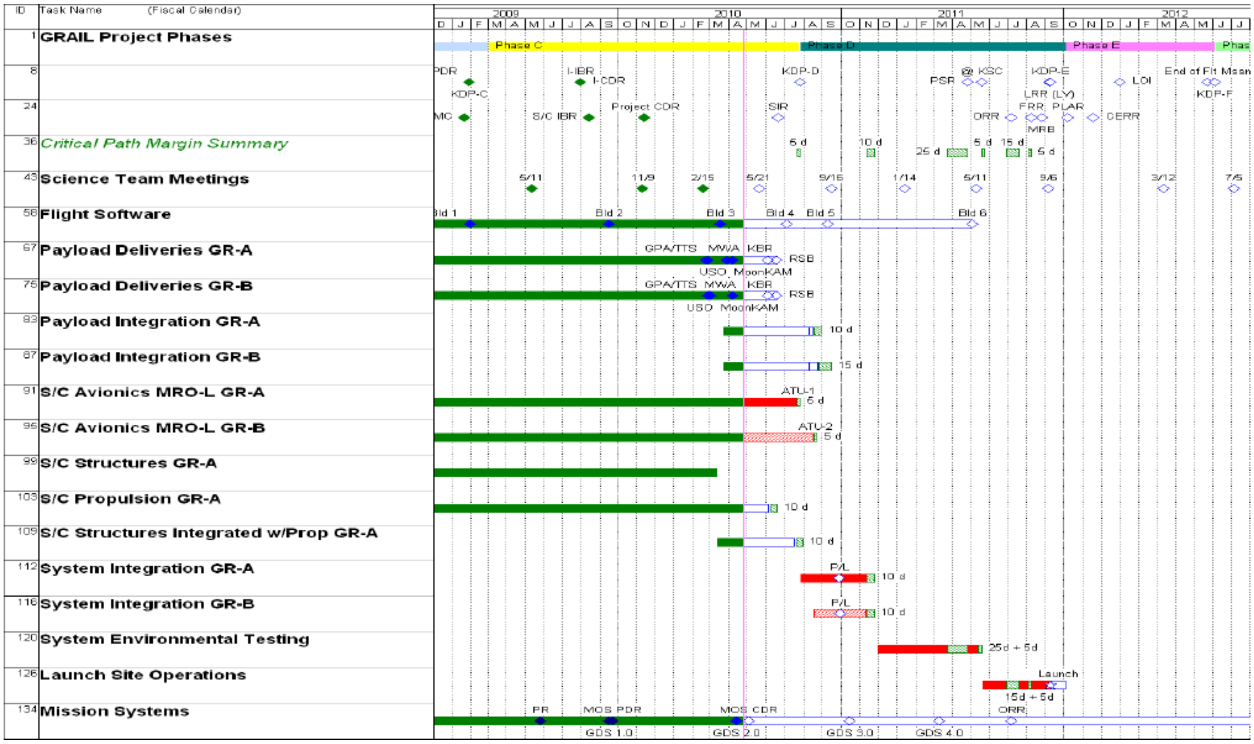


Figure 8-14. A Summary Schedule report with an added "critical path margin" summary row for easier traceability.

When the *Summary Schedule* reflects a summary *IMS* for the complete P/p, it is often referred to as a "Master Schedule". Whether representative of the complete *IMS* or not, the amount of detail contained in a *Summary Schedule* often depends on the level of insight the stakeholders need. While more detailed information, as shown in Figure 8-15 and Figure 8-16, may be appropriate for the PM, a simpler report, as shown above in Figure 8-13 may be more appropriate for senior management reviews.

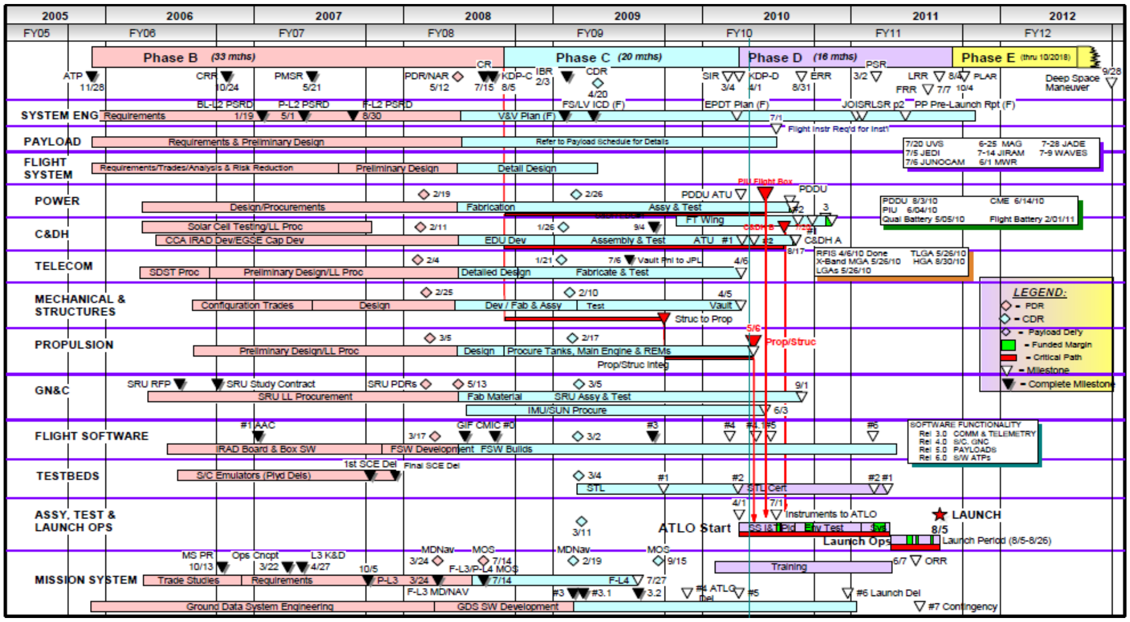


Figure 8-15. A Summary Schedule with a legend to help identify key milestones symbols and color coding.

Figure 8-16. A Summary Schedule used as a management tool to track key information for all project elements. While a source of immense information that may be helpful to the PM, it may be overwhelming for other stakeholders.

Summary Schedules may also be produced with a focus on a sub-project, subsystem, or instrument element of the schedule when the P/S needs to communicate with Technical Leads, or when the Technical Leads need to communicate with the PM, for example. A sub-project *Summary Schedule* is shown in Figure 8-17.

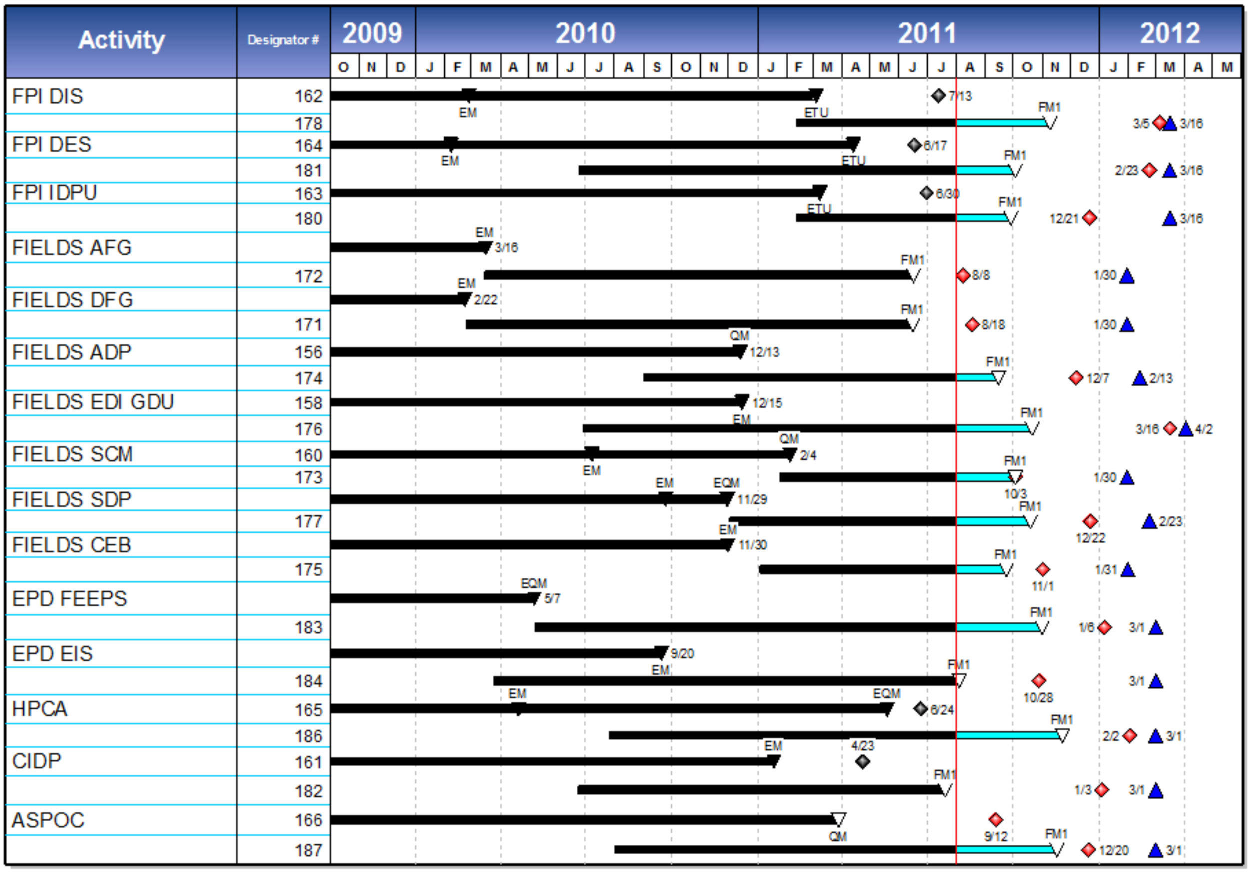


Figure 8-17. A sub-project Summary Schedule, which represents progress against sub-project key elements and milestones.

A *Summary Schedule* does not provide enough schedule detail for thorough schedule analysis. Thus, it is not intended for use as an analysis tool and is not an *IMS*; however, as it is a representation of the *IMS*, it should be traceable to the *IMS*.

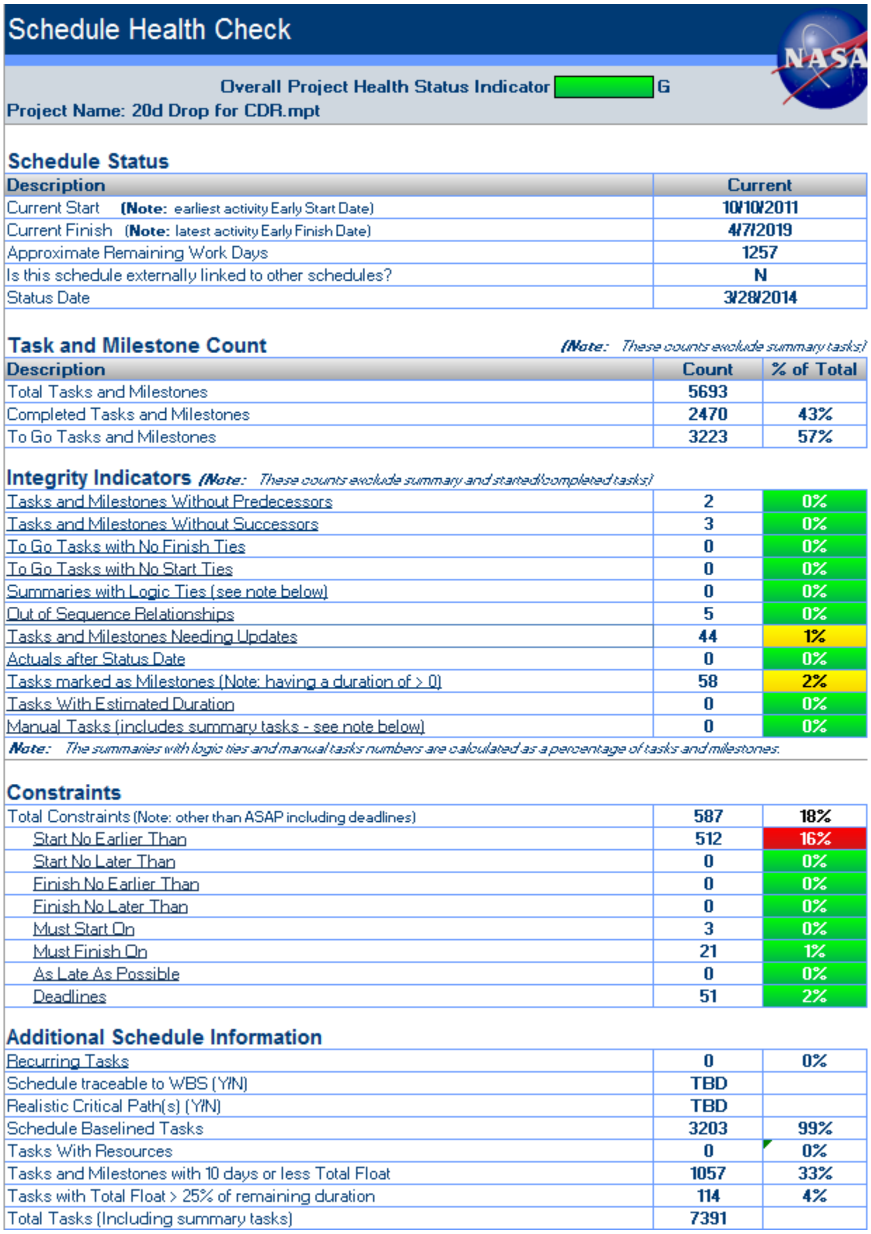
IMS Report

The *IMS* is the backbone for all Schedule Management reports, in that all schedule-related reports should be traceable to the *IMS*. The *IMS* is also used to facilitate any assessments and analysis that will aid in both routine Schedule Management, as well as senior-level management and PM decision making through various reporting forums, such as Center Management Councils (CMCs), Quarterly Status Reviews (QSRs), Monthly Status Reviews (MSRs), or other internal P/p reviews.

Project elements, such as subsystems, instruments, or sub-projects are typically required to deliver their schedules on a monthly basis to support the routine maintenance of the P/p *IMS*. There are also instances throughout the P/p life cycle, such as in preparation for LCRs, where the complete P/p *IMS* is a necessary “report” or required data product for the associated stakeholders, such as an SRB. A description of the *IMS* and its necessary contents for both Programs and projects is covered in Section 5.6.1. When the *IMS* serves as a reporting product, it should be provided in its native file format.

Health Check Report

A *Health Check Report* is a useful output of schedule health check tools. *Health Check Reports* facilitate the Schedule Maintenance sub-function because they enable effective communication between the P/S and the Technical Lead regarding activities and milestones that may require status updates. The example in Figure 8-18 and Figure 8-19 illustrate health check reports generated from different tools describing schedule status, such the number of activities with missing logic, hard constraints, negative float, number of lags/leads, etc. Most of the other health check metrics described in Section 6.2.2.1.2 can be represented through these types of Health Check reports. The health check tools generally provide a listing of the activities for each "count", so they can be further examined and updated or corrected, if necessary.



Schedule Health Check

Overall Project Health Status Indicator 🟩 G

Project Name: 20d Drop for CDR.mpt

Schedule Status

Description	Current
Current Start (**Note:** earliest activity Early Start Date)	10/10/2011
Current Finish (**Note:** latest activity Early Finish Date)	4/7/2019
Approximate Remaining Work Days	1257
Is this schedule externally linked to other schedules?	N
Status Date	3/28/2014

Task and Milestone Count *(Note: These counts exclude summary tasks)*

Description	Count	% of Total
Total Tasks and Milestones	5693	
Completed Tasks and Milestones	2470	43%
To Go Tasks and Milestones	3223	57%

Integrity Indicators *(Note: These counts exclude summary and started/completed tasks)*

Tasks and Milestones Without Predecessors	2	0%
Tasks and Milestones Without Successors	3	0%
To Go Tasks with No Finish Ties	0	0%
To Go Tasks with No Start Ties	0	0%
Summaries with Logic Ties (see note below)	0	0%
Out of Sequence Relationships	5	0%
Tasks and Milestones Needing Updates	44	1%
Actuals after Status Date	0	0%
Tasks marked as Milestones (Note: having a duration of > 0)	58	2%
Tasks With Estimated Duration	0	0%
Manual Tasks (includes summary tasks - see note below)	0	0%

Note: The summaries with logic ties and manual tasks numbers are calculated as a percentage of tasks and milestones.

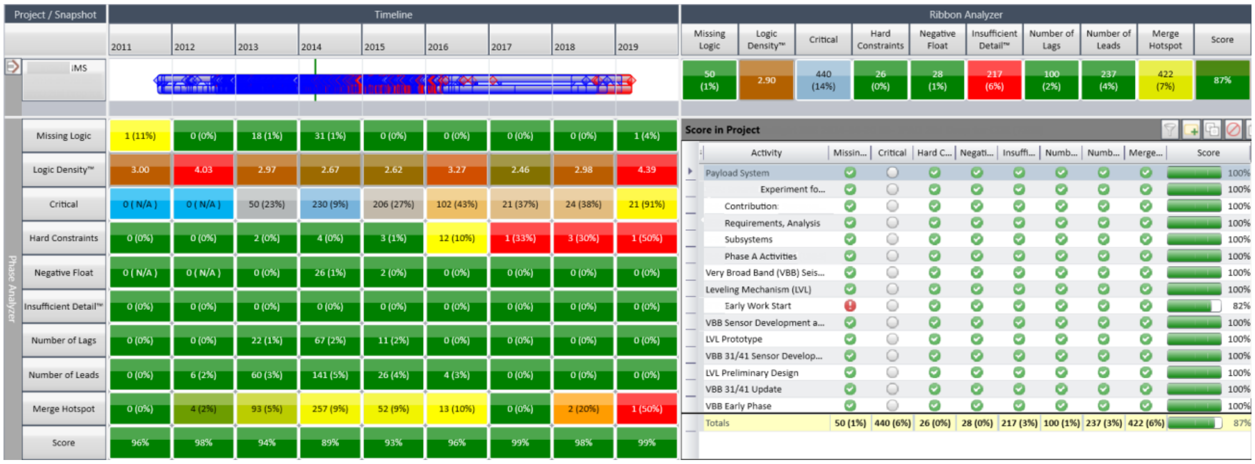
Constraints

Total Constraints (Note: other than ASAP including deadlines)	587	18%
Start No Earlier Than	512	16%
Start No Later Than	0	0%
Finish No Earlier Than	0	0%
Finish No Later Than	0	0%
Must Start On	3	0%
Must Finish On	21	1%
As Late As Possible	0	0%
Deadlines	51	2%

Additional Schedule Information

Recurring Tasks	0	0%
Schedule traceable to WBS (Y/N)	TBD	
Realistic Critical Path(s) (Y/N)	TBD	
Schedule Baselined Tasks	3203	99%
Tasks With Resources	0	0%
Tasks and Milestones with 10 days or less Total Float	1057	33%
Tasks with Total Float > 25% of remaining duration	114	4%
Total Tasks (Including summary tasks)	7391	

Figure 8-18. A Health Check Report generated from the NASA Schedule Test and Assessment Tool (STAT).



Project / Snapshot | Timeline

IMS

Phase Analyzer	2011	2012	2013	2014	2015	2016	2017	2018	2019
Missing Logic	1 (11%)	0 (0%)	18 (1%)	31 (1%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	1 (4%)
Logic Density™	3.00	4.03	2.97	2.67	2.62	3.27	2.46	2.98	4.39
Critical	0 (N/A)	0 (N/A)	50 (23%)	230 (9%)	206 (27%)	102 (43%)	21 (37%)	24 (38%)	21 (91%)
Hard Constraints	0 (0%)	0 (0%)	2 (0%)	4 (0%)	3 (1%)	12 (10%)	1 (33%)	3 (30%)	1 (50%)
Negative Float	0 (N/A)	0 (N/A)	0 (0%)	26 (1%)	2 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Insufficient Detail™	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Number of Lags	0 (0%)	0 (0%)	22 (1%)	67 (2%)	11 (2%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Number of Leads	0 (0%)	6 (2%)	60 (3%)	141 (5%)	26 (4%)	4 (3%)	0 (0%)	0 (0%)	0 (0%)
Merge Hotspot	0 (0%)	4 (2%)	93 (5%)	257 (9%)	52 (9%)	13 (10%)	0 (0%)	2 (20%)	1 (50%)
Score	96%	98%	94%	89%	93%	96%	99%	98%	99%

Ribbon Analyzer

Missing Logic	Logic Density™	Critical	Hard Constraints	Negative Float	Insufficient Detail™	Number of Lags	Number of Leads	Merge Hotspot	Score
50 (1%)	2.90	440 (14%)	26 (0%)	28 (1%)	217 (6%)	100 (2%)	237 (4%)	422 (7%)	87%

Score in Project

Activity	Missin...	Critical	Hard C...	Negati...	Insuffi...	Numb...	Numb...	Merge...	Score
Payload System	✓	○	✓	✓	✓	✓	✓	✓	100%
Experiment fo...	✓	○	✓	✓	✓	✓	✓	✓	100%
Contribution	✓	○	✓	✓	✓	✓	✓	✓	100%
Requirements, Analysis	✓	○	✓	✓	✓	✓	✓	✓	100%
Subsystems	✓	○	✓	✓	✓	✓	✓	✓	100%
Phase A Activities	✓	○	✓	✓	✓	✓	✓	✓	100%
Very Broad Band (VBB) Seis...	✓	○	✓	✓	✓	✓	✓	✓	100%
Leveling Mechanism (LVL)	✓	○	✓	✓	✓	✓	✓	✓	100%
Early Work Start	!	○	✓	✓	✓	✓	✓	✓	82%
VBB Sensor Development a...	✓	○	✓	✓	✓	✓	✓	✓	100%
LVL Prototype	✓	○	✓	✓	✓	✓	✓	✓	100%
VBB 31/41 Sensor Develop...	✓	○	✓	✓	✓	✓	✓	✓	100%
LVL Preliminary Design	✓	○	✓	✓	✓	✓	✓	✓	100%
VBB 31/41 Update	✓	○	✓	✓	✓	✓	✓	✓	100%
VBB Early Phase	✓	○	✓	✓	✓	✓	✓	✓	100%
Totals	50 (1%)	440 (6%)	26 (0%)	28 (0%)	217 (3%)	100 (1%)	237 (3%)	422 (6%)	87%

Figure 8-19. A Health Check assessment generated from the Deltek Acumen Fuse tool. A variety of Health Check Reports can be generated using the dashboards and report formats available for illustrating both built-in and custom health check metrics.

Critical Milestones Report

A *Critical Milestones Report* is a table of critical milestones organized according to total slack values and then by need date as shown in Figure 8-20. Not all of the milestones in this list are necessarily on the critical path. "Critical" milestones may be on the critical path, or they may simply have zero total float (slack) due to constraints imposed on the milestone. Such a constraint makes the milestone and its predecessor activities "critical" with respect to the constraint, but not necessarily with respect to the P/p finish date or end-item delivery. It may be helpful for the P/S to distinguish between "critical" milestones and "critical path" milestones in a *Critical Milestones Report*.

Unique ID	Critical Milestones	Need Dates	Total Float (days)
5290	(Rec) Instr, L/V, S/C Component Mechanical ICDs	3/15/2006	0
5716	Solar Cell Vendor Contract Award	5/31/2006	0
4103	Propulsion Module Structure Award	6/30/2006	0
5682	(Del) Flt IM Strucutre to I&T	9/27/2007	0
3309	(Rec) Instrument Module Structure for I&T	9/27/2007	0
5704	Group 3 FLT Modules from Power Gropu	10/17/2007	0
5527	(Del) Solar Array to S/C I&T	1/31/2008	0
4097	Mandatory Launch Date	10/31/2008	0
5509	(Rec) Modules from Vendor (Power)	9/21/2007	1
5655	(Rec) Solar Array System	1/31/2008	1
4121	Avionics Module Structure Award	6/30/2006	2
4751	Instrument Module Ready for Orbiter I&T	11/5/2007	2

Figure 8-20. A Critical Milestones Report showing "critical" milestones according to total float calculations from the IMS.

Total Float Report

A *Total Float Report* is a status report that shows the current total float value for key milestones and activities. The *Total Float Report* can have different formats. Similar to Figure 8-20, Figure 8-21 illustrates a table of critical milestones. However, this table includes only key milestones and is sorted in ascending order according to need date (vs. total float). A planned finish date column is included, as well as the total float value column. Milestones with low levels of float, corresponding to the critical path(s) can be color-coded for further visualization.

Total Float Report		
		Working Days
Milestone	**Planned Finish**	**Nov '14**
S/C - Propulsion Delivery to I&T	3/27/2015	0
S/C - PDDU Delivery to I&T	3/26/2015	1
S/C - SARA (SRC/TAG SAM) Del to I&T	8/5/2015	0
S/C - C&DH #1 Delivery to I&T	3/17/2015	8
S/C - GN&C Lidar Delivery to I&T	7/16/2015	7
S/C - SDST Delivery to I&T	3/31/2015	4
OVIRS Instr - Delivery to S/C I&T	8/12/2015	39
OCAMS Instr - Deliveyr to S/C I&T	8/17/2015	4
Ground System - Launch Readiness	6/30/2016	45

Figure 8-21. A Total Float Report illustrating the total float calculated against planned milestone finish dates.

Figure 8-22 shows an example of a *Total Float Report* in a graph format, which incorporates both float and margin for key milestones and activities.

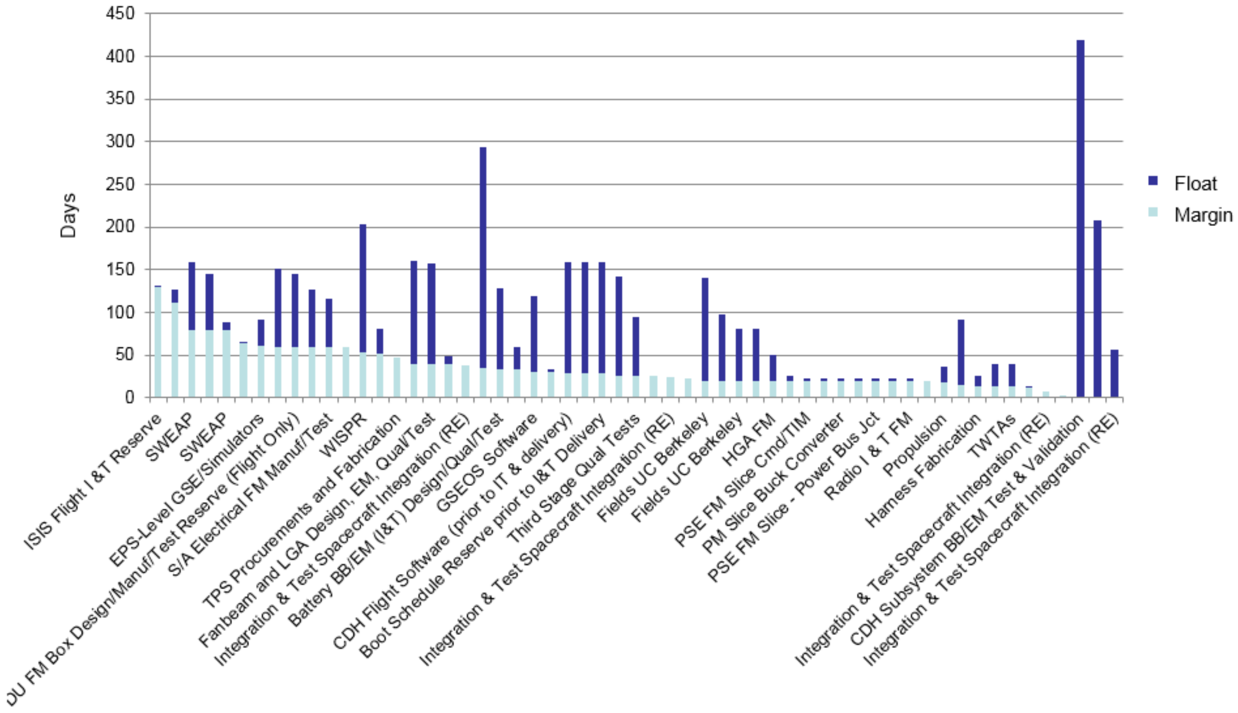


Figure 8-22. A Total Float Report illustrating both the total float and margin on key activities and milestones.

Margin Status Report

A *Margin Status Report* is simply a current margin count reported on the critical path of a ***Summary Schedule***, as shown in Figure 8-23. These reports offer a high-level illustration of where the margin is allocated in the schedule.

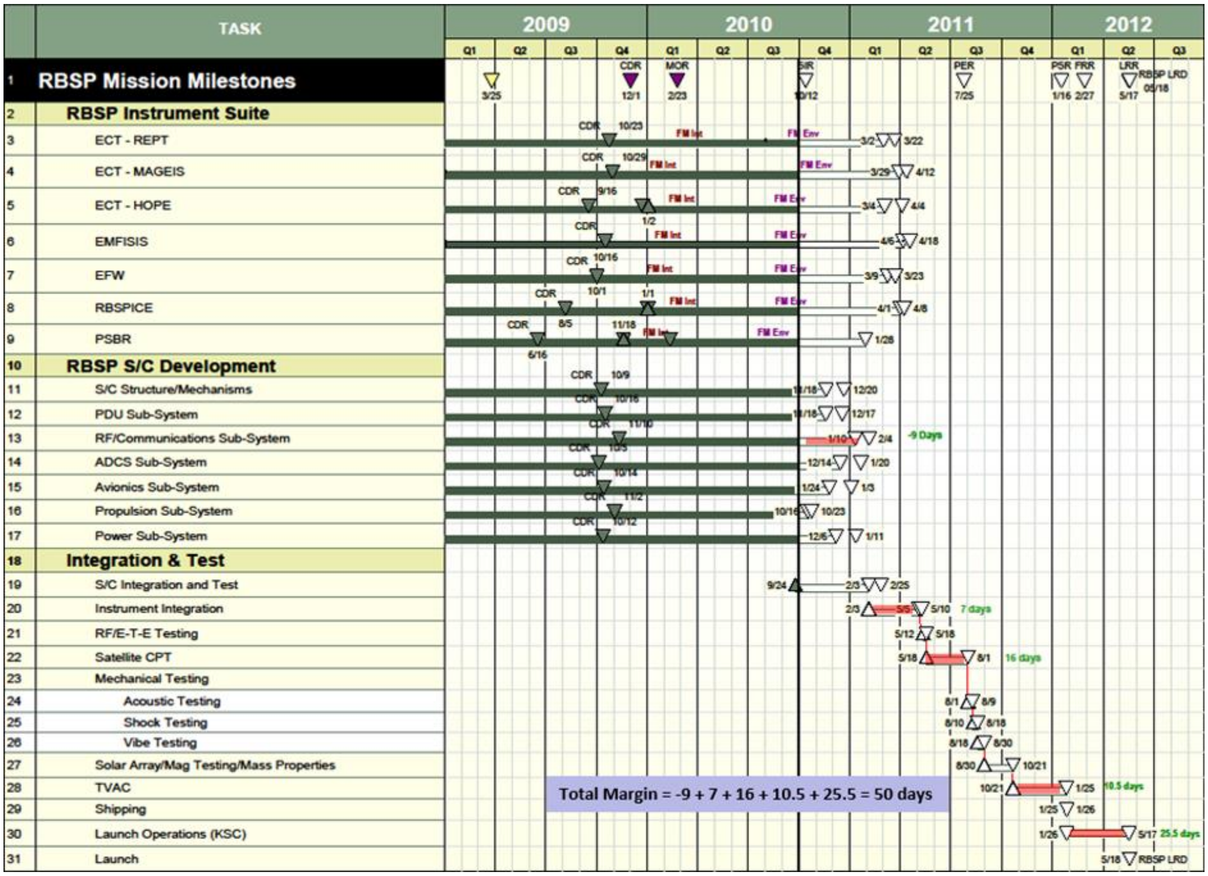
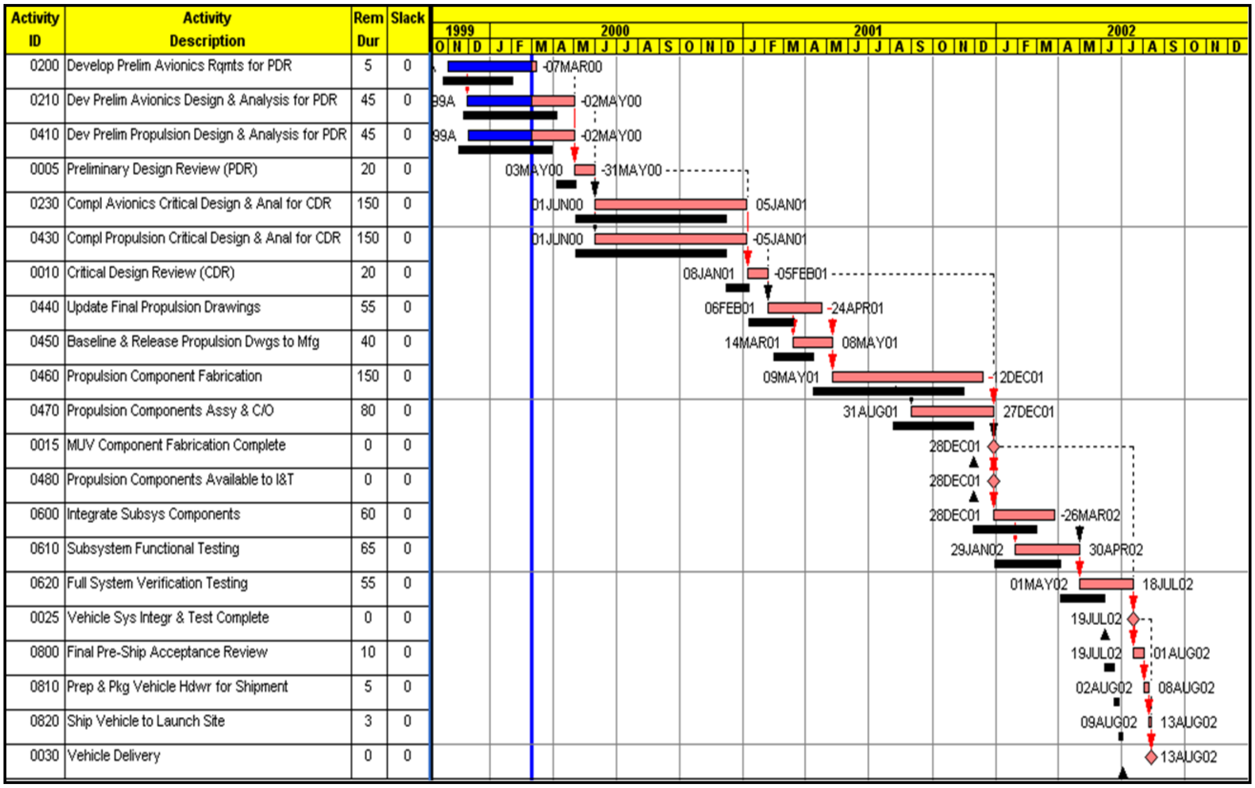


Figure 8-23. A Margin Status Report illustrating the available margin along the critical path.

Critical Path Report

A *Critical Path Report* is an extract from the P/p *IMS* and includes all tasks and milestones that make up the critical path(s) with the associated amounts of total float. The report should be displayed in a waterfall format and organized in manner such that the path with the least amount of float is delineated first (primary critical path), followed by each successive path according to total float values (secondary, tertiary, etc.). This formatting is typically accomplished through filtering and sorting capabilities within the scheduling tool. It is important to verify that the activities shown in the critical path report are in fact on the critical path versus simply "critical activities", which are often critical (i.e., zero slack) due to imposed constraints. Using the longest path method to calculate the critical path versus simply relying on the total float calculation will help to distinguish between critical path(s) versus other "critical" activities or milestones that may not drive the P/p finish or end-item completion date. Figure 8-25 shows an example of a typical *Critical Path Report*.



Activity ID	Activity Description	Rem Dur	Slack
0200	Develop Prelim Avionics Rqmts for PDR	5	0
0210	Dev Prelim Avionics Design & Analysis for PDR	45	0
0410	Dev Prelim Propulsion Design & Analysis for PDR	45	0
0005	Preliminary Design Review (PDR)	20	0
0230	Compl Avionics Critical Design & Anal for CDR	150	0
0430	Compl Propulsion Critical Design & Anal for CDR	150	0
0010	Critical Design Review (CDR)	20	0
0440	Update Final Propulsion Drawings	55	0
0450	Baseline & Release Propulsion Dwgs to Mfg	40	0
0460	Propulsion Component Fabrication	150	0
0470	Propulsion Components Assy & C/O	80	0
0015	MUV Component Fabrication Complete	0	0
0480	Propulsion Components Available to I&T	0	0
0600	Integrate Subsys Components	60	0
0610	Subsystem Functional Testing	65	0
0620	Full System Verification Testing	55	0
0025	Vehicle Sys Integr & Test Complete	0	0
0800	Final Pre-Ship Acceptance Review	10	0
0810	Prep & Pkg Vehicle Hdwr for Shipment	5	0
0820	Ship Vehicle to Launch Site	3	0
0030	Vehicle Delivery	0	0

Figure 8-24. A Critical Path Report, showing the primary critical path filtered from the IMS according to calculated total float values.

Critical Path Reports may include any number of critical and near-critical paths; however, it is a recommended practice that the report reflects all paths with ten (10) workdays or less of total float, at a minimum. Figure 8-25 shows an example of a *Critical Path* Report illustrating both the primary and secondary critical paths.

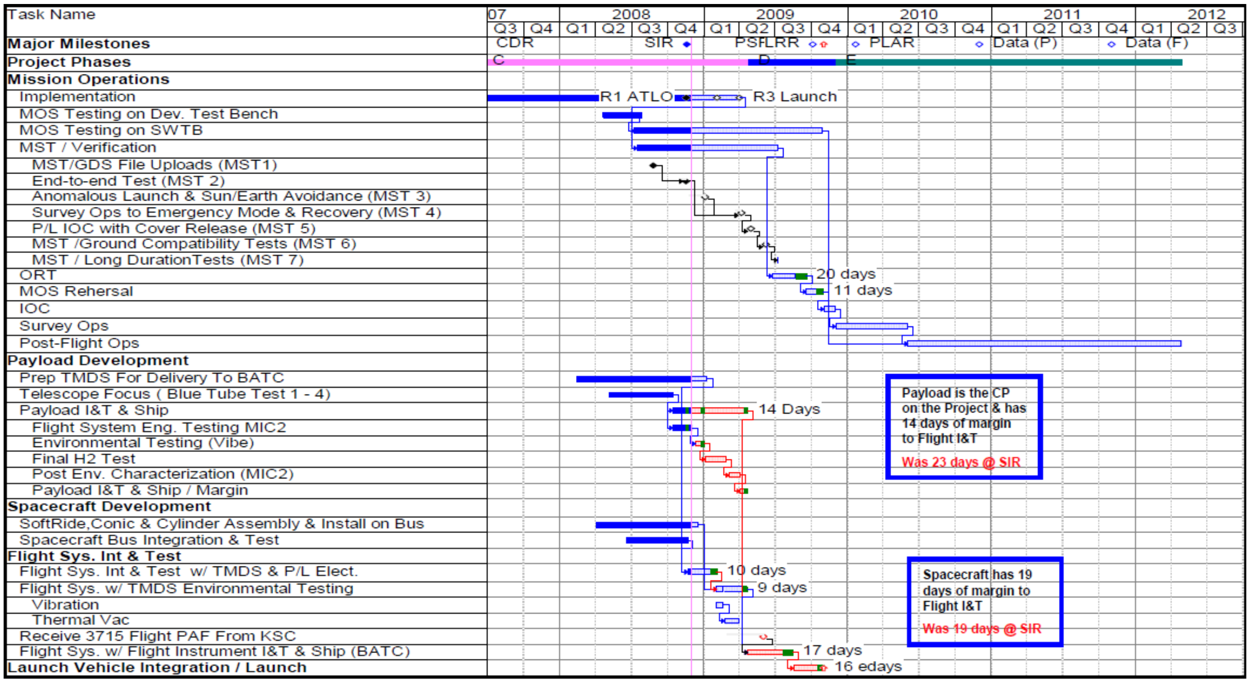


Figure 8-25. A Critical Path Report, highlighting the primary critical and secondary critical paths using the Summary Schedule as its foundation. This report also highlights the margin on each path.

Resource Allocation Report

When resource loading a schedule, *Resource Allocation Reports* aid in communication between the P/S and the Technical Leads with respect to ensure that resources are not over allocated. When a *Resource Allocation Report* shows that resources are over allocated, resource leveling, described in Section 5.5.12, can be performed to help optimize the use of resources. Figure 8-26 shows a *Resource Allocation Report* and the subsequent resource leveling.

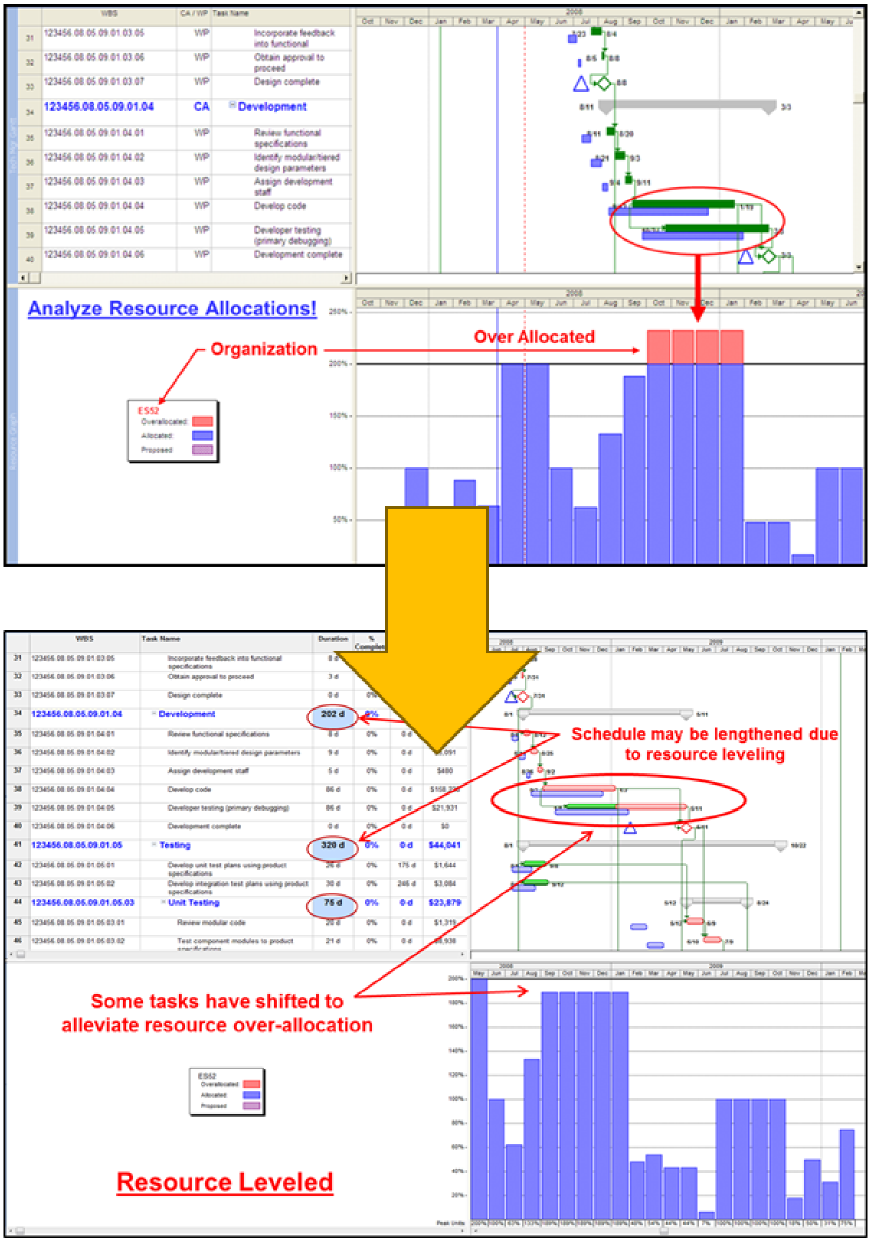


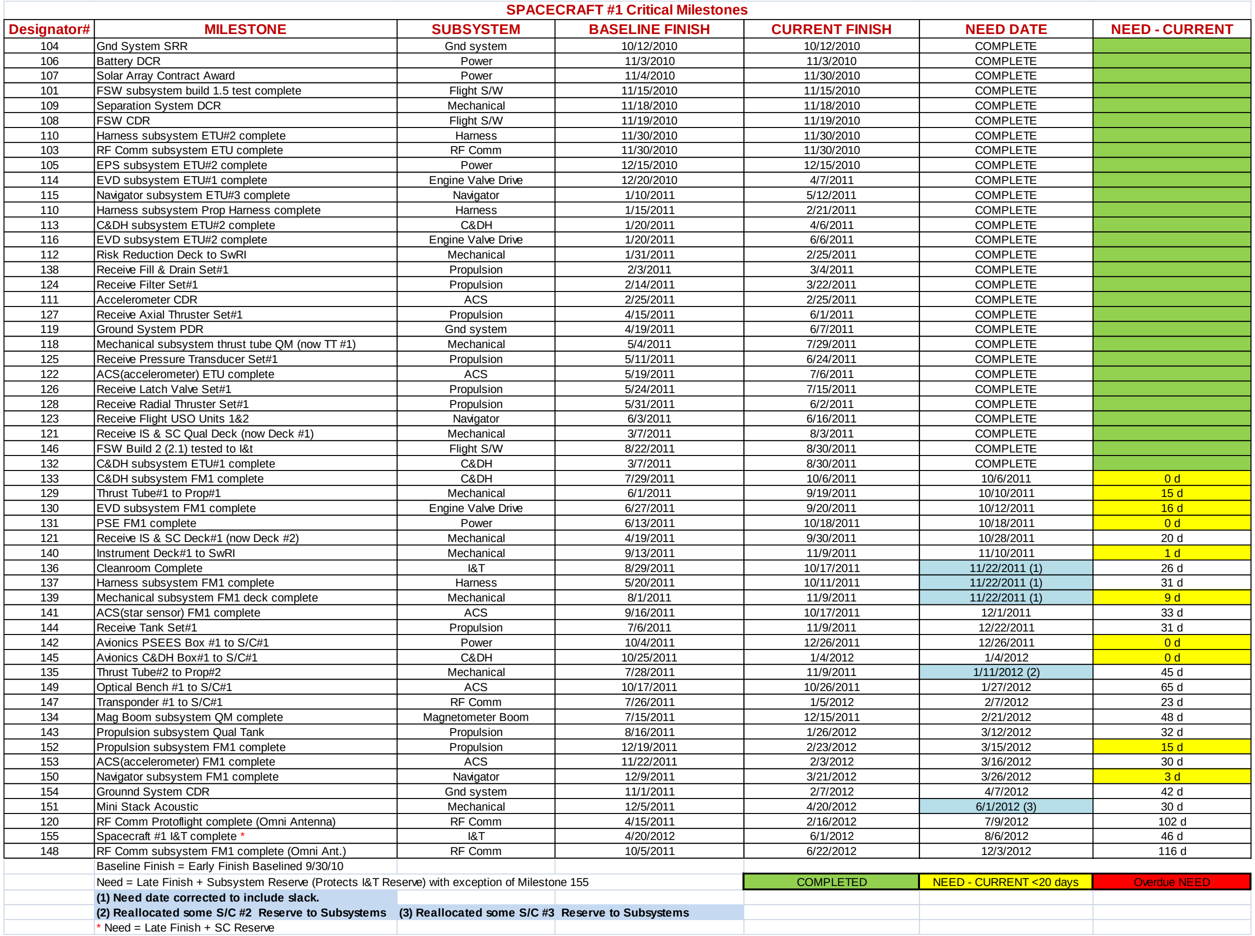
Figure 8-26. A Resource Allocation Report showing over-allocated resources and the changes made to effectively "level" the resources.

8.3.2.4.2 Progress Reporting: What has been Accomplished (Plan vs. Actual Data)

Even before the schedule has been baselined, the P/p can track performance against planned dates. Progress reporting refers to any report generated from schedule data involving a comparison (e.g., variance) or trend. Once the P/p has been baselined, the P/p can measure performance against baseline dates for performance purposes to generate performance metrics (e.g., EVM, see section 7.3.3). Although these reports often project future activity/milestone dates, the comparisons, calculations, and/or metrics are deterministic in nature, not accounting for the uncertainty and risk inherent in forecasting; thus, these reports are captured in this Progress Reporting section instead of the following Forecasting section. Examples of progress reports are described below.

Milestone Progress Report

A *Milestone Progress Report* is generally a list of milestones showing the baseline finish dates versus the current planned finish dates, as shown in Figure 8-27. These reports help the P/p team to stay aware of near-term milestones.



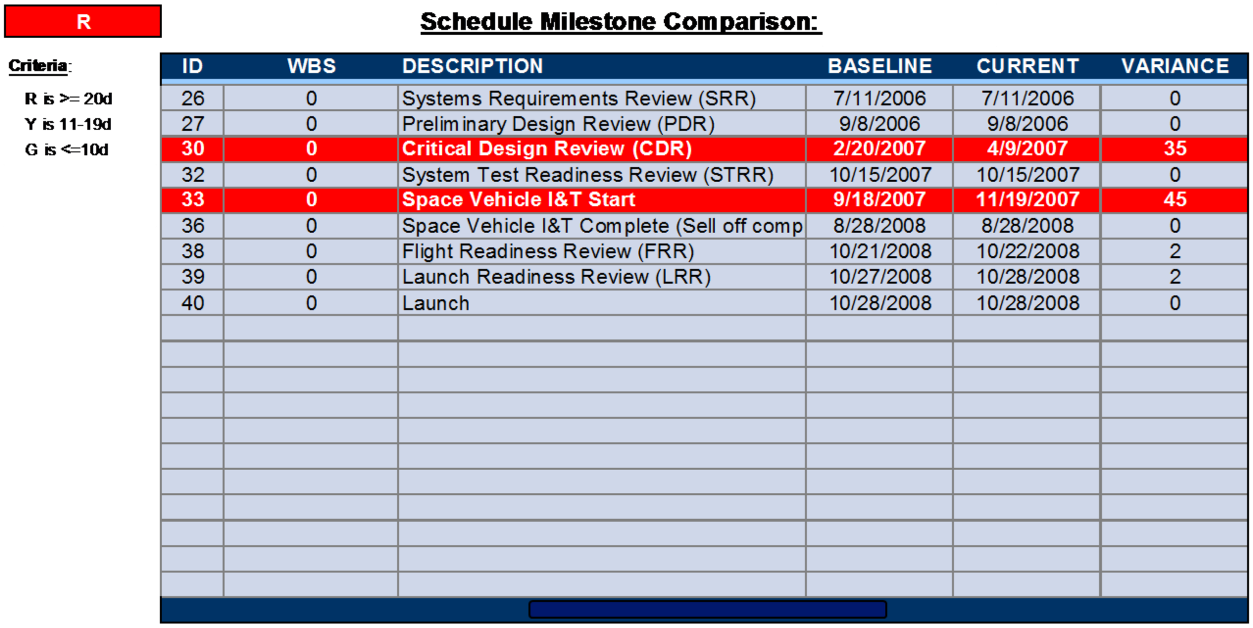
SPACECRAFT #1 Critical Milestones

Designator#	MILESTONE	SUBSYSTEM	BASELINE FINISH	CURRENT FINISH	NEED DATE	NEED - CURRENT
104	Gnd System SRR	Gnd system	10/12/2010	10/12/2010	COMPLETE	🟩
106	Battery DCR	Power	11/3/2010	11/3/2010	COMPLETE	🟩
107	Solar Array Contract Award	Power	11/4/2010	11/30/2010	COMPLETE	🟩
101	FSW subsystem build 1.5 test complete	Flight S/W	11/15/2010	11/15/2010	COMPLETE	🟩
109	Separation System DCR	Mechanical	11/18/2010	11/18/2010	COMPLETE	🟩
108	FSW CDR	Flight S/W	11/19/2010	11/19/2010	COMPLETE	🟩
110	Harness subsystem ETU#2 complete	Harness	11/30/2010	11/30/2010	COMPLETE	🟩
103	RF Comm subsystem ETU complete	RF Comm	11/30/2010	11/30/2010	COMPLETE	🟩
105	EPS subsystem ETU#2 complete	Power	12/15/2010	12/15/2010	COMPLETE	🟩
114	EVD subsystem ETU#1 complete	Engine Valve Drive	12/20/2010	4/7/2011	COMPLETE	🟩
115	Navigator subsystem ETU#3 complete	Navigator	1/10/2011	5/12/2011	COMPLETE	🟩
110	Harness subsystem Prop Harness complete	Harness	1/15/2011	2/21/2011	COMPLETE	🟩
113	C&DH subsystem ETU#2 complete	C&DH	1/20/2011	4/6/2011	COMPLETE	🟩
116	EVD subsystem ETU#2 complete	Engine Valve Drive	1/20/2011	6/6/2011	COMPLETE	🟩
112	Risk Reduction Deck to SwRI	Mechanical	1/31/2011	2/25/2011	COMPLETE	🟩
138	Receive Fill & Drain Set#1	Propulsion	2/3/2011	3/4/2011	COMPLETE	🟩
124	Receive Filter Set#1	Propulsion	2/14/2011	3/22/2011	COMPLETE	🟩
111	Accelerometer CDR	ACS	2/25/2011	2/25/2011	COMPLETE	🟩
127	Receive Axial Thruster Set#1	Propulsion	4/15/2011	6/1/2011	COMPLETE	🟩
119	Ground System PDR	Gnd system	4/19/2011	6/7/2011	COMPLETE	🟩
118	Mechanical subsystem thrust tube QM (now TT #1)	Mechanical	5/4/2011	7/29/2011	COMPLETE	🟩
125	Receive Pressure Transducer Set#1	Propulsion	5/11/2011	6/24/2011	COMPLETE	🟩
122	ACS(accelerometer) ETU complete	ACS	5/19/2011	7/6/2011	COMPLETE	🟩
126	Receive Latch Valve Set#1	Propulsion	5/24/2011	7/15/2011	COMPLETE	🟩
128	Receive Radial Thruster Set#1	Propulsion	5/31/2011	6/2/2011	COMPLETE	🟩
123	Receive Flight USO Units 1&2	Navigator	6/3/2011	6/16/2011	COMPLETE	🟩
121	Receive IS & SC Qual Deck (now Deck #1)	Mechanical	3/7/2011	8/3/2011	COMPLETE	🟩
146	FSW Build 2 (2.1) tested to I&t	Flight S/W	8/22/2011	8/30/2011	COMPLETE	🟩
132	C&DH subsystem ETU#1 complete	C&DH	3/7/2011	8/30/2011	COMPLETE	🟩
133	C&DH subsystem FM1 complete	C&DH	7/29/2011	10/6/2011	10/6/2011	0 d
129	Thrust Tube#1 to Prop#1	Mechanical	6/1/2011	9/19/2011	10/10/2011	15 d
130	EVD subsystem FM1 complete	Engine Valve Drive	6/27/2011	9/20/2011	10/12/2011	16 d
131	PSE FM1 complete	Power	6/13/2011	10/18/2011	10/18/2011	0 d
121	Receive IS & SC Deck#1 (now Deck #2)	Mechanical	4/19/2011	9/30/2011	10/28/2011	20 d
140	Instrument Deck#1 to SwRI	Mechanical	9/13/2011	11/9/2011	11/10/2011	1 d
136	Cleanroom Complete	I&T	8/29/2011	10/17/2011	11/22/2011 (1)	26 d
137	Harness subsystem FM1 complete	Harness	5/20/2011	10/11/2011	11/22/2011 (1)	31 d
139	Mechanical subsystem FM1 deck complete	Mechanical	8/1/2011	11/9/2011	11/22/2011 (1)	9 d
141	ACS(star sensor) FM1 complete	ACS	9/16/2011	10/17/2011	12/1/2011	33 d
144	Receive Tank Set#1	Propulsion	7/6/2011	11/9/2011	12/22/2011	31 d
142	Avionics PSEES Box #1 to S/C#1	Power	10/4/2011	12/26/2011	12/26/2011	0 d
145	Avionics C&DH Box#1 to S/C#1	C&DH	10/25/2011	1/4/2012	1/4/2012	0 d
135	Thrust Tube#2 to Prop#2	Mechanical	7/28/2011	11/9/2011	1/11/2012 (2)	45 d
149	Optical Bench #1 to S/C#1	ACS	10/17/2011	10/26/2011	1/27/2012	65 d
147	Transponder #1 to S/C#1	RF Comm	7/26/2011	1/5/2012	2/7/2012	23 d
134	Mag Boom subsystem QM complete	Magnetometer Boom	7/15/2011	12/15/2011	2/21/2012	48 d
143	Propulsion subsystem Qual Tank	Propulsion	8/16/2011	1/26/2012	3/12/2012	32 d
152	Propulsion subsystem FM1 complete	Propulsion	12/19/2011	2/23/2012	3/15/2012	15 d
153	ACS(accelerometer) FM1 complete	ACS	11/22/2011	2/3/2012	3/16/2012	30 d
150	Navigator subsystem FM1 complete	Navigator	12/9/2011	3/21/2012	3/26/2012	3 d
154	Grounnd System CDR	Gnd system	11/1/2011	2/7/2012	4/7/2012	42 d
151	Mini Stack Acoustic	Mechanical	12/5/2011	4/20/2012	6/1/2012 (3)	30 d
120	RF Comm Protoflight complete (Omni Antenna)	RF Comm	4/15/2011	2/16/2012	7/9/2012	102 d
155	Spacecraft #1 I&T complete *	I&T	4/20/2012	6/1/2012	8/6/2012	46 d
148	RF Comm subsystem FM1 complete (Omni Ant.)	RF Comm	10/5/2011	6/22/2012	12/3/2012	116 d
	Baseline Finish = Early Finish Baselined 9/30/10					
	Need = Late Finish + Subsystem Reserve (Protects I&T Reserve) with exception of Milestone 155			COMPLETED	NEED - CURRENT <20 days	Overdue NEED
	(1) Need date corrected to include slack.					
	(2) Reallocated some S/C #2 Reserve to Subsystems	**(3) Reallocated some S/C #3 Reserve to Subsystems**				
	* Need = Late Finish + SC Reserve					

Figure 8-27. A Milestone Progress Report illustrating milestone baseline vs. current planned finish dates.

Milestone Variance Report/Log

A *Milestone Variance Report* can be illustrated in one of two ways. The first type of *Milestone Variance Report* is simply an extension of the *Milestone Status Report*, discussed in the previous section. It is a milestone list showing a comparison of the baseline vs. current dates with an added variance column, as shown in Figure 8-28. Figure 8-29 provides a similar example, which also shows the "need date", providing the PM with additional information as to the risk associated with any variances in milestone dates. This *Milestone Variance Report* is therefore more informative than the *Milestone Status Report.*



🟥 R

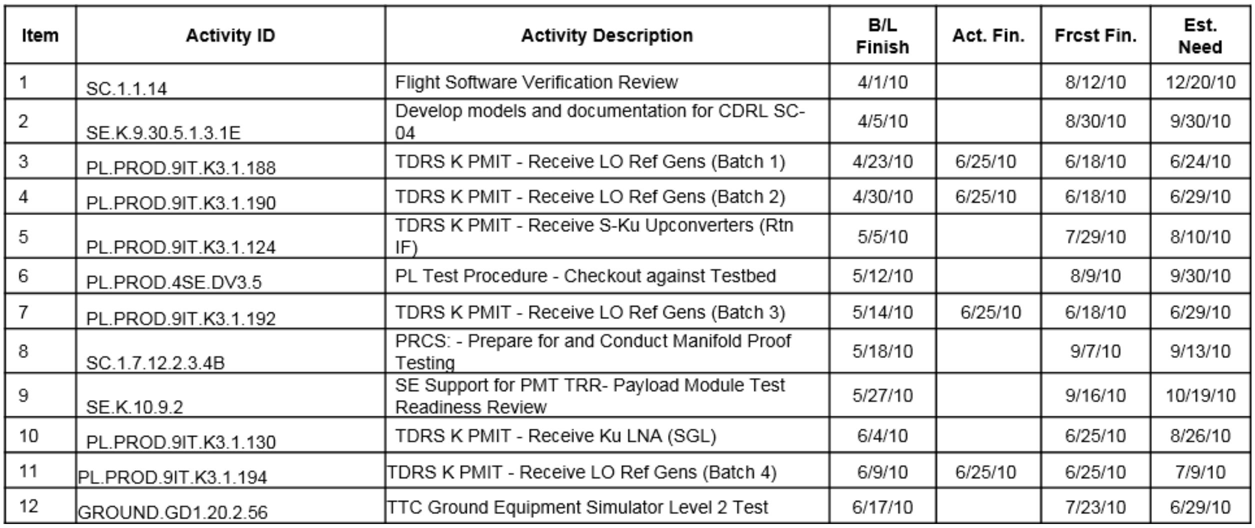
Schedule Milestone Comparison:

Criteria:

R is >= 20d
Y is 11-19d
G is <=10d

ID	WBS	DESCRIPTION	BASELINE	CURRENT	VARIANCE
26	0	Systems Requirements Review (SRR)	7/11/2006	7/11/2006	0
27	0	Preliminary Design Review (PDR)	9/8/2006	9/8/2006	0
30	**0**	**Critical Design Review (CDR)**	**2/20/2007**	**4/9/2007**	**35**
32	0	System Test Readiness Review (STRR)	10/15/2007	10/15/2007	0
33	**0**	**Space Vehicle I&T Start**	**9/18/2007**	**11/19/2007**	**45**
36	0	Space Vehicle I&T Complete (Sell off comp	8/28/2008	8/28/2008	0
38	0	Flight Readiness Review (FRR)	10/21/2008	10/22/2008	2
39	0	Launch Readiness Review (LRR)	10/27/2008	10/28/2008	2
40	0	Launch	10/28/2008	10/28/2008	0

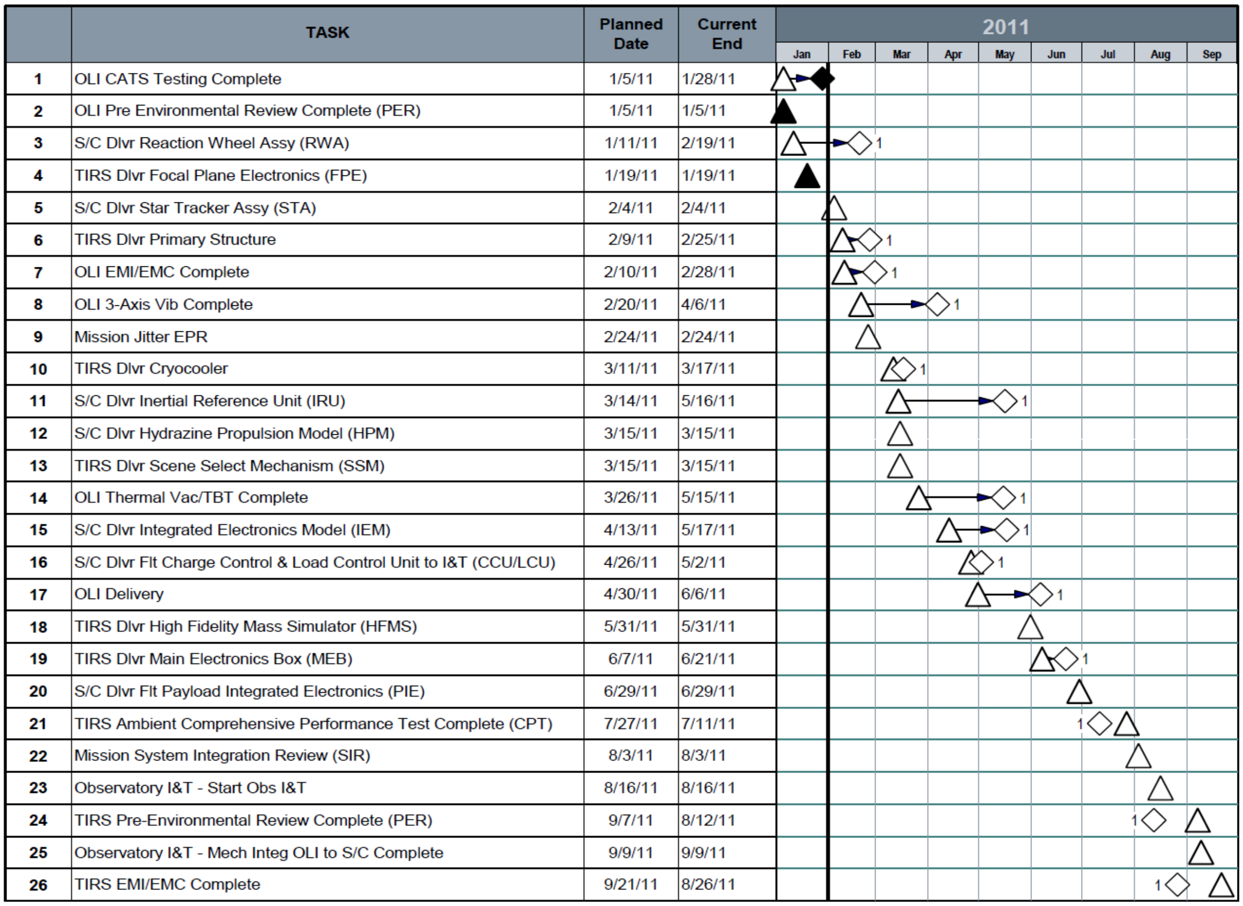
Figure 8-28. A Milestone Variance Report illustrating milestone baseline vs. current planned finish dates, as well as the variance (days) between the dates.



Item	Activity ID	Activity Description	B/L Finish	Act. Fin.	Frcst Fin.	Est. Need
1	SC.1.1.14	Flight Software Verification Review	4/1/10		8/12/10	12/20/10
2	SE.K.9.30.5.1.3.1E	Develop models and documentation for CDRL SC-04	4/5/10		8/30/10	9/30/10
3	PL.PROD.9IT.K3.1.188	TDRS K PMIT - Receive LO Ref Gens (Batch 1)	4/23/10	6/25/10	6/18/10	6/24/10
4	PL.PROD.9IT.K3.1.190	TDRS K PMIT - Receive LO Ref Gens (Batch 2)	4/30/10	6/25/10	6/18/10	6/29/10
5	PL.PROD.9IT.K3.1.124	TDRS K PMIT - Receive S-Ku Upconverters (Rtn IF)	5/5/10		7/29/10	8/10/10
6	PL.PROD.4SE.DV3.5	PL Test Procedure - Checkout against Testbed	5/12/10		8/9/10	9/30/10
7	PL.PROD.9IT.K3.1.192	TDRS K PMIT - Receive LO Ref Gens (Batch 3)	5/14/10	6/25/10	6/18/10	6/29/10
8	SC.1.7.12.2.3.4B	PRCS: - Prepare for and Conduct Manifold Proof Testing	5/18/10		9/7/10	9/13/10
9	SE.K.10.9.2	SE Support for PMT TRR- Payload Module Test Readiness Review	5/27/10		9/16/10	10/19/10
10	PL.PROD.9IT.K3.1.130	TDRS K PMIT - Receive Ku LNA (SGL)	6/4/10		6/25/10	8/26/10
11	PL.PROD.9IT.K3.1.194	TDRS K PMIT - Receive LO Ref Gens (Batch 4)	6/9/10	6/25/10	6/25/10	7/9/10
12	GROUND.GD1.20.2.56	TTC Ground Equipment Simulator Level 2 Test	6/17/10		7/23/10	6/29/10

Figure 8-29. A Milestone Progress Report illustrating milestone baseline vs. current planned finish dates, as well as the estimated "need date".

The second type of *Milestone Variance Report*, shown in Figure 8-30, combines the milestone list with a graphical display of the milestone variance. The graphical representation is organized similar to a Gantt chart with one milestone per line, according the milestone list. Each milestone is located horizontally along a time scale showing when it occurred/occurs along with any associated or expected slips (i.e., variances). Milestones differ from the bars in a Gantt chart in that they show only a single date and are usually depicted as a triangle instead of a bar. Milestones can be shown in various colors or opaqueness depicting the status of the milestone, and slips are typically shown using arrows.



	TASK	Planned Date	Current End
1	OLI CATS Testing Complete	1/5/11	1/28/11
2	OLI Pre Environmental Review Complete (PER)	1/5/11	1/5/11
3	S/C Dlvr Reaction Wheel Assy (RWA)	1/11/11	2/19/11
4	TIRS Dlvr Focal Plane Electronics (FPE)	1/19/11	1/19/11
5	S/C Dlvr Star Tracker Assy (STA)	2/4/11	2/4/11
6	TIRS Dlvr Primary Structure	2/9/11	2/25/11
7	OLI EMI/EMC Complete	2/10/11	2/28/11
8	OLI 3-Axis Vib Complete	2/20/11	4/6/11
9	Mission Jitter EPR	2/24/11	2/24/11
10	TIRS Dlvr Cryocooler	3/11/11	3/17/11
11	S/C Dlvr Inertial Reference Unit (IRU)	3/14/11	5/16/11
12	S/C Dlvr Hydrazine Propulsion Model (HPM)	3/15/11	3/15/11
13	TIRS Dlvr Scene Select Mechanism (SSM)	3/15/11	3/15/11
14	OLI Thermal Vac/TBT Complete	3/26/11	5/15/11
15	S/C Dlvr Integrated Electronics Model (IEM)	4/13/11	5/17/11
16	S/C Dlvr Flt Charge Control & Load Control Unit to I&T (CCU/LCU)	4/26/11	5/2/11
17	OLI Delivery	4/30/11	6/6/11
18	TIRS Dlvr High Fidelity Mass Simulator (HFMS)	5/31/11	5/31/11
19	TIRS Dlvr Main Electronics Box (MEB)	6/7/11	6/21/11
20	S/C Dlvr Flt Payload Integrated Electronics (PIE)	6/29/11	6/29/11
21	TIRS Ambient Comprehensive Performance Test Complete (CPT)	7/27/11	7/11/11
22	Mission System Integration Review (SIR)	8/3/11	8/3/11
23	Observatory I&T - Start Obs I&T	8/16/11	8/16/11
24	TIRS Pre-Environmental Review Complete (PER)	9/7/11	8/12/11
25	Observatory I&T - Mech Integ OLI to S/C Complete	9/9/11	9/9/11
26	TIRS EMI/EMC Complete	9/21/11	8/26/11

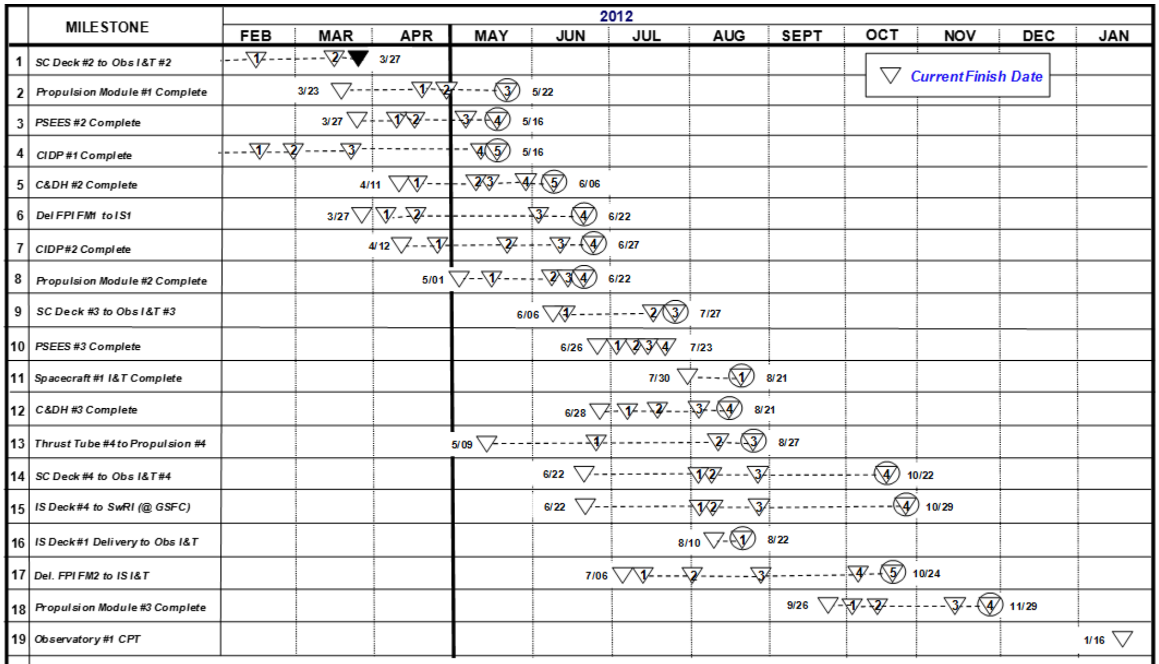
Figure 8-30. A Gantt-style Milestone Variance Report illustrating milestone baseline vs. current planned finish dates.

A *Milestone Variance Log*, shown in Figure 8-31, is an associated report that provides additional explanation of milestone status or slips. It is a recommended practice for *Milestone Variance Log* information to be captured within the "Notes" field of the scheduling tool for any milestones that experience changes from their planned or baselined dates.

Task	Month End Nov	Month End Dec	Explanation
1. OLI CATS Testing	1/5/11	1/28/11	Waiting for GMI to exit chamber, set-up issues, testing took longer than expected, issues with test GSE (monochromater)
6. TIRS FM Structure	2/9/11	2/25/11	Radiator insert delaying secondary assy. Not on critical path.
7. OLI EMI/EMC Complete	2/10/11	3/28/11	Delay of CATS completion; and Instrument activities bypassed because of late mechanical deliveries and to facilitate SPATS completion adds about 3 weeks of work to get the instrument ready for the start of baseplate integration.
8. OLI 3-Axis Vib Complete	2/20/11	4/6/11	See #1 & 7
10. Dlvr TIRS Cryocooler	3/11/11	3/17/11	Added 5 day "Exported Vibe Test" (Critcal Path)
11. Dlvr SC IRU	3/14/11	5/15/11	2 months - 2 HRGs replaced due to out-of-family performance; rerun acceptance testing
14. OLI TV/TBT Complete	3/26/11	5/15/11	See #1 & 7
15. Dlvr SC IEM	4/13/11	5/15/11	1 month - Rebuild "UDL" board for DCMA mishandling
16. Dlvr SC CCU/LCU	4/26/11	5/2/11	1 week - Temperature compensation component failed
17. OLI Dlvry	4/30/11	6/6/11	See #1 & 7
19. TIRS MEB	6/7/11	6/21/11	"Transmit all" Implementation

Figure 8-31. A Milestone Variance Log documents the rationale for milestone finish date changes.

Variance explanations may also be captured directly on each *Milestone Variance Report* to provide stakeholders with more complete information, as shown in Figure 8-32.



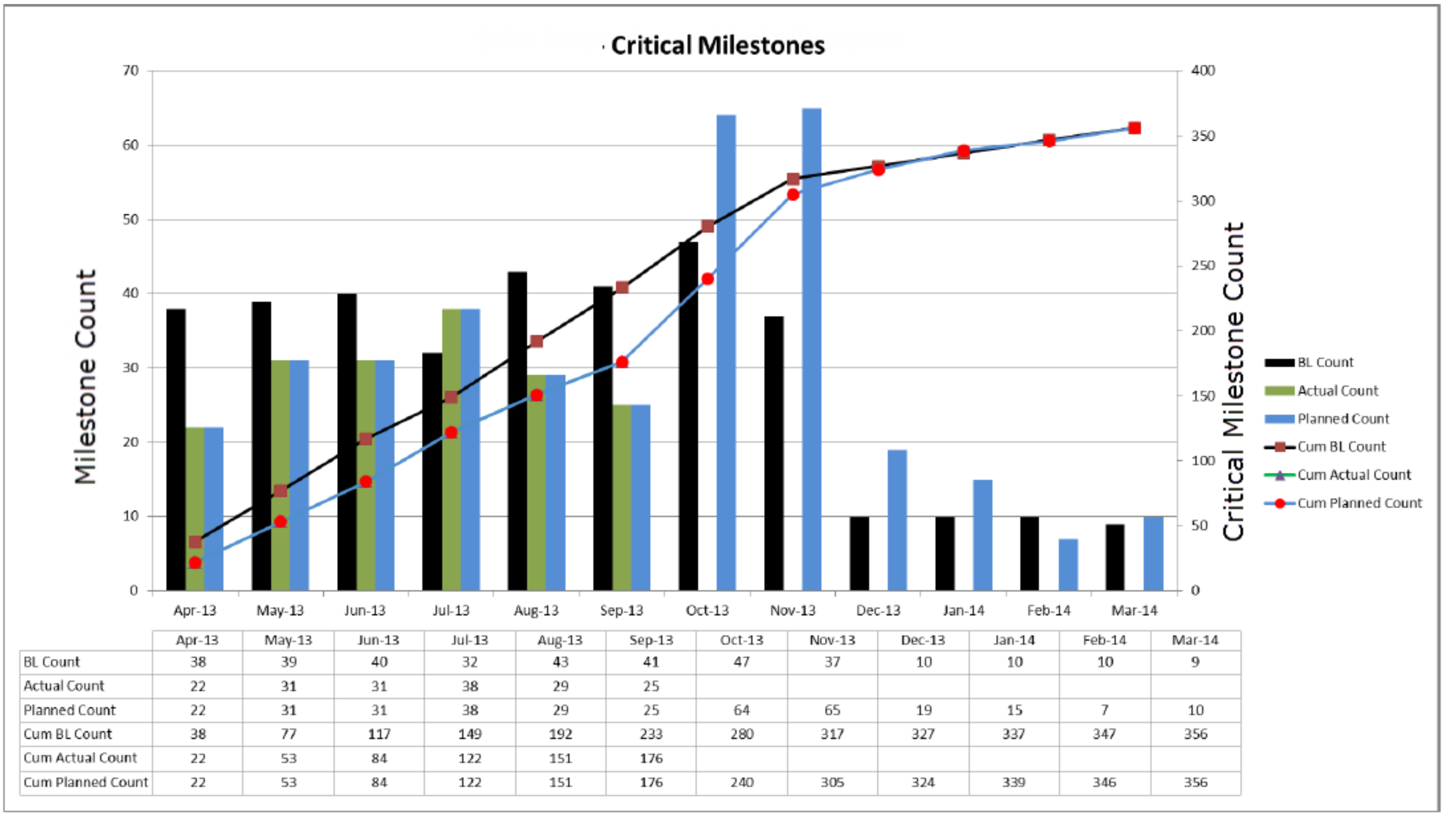
Current Month Variance Explanations:

2, 8, 11) Interference issues uncovered during assembly delayed tank mounting.
3) Delay in EMI facility readiness.
4, 7) Outages uncovered during EMI test.
5, 12) Delay in completing board conformal coat.
6, 17) DIS final hardware mods.
9, 13, 14, 15, 18) Centrifuge repair delays.
16) SDP radial wire clamp design fix.

Figure 8-32. A Gantt-style Milestone Variance Report complete with variance explanations.

Milestone Trend Report

A *Milestone Trend Report* shows the trends of milestones completed on a month-to-month basis. The *Milestone Trend Report* in Figure 8-33 shows both the count of the baseline milestones per month and the actual milestones completed per month. It also shows the cumulative count of milestones over time for both the baseline and actuals. This type of report can be used even before milestones have been baselined, as variance can be shown against preliminary planned dates for P/ps early in their life cycles.



	Apr-13	May-13	Jun-13	Jul-13	Aug-13	Sep-13	Oct-13	Nov-13	Dec-13	Jan-14	Feb-14	Mar-14
BL Count	38	39	40	32	43	41	47	37	10	10	10	9
Actual Count	22	31	31	38	29	25						
Planned Count	22	31	31	38	29	25	64	65	19	15	7	10
Cum BL Count	38	77	117	149	192	233	280	317	327	337	347	356
Cum Actual Count	22	53	84	122	151	176						
Cum Planned Count	22	53	84	122	151	176	240	305	324	339	346	356

Figure 8-33. A Milestone Trend Report showing the planned number of milestones completed versus the actual number of milestones completed over the course of several months, with projected milestone counts for upcoming months.

The *Milestone Trend Report* in Figure 8-34 illustrates how forecasted dates for key milestones have shifted over time based on schedule performance. This figure can be generated using actual schedule performance, as well as using risk-based techniques (e.g., *SRAs*).

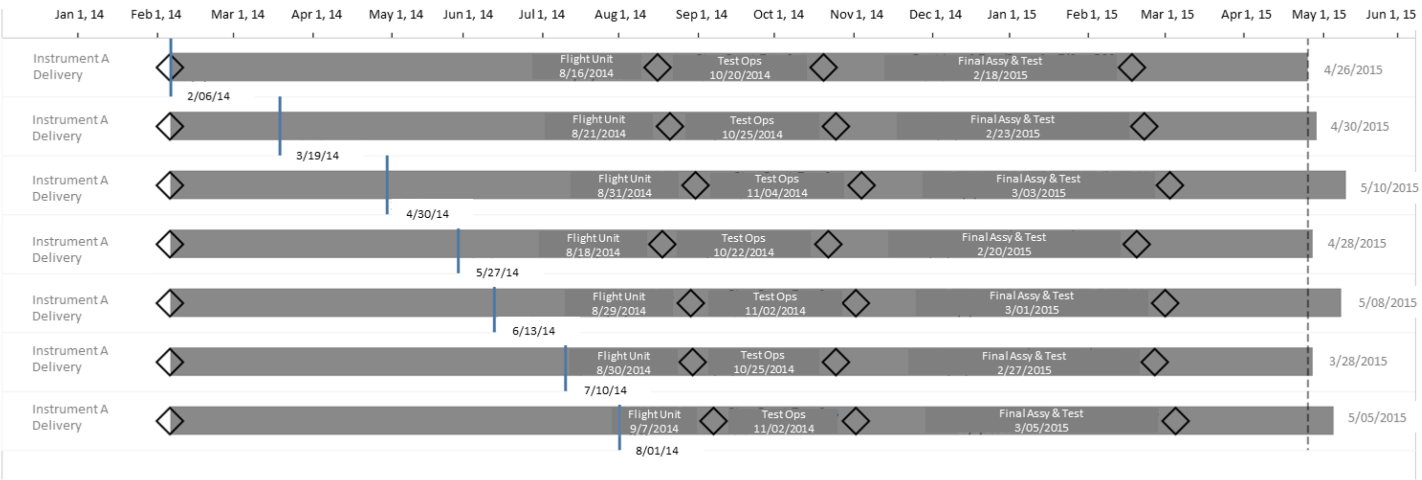
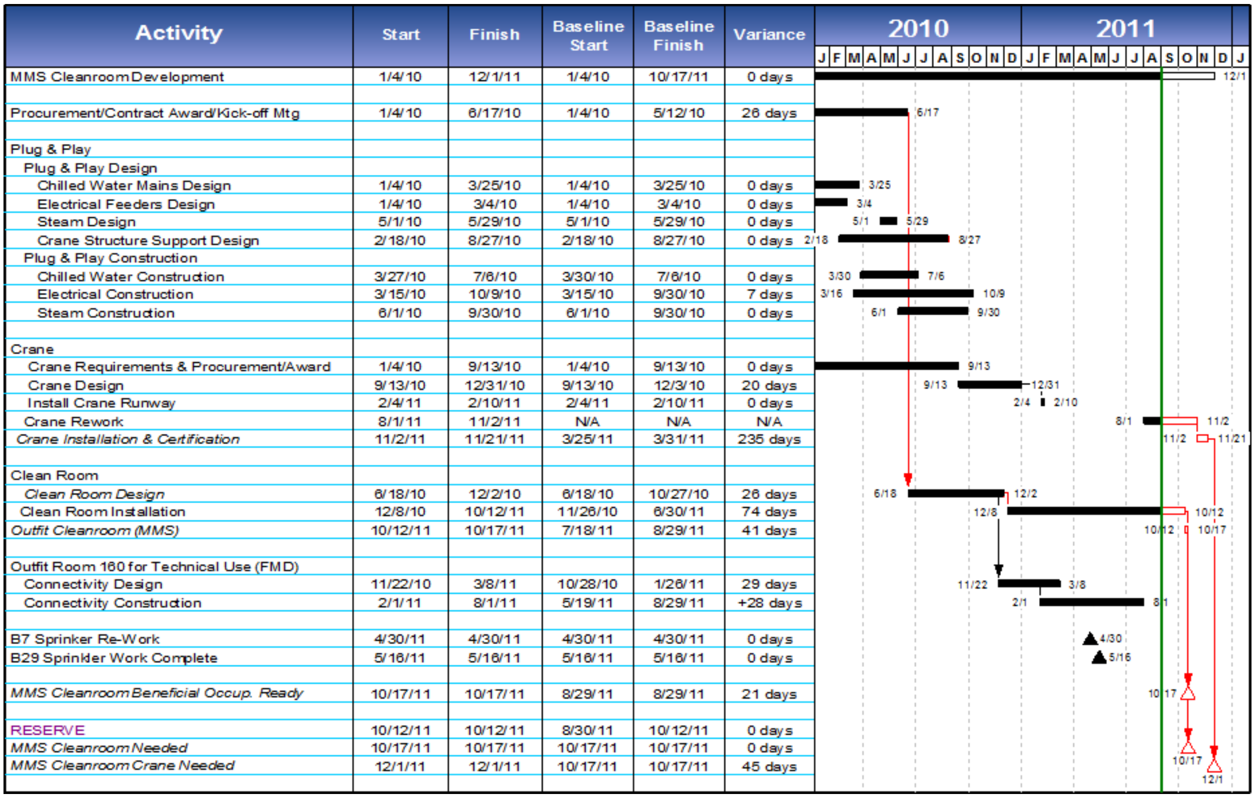


Figure 8-34. Example of a Milestone Trend Report for key milestones showing a change in expected finish dates over time.

Summary Schedule Variance Report

A *Summary Schedule Variance Report* is simply a *Summary Schedule Report* that includes a variance column to further illustrate planned/baseline vs actual start/finish dates. These additional columns provide valuable information about schedule performance while still at a high level. An example of a typical *Summary Schedule Variance Report* is shown in Figure 8-35.



Activity	Start	Finish	Baseline Start	Baseline Finish	Variance
MMS Cleanroom Development	1/4/10	12/1/11	1/4/10	10/17/11	0 days
Procurement/Contract Award/Kick-off Mtg	1/4/10	6/17/10	1/4/10	5/12/10	26 days
Plug & Play					
Plug & Play Design					
Chilled Water Mains Design	1/4/10	3/25/10	1/4/10	3/25/10	0 days
Electrical Feeders Design	1/4/10	3/4/10	1/4/10	3/4/10	0 days
Steam Design	5/1/10	5/29/10	5/1/10	5/29/10	0 days
Crane Structure Support Design	2/18/10	8/27/10	2/18/10	8/27/10	0 days
Plug & Play Construction					
Chilled Water Construction	3/27/10	7/6/10	3/30/10	7/6/10	0 days
Electrical Construction	3/15/10	10/9/10	3/15/10	9/30/10	7 days
Steam Construction	6/1/10	9/30/10	6/1/10	9/30/10	0 days
Crane					
Crane Requirements & Procurement/Award	1/4/10	9/13/10	1/4/10	9/13/10	0 days
Crane Design	9/13/10	12/31/10	9/13/10	12/3/10	20 days
Install Crane Runway	2/4/11	2/10/11	2/4/11	2/10/11	0 days
Crane Rework	8/1/11	11/2/11	N/A	N/A	N/A
Crane Installation & Certification	11/2/11	11/21/11	3/25/11	3/31/11	235 days
Clean Room					
Clean Room Design	6/18/10	12/2/10	6/18/10	10/27/10	26 days
Clean Room Installation	12/8/10	10/12/11	11/26/10	6/30/11	74 days
Outfit Cleanroom (MMS)	10/12/11	10/17/11	7/18/11	8/29/11	41 days
Outfit Room 160 for Technical Use (FMD)					
Connectivity Design	11/22/10	3/8/11	10/28/10	1/26/11	29 days
Connectivity Construction	2/1/11	8/1/11	5/19/11	8/29/11	+28 days
B7 Sprinker Re-Work	4/30/11	4/30/11	4/30/11	4/30/11	0 days
B29 Sprinkler Work Complete	5/16/11	5/16/11	5/16/11	5/16/11	0 days
MMS Cleanroom Beneficial Occup. Ready	10/17/11	10/17/11	8/29/11	8/29/11	21 days
RESERVE	10/12/11	10/12/11	8/30/11	10/12/11	0 days
MMS Cleanroom Needed	10/17/11	10/17/11	10/17/11	10/17/11	0 days
MMS Cleanroom Crane Needed	12/1/11	12/1/11	10/17/11	10/17/11	45 days

Figure 8-35. A Summary Schedule Variance Report adds columns to a basic Summary Schedule to show start date and finish date variances in summary-level activities.

Float/Slack Trend Report

Float/Slack Trend Reports show the history of slack for a particular area or group of P/p activities, usually with float/slack totals organized in a table format with an associated graph showing the float/slack changes over time. This report may be used to show trends by WBS element, by milestone, by driving paths for certain technical milestones, or by any other logical grouping. The report should show the total slack for each reporting period. Reasons for total slack changes between reporting periods should be noted. Figure 8-36 and Figure 8-37 illustrate typical *Float Erosion Tables* and Figure 8-38 illustrates a typical *Float Trend Report*. Figure 8-39 shows another *Float Trend Report* with summary activities for additional context as to when float degradation occurred during the P/p life cycle. See Figure 7-34 and Figure 7-35 for additional examples and guidance on using these reports for Schedule Control.

Total Float Report					
			Working Days		
Milestone	**Baseline Finish**	**Forecast Finish**	**Sep '14**	**Oct '14**	**Nov '14**
S/C - Propulsion Delivery to I&T	3/27/2015	3/27/2015	0	0	0
S/C - PDDU Delivery to I&T	3/17/2015	3/26/2015	6	1	1
S/C - SARA (SRC/TAG SAM) Del to I&T	8/5/2015	8/5/2015	2	0	0
S/C - C&DH #1 Delivery to I&T	3/6/2015	3/17/2015	8	8	8
S/C - GN&C Lidar Delivery to I&T	7/20/2015	7/16/2015	13	7	7
S/C - SDST Delivery to I&T	3/6/2015	3/31/2015	8	4	4
OVIRS Instr - Delivery to S/C I&T	8/12/2015	8/12/2015	43	39	39
OCAMS Instr - Deliveyr to S/C I&T	8/21/2015	8/17/2015	4	4	4
Ground System - Launch Readiness	6/30/2016	6/30/2016	45	45	45

Figure 8-36. A Float Erosion Table, showing the decrease in total float on key milestones over time.

Activity	Comment	Plan Date	Need Date	Forecast Date	Plan Float	Current Float	Stoplight
C&DH	None	6/1/20	7/1/20	6/15/20	30	16	🟩
Avionics	Attitude controllers failed qual tests, design change pending	5/15/20	7/1/20	6/28/20	47	3	🟥
Structures							
Primary Structure	Late delivery of sidewall panels	6/1/20	6/15/20	6/17/20	14	-2	🟥
Secondary Structure	None	6/20/20	7/1/20	6/25/20	11	6	🟨
Mechanisms	Early delivery of hatches.	7/1/20	7/5/20	6/20/20	4	15	🟩
Pyros	GUIDEP notice of bad lots, batch testing underway	7/1/20	7/10/20	7/15/20	9	-5	🟥
Thermal Control	None	7/10/20	7/20/20	7/10/20	10	10	🟩
----		----	----	----	----	----	
----		----	----	----	----	----	

Figure 8-37. A Float Erosion Table, showing the decrease in total float on key activities over time, with planned dates, need dates, and forecast dates, as well as a stoplight indicator.

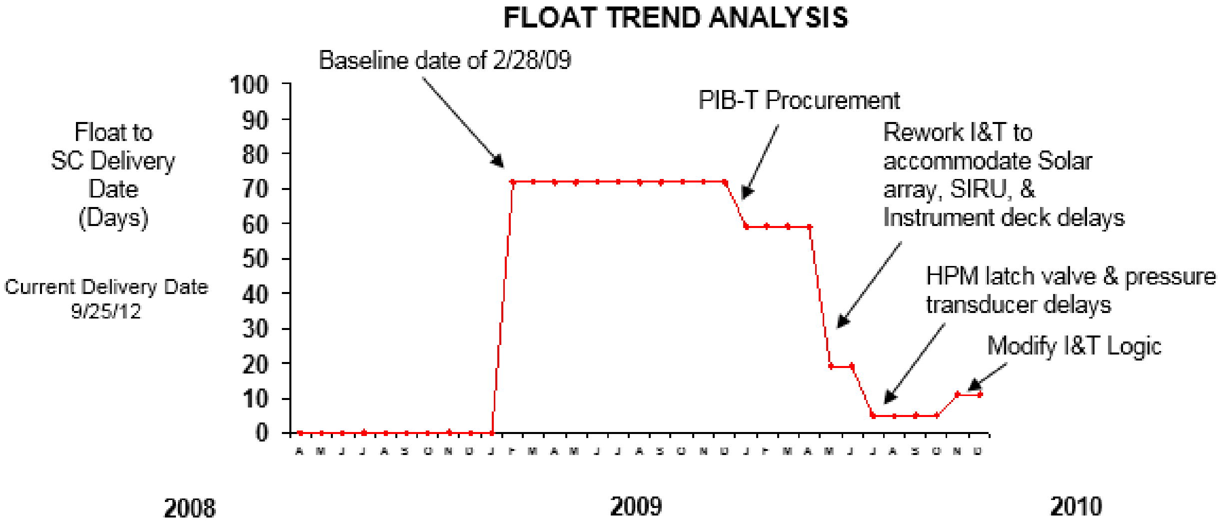


Figure 8-38. A Float Trend Report with callouts identifying the reasons for float degradation over time for activities leading to a specific milestone (e.g., Spacecraft Delivery).

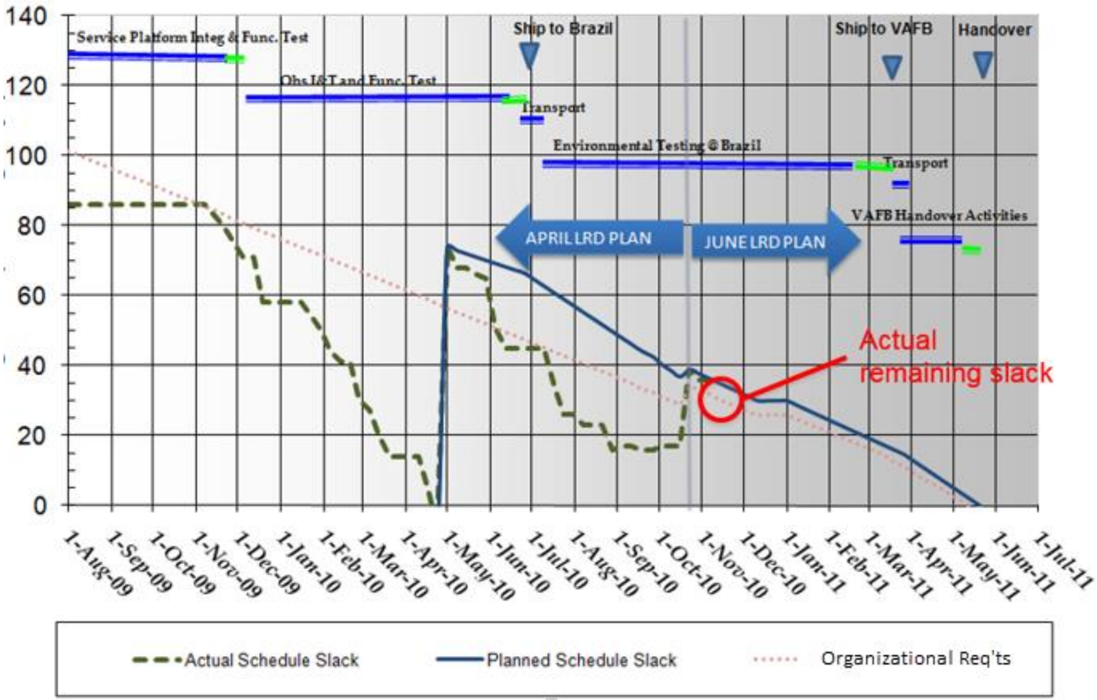
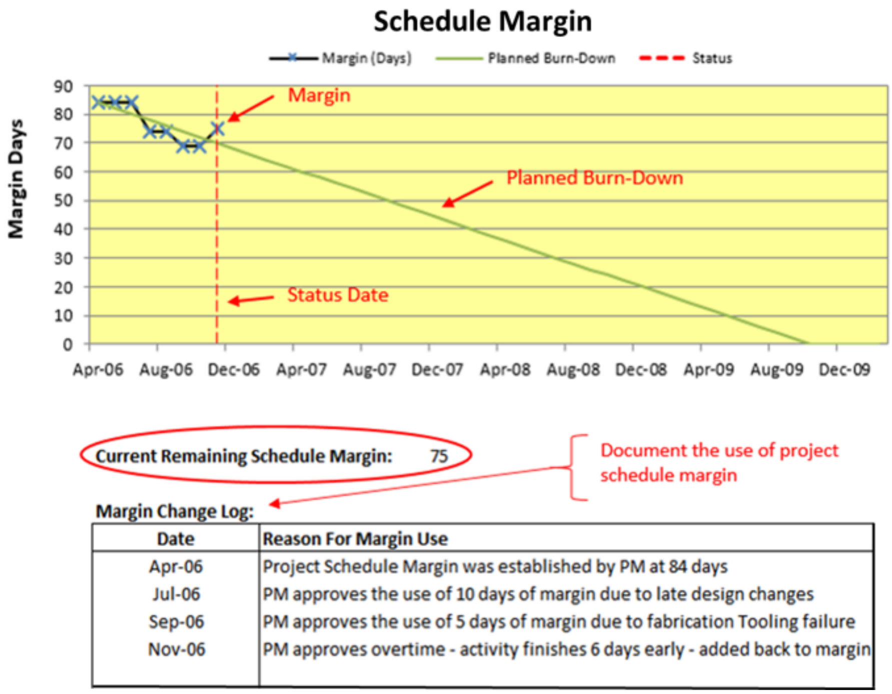


Figure 8-39. A Float Trend Report highlighting planned schedule float versus actual schedule float over time in relation to key activities and milestones.

Margin Trend Report/Log

Margin Trend Reports show the trend, or burndown, of schedule margin usage over the life of the P/p. Any change between reporting periods or deviation from a pre-determined margin burndown should be clearly explained in an associated *Margin Change Log*. *Margin Trend Reports* are further explained in

7.3.3 as used for Schedule Control. Figure 8-40 shows a *Margin Trend Report* and the associated *Margin Change Log*.



Current Remaining Schedule Margin: 75

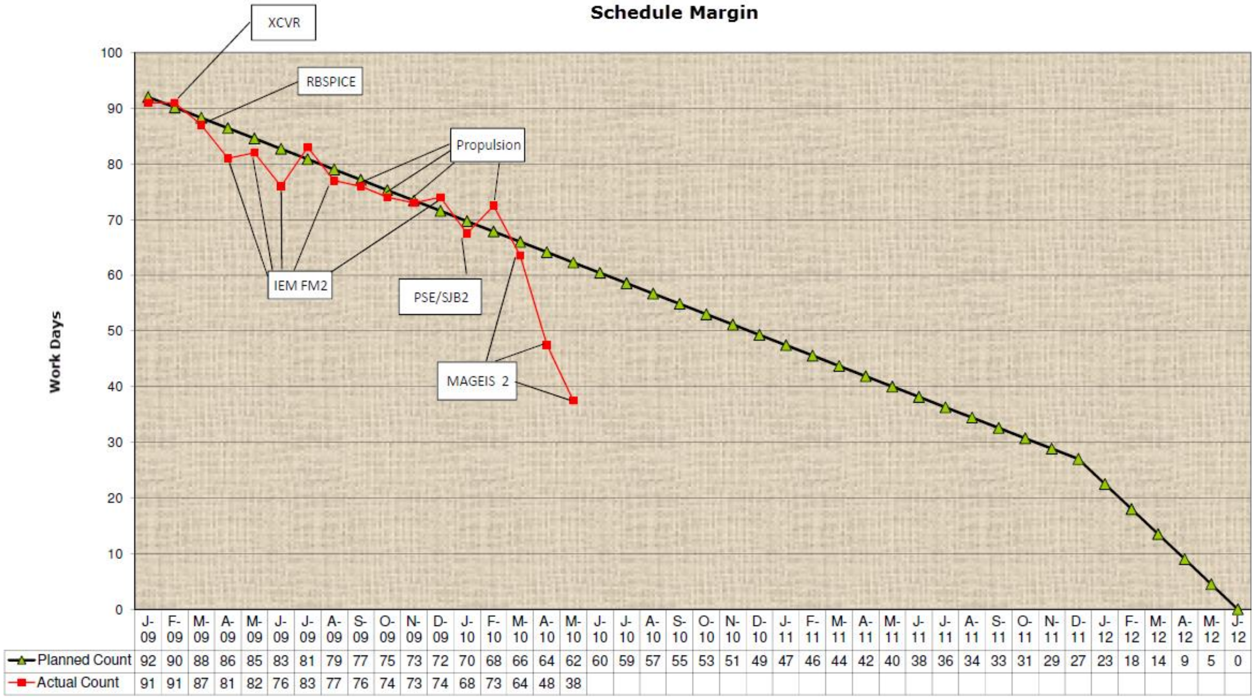
Document the use of project schedule margin

Margin Change Log:

Date	Reason For Margin Use
Apr-06	Project Schedule Margin was established by PM at 84 days
Jul-06	PM approves the use of 10 days of margin due to late design changes
Sep-06	PM approves the use of 5 days of margin due to fabrication Tooling failure
Nov-06	PM approves overtime - activity finishes 6 days early - added back to margin

Figure 8-40. A Margin Trend Report and associated Margin Change Log captures the actual burndown of P/p schedule margin over time in relation to the planned burndown.

Figure 8-41 and Figure 8-42 show typical *Margin Trend Reports* with minor differences in added contextual information.



	J-09	F-09	M-09	A-09	M-09	J-09	J-09	A-09	S-09	O-09	N-09	D-09	J-10	F-10	M-10	A-10	M-10	J-10	J-10	A-10	S-10
▲ Planned Count	92	90	88	86	85	83	81	79	77	75	73	72	70	68	66	64	62	60	59	57	55
■ Actual Count	91	91	87	81	82	76	83	77	76	74	73	74	68	73	64	48	38				

	O-10	N-10	D-10	J-11	F-11	M-11	A-11	M-11	J-11	J-11	A-11	S-11	O-11	N-11	D-11	J-12	F-12	M-12	A-12	M-12	J-12
▲ Planned Count	53	51	49	47	46	44	42	40	38	36	34	33	31	29	27	23	18	14	9	5	0
■ Actual Count																					

Figure 8-41. A Margin Trend Report, with an associated table showing planned versus actual margin days over time.

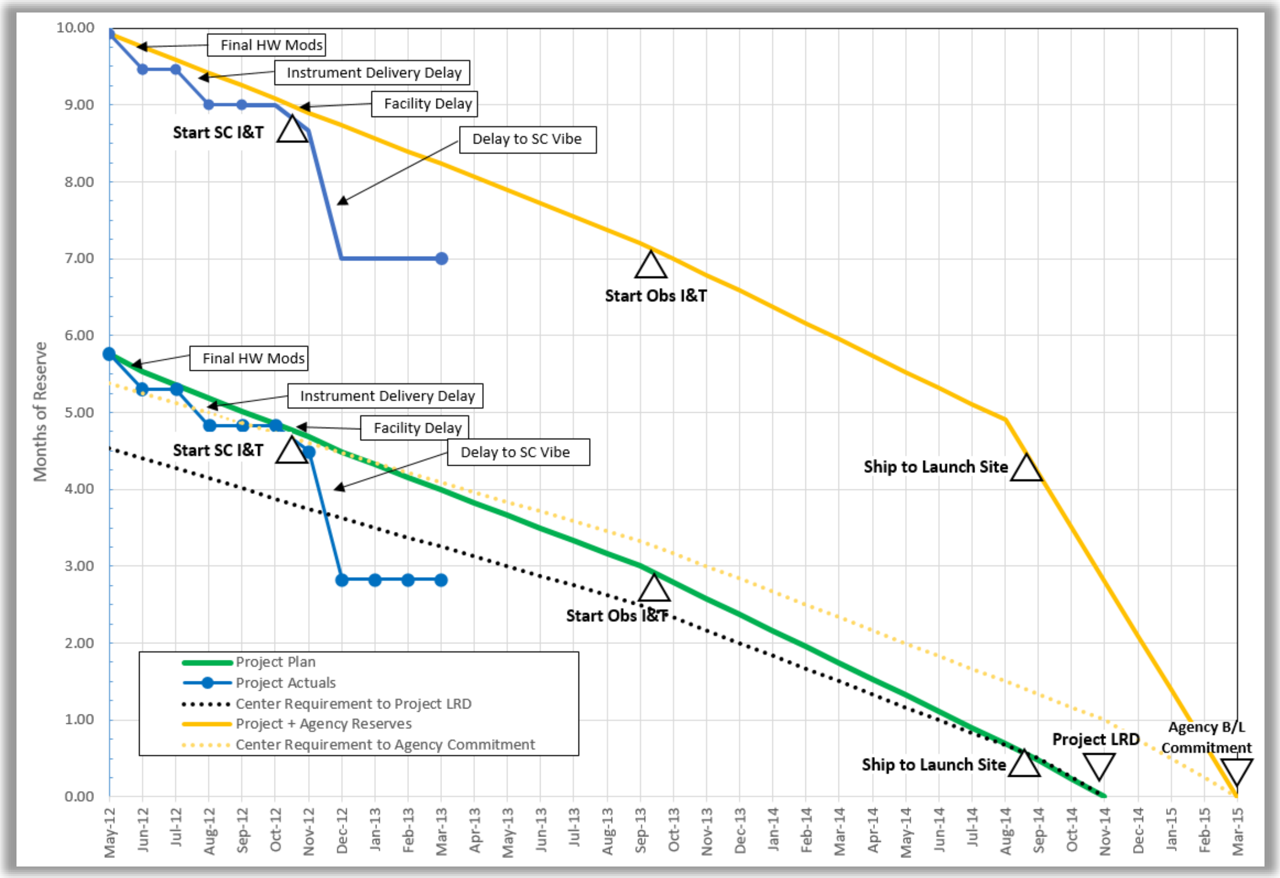


Figure 8-42. A Margin Trend Report with contextual callouts and major milestones, comparing the actual margin burndown to: (1) the planned burndown for the P/p Management Agreement LRD, and (2) the planned burndown for the Agency Baseline Commitment LRD.

As described in Section 7.3.3, understanding the difference between available margin days and other non-working calendar days is helpful to the PM, especially in the later phases of the P/p. Figure 8-43 illustrates how a P/p can track schedule margin (and contingency) erosion (and restoration) over time against the planned depletion.

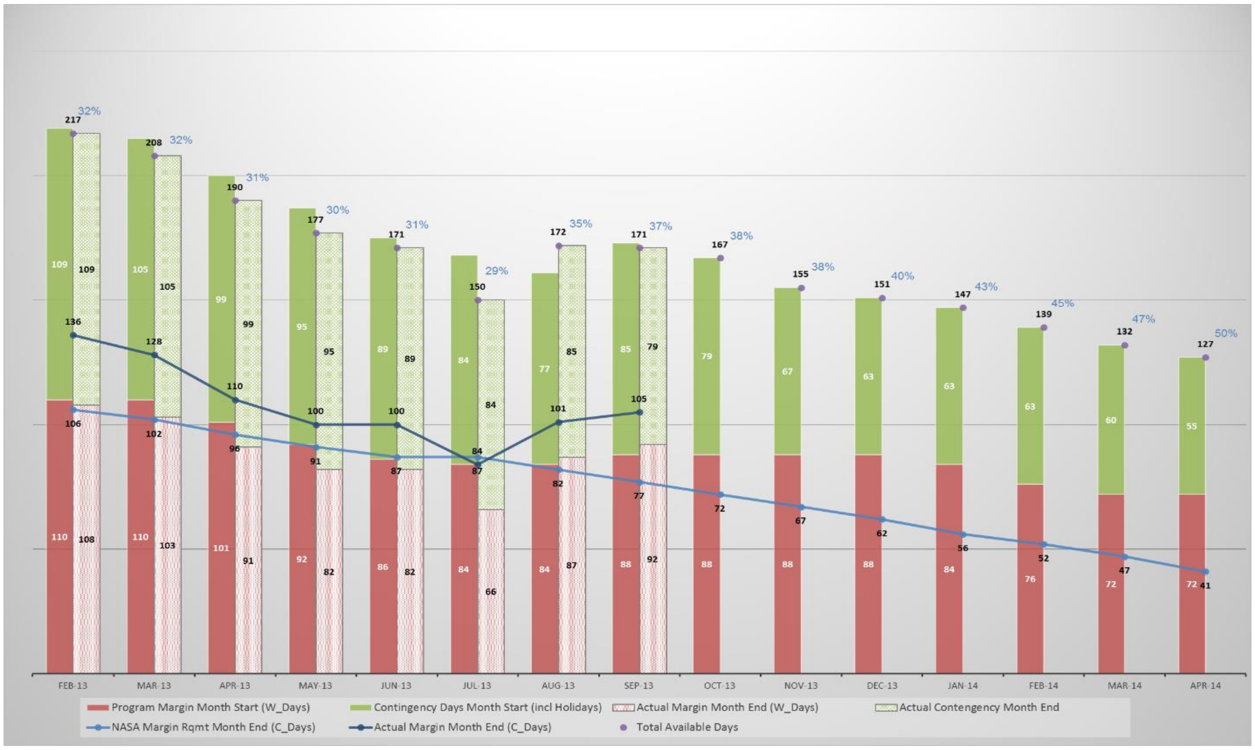


Figure 8-43. A Margin Trend Report differentiating between working days (margin) and non-working days (contingency). A report that captures both working and non-working days provides additional clarity for the PM to understand the total time available for mitigating risks versus addressing performance issues.

EVM Reports

EVM metrics are widely used to communicate progress against baseline as well as changes in the schedule progress month-to-month. Several examples of *EVM Reports* follow:

BEI: The BEI is the ratio of activities actually completed to activities planned to be completed. BEI is described further in Section 7.3.3.1.3. Figure 7-18 illustrates a typical BEI report showing both the current BEI calculation and the BEI trend over time. Figure 8-44 also illustrates a cumulative BEI report. Figure 8-45 shows the BEI performance calculated on a month-by-month basis over the entire length of a project. Figure 8-46 shows the BEI performance over a nine-month window.

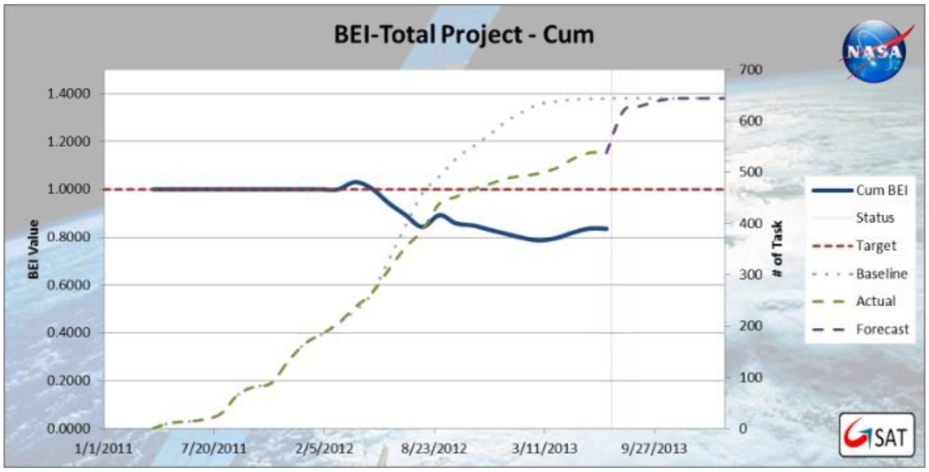


Figure 8-44. An example of a cumulative BEI Trend Report.

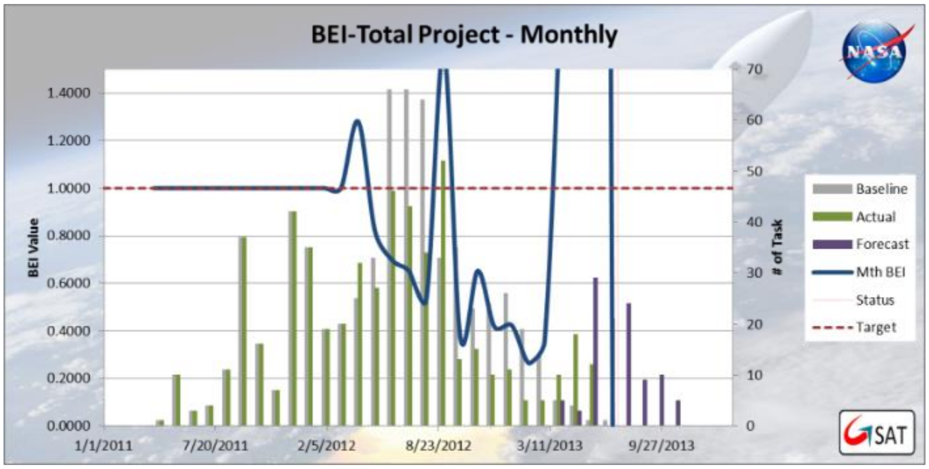
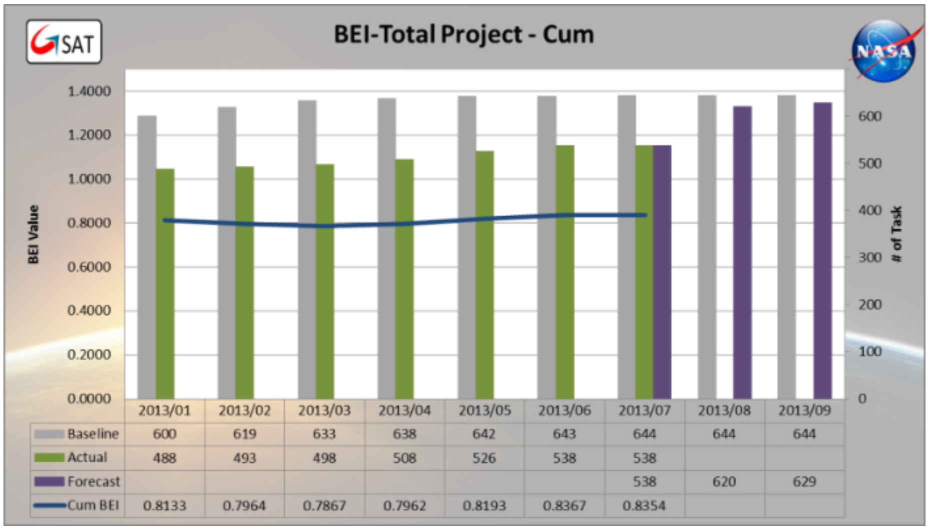


Figure 8-45. An example of BEI Trend Report month-by-month over the entire length of a NASA project.



	2013/01	2013/02	2013/03	2013/04	2013/05	2013/06	2013/07	2013/08	2013/09
Baseline	600	619	633	638	642	643	644	644	644
Actual	488	493	498	508	526	538	538		
Forecast							538	620	629
Cum BEI	0.8133	0.7964	0.7867	0.7962	0.8193	0.8367	0.8354		

Figure 8-46. An example BEI Trend Report showing performance over a nine-month window.

CEI: The CEI reflects an index value, which is determined by dividing the number of tasks/milestones that actually finished during the current reporting period by the number of tasks that were forecasted to finish during the reporting period. CEI is described further in Section 7.3.3.1.3. Figure 7-20 illustrates a typical CEI trend chart. Figure 8-47 shows the CEI performance calculated on a month-by-month basis over the entire length of a project. Figure 8-48 shows the CEI performance over a nine-month window.

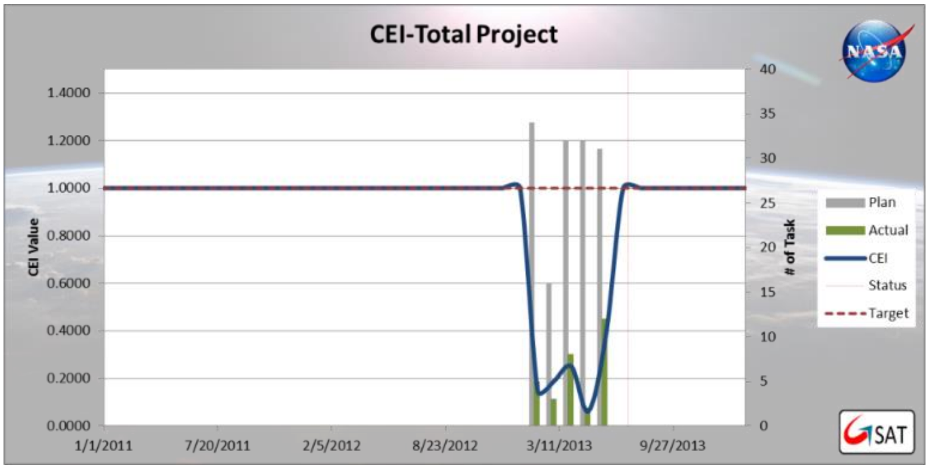
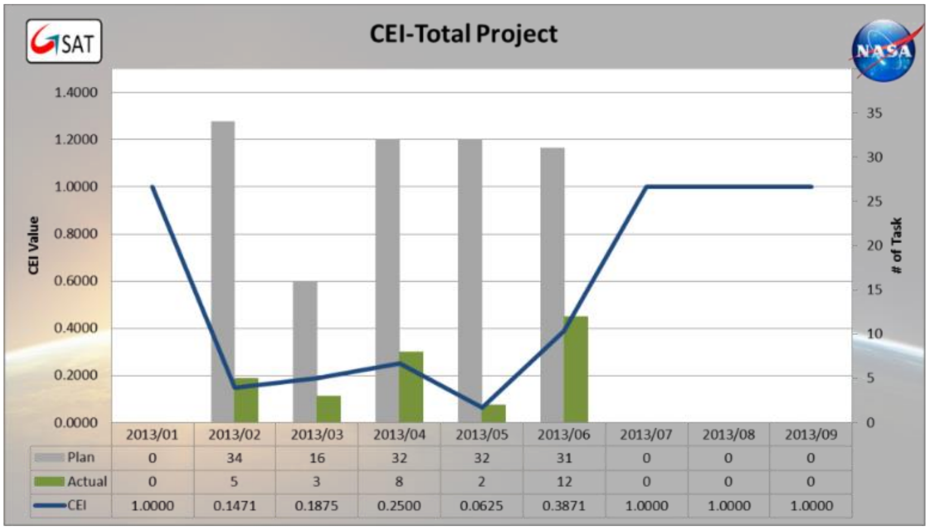


Figure 8-47. An example of CEI Trend Report month-by-month over the entire length of a NASA project.



	2013/01	2013/02	2013/03	2013/04	2013/05	2013/06	2013/07	2013/08	2013/09
Plan	0	34	16	32	32	31	0	0	0
Actual	0	5	3	8	2	12	0	0	0
CEI	1.0000	0.1471	0.1875	0.2500	0.0625	0.3871	1.0000	1.0000	1.0000

Figure 8-48. An example CEI Trend Report showing performance over a nine-month window.

HMI: HMI measures the number of baseline tasks completed early or on time to the number of tasks with a baseline finish within a given month. HMI is described further in Section 7.3.3.1.3. Figure 7-21 illustrates a typical HMI trend report. Figure 8-49 shows the HMI performance calculated on a month-by-month basis over the entire length of a project. Figure 8-50 shows the HMI performance over a nine-month window.

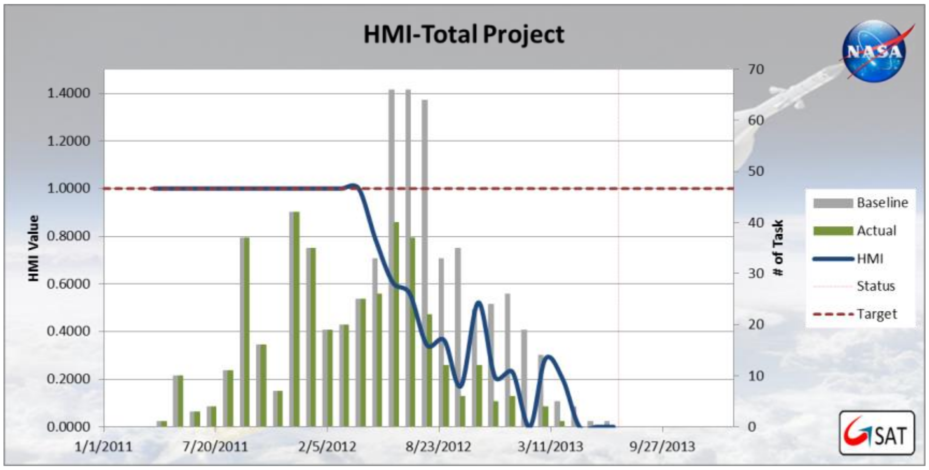
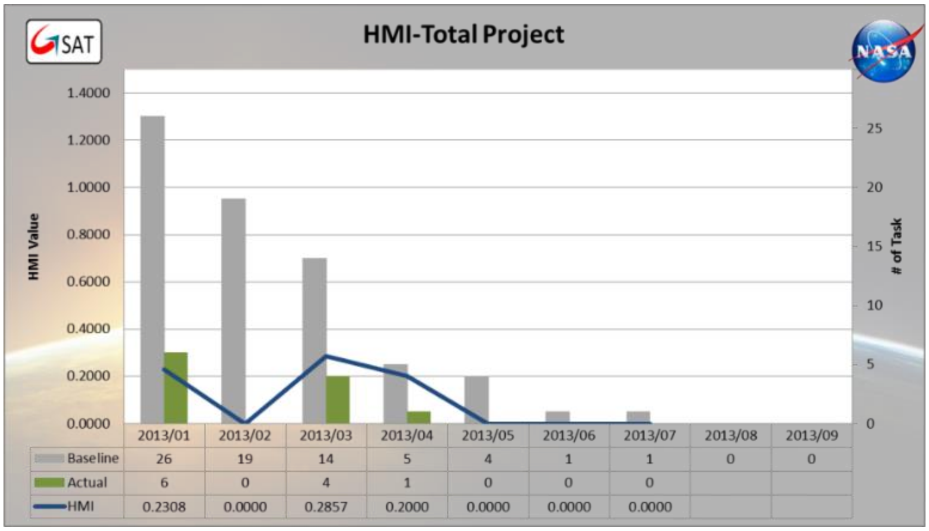


Figure 8-49. An example of HMI Trend Report month-by-month over the entire length of a NASA project.



	2013/01	2013/02	2013/03	2013/04	2013/05	2013/06	2013/07	2013/08	2013/09
Baseline	26	19	14	5	4	1	1	0	0
Actual	6	0	4	1	0	0	0		
HMI	0.2308	0.0000	0.2857	0.2000	0.0000	0.0000	0.0000		

Figure 8-50. An example HMI Trend Report showing performance over a nine-month window.

SPI: The measures the budgeted cost of work performed up to the "Time Now" date, divided by the budgeted cost of work scheduled to be performed. It provides the ratio of P/p dollars earned-to-date (work performed) to the dollars the P/p should have earned (work planned). SPI is described further in Section 7.3.3.1.4 and shown in Figure 7-23.

SPI$_t$: SPI$_t$ is the ratio of earned schedule to actual duration. This is determined by calculating the Earned Schedule (ES), which is the time that equates the budgeted cost of work performed (BCWP) to the budgeted cost of work scheduled (BCWS), and the dividing the ES by the actual P/p duration up to "Time Now" (AT). It is analogous to the cost indicator for Cost Performance Index (CPI), as both are referenced to "actuals". It provides the ratio of the P/p time earned-to-date to the time the P/p should have earned. SPI_t is described further in Section 7.3.3.1.3. Figure 8-51 illustrates the SPI and SPI(t) calculations.[175]

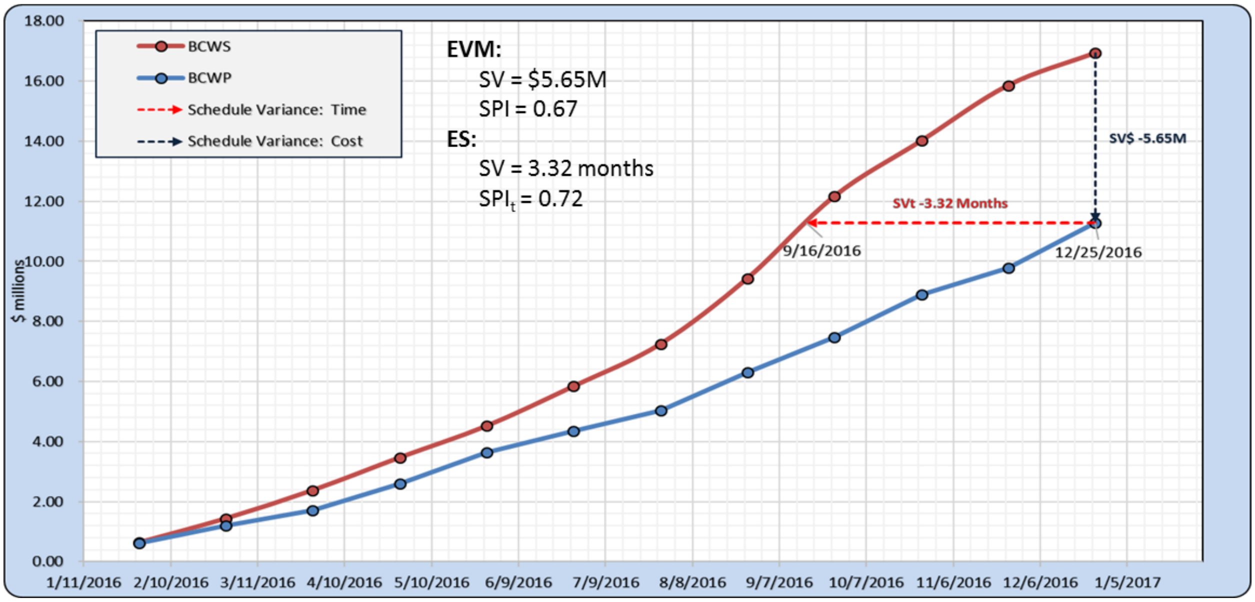


Figure 8-51. An EVM Trend Report showing EVM and Earned Schedule-based calculations for Schedule Variance (SV vs SV_t) and Schedule Performance Index (SPI vs. SPI_t).

For P/ps that do not require EVM, similar reports can be generated can be generated using the planned or schedule baseline dates.

Risk-Based Completion Trend Report

A *Risk-Based Completion Trend Report* is determined by repeating the *SRA* at routine intervals and tracking the trend of the probabilistic completion date over time. This trend report can help to communicate the effectiveness of risk mitigation over time. Risk-based Completion Trend charts are further discussed in Section 7.3.3.2.2 and illustrated in Figure 7-43. Figure 8-52 shows another example of a risk-based trend report showing the confidence level associated a project's end-item delivery date over time.

---

[175] Drexler, J., T. Parkey and C. Blake. "Techniques for Assessing a Project's Cost and Schedule Performance." NASA Cost and Schedule Symposium. 2017.

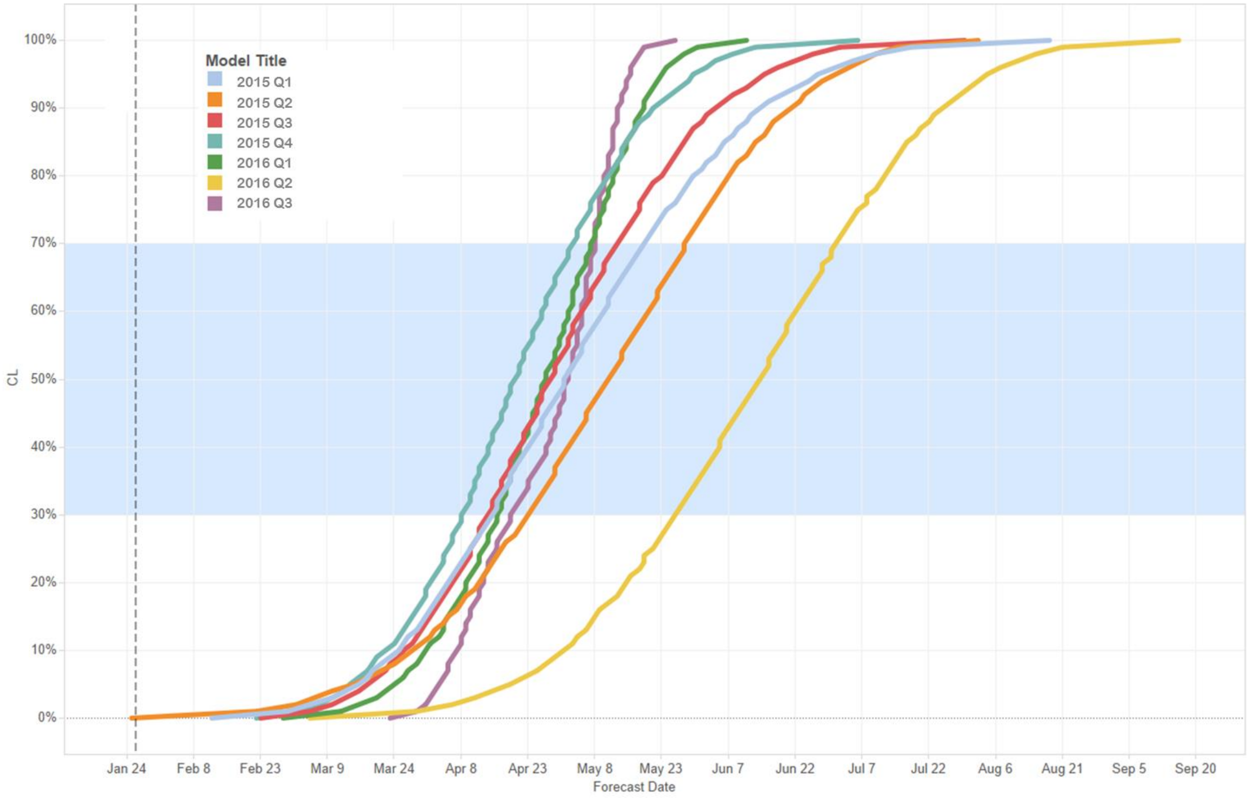


Figure 8-52. Example of a Risk-based Trend Chart for completion date used in a NASA project.

Risk-Based Tracking against MA/ABC Report

Results from *ICSRAs* can be tracked over time to help the P/p understand how it's performing against the MA and ABC. This process is described in Section 7.3.3.2.4 and illustrated in Figure 7-46.

Schedule Baseline Change Log

The *Schedule Baseline Change Log* is used to record and track approved changes to the baseline, as described in Section 7.3.1. A typical template is included in Figure 7-4, and an example is shown in Figure 8-53.

Project Element	Provider	IMS Baseline Revision	Revision Date	Notes
Total ABC Project	GSFC	KDP-C Baseline	May 7, 2016	
Spacecraft / Observatory I&T / Launch Site I&T	Lockheed Martin	Revision C	April 2, 2016	ECP 202 – combine S/C with mission CDR
TM-1 Instrument	AETD	Revision A	December 1, 2015	Budget adjustment
IVI Instrument	Ball	Contract Baseline	November 1, 2015	IBR Complete
Ground System	Harris	Revision B	April 5, 2016	ECP 23 – Add ETE3
Launch Vehicle	SpaceX	TBD	TBD	Exercise option 1Q 2018

Figure 8-53. An example of a Schedule Baseline Change Log.

8.3.2.4.3 Forecast Reporting: Prediction of Future Status and Progress (Projections)

This category of communication and reporting refers to any report generated from a stochastic or probabilistic modeling technique such as an SRA/ICSRA. This report also involves comparison, trend or generates a metric that is risk and uncertainty informed including predictions utilizing EVM metrics. Examples of forecast reports are described in the following sections.

Probability of On-time Delivery of Critical Items Report

As described in Section 7.3.3.2.1, SRAs can be performed routinely, considering the current risks and uncertainties at each status date, to show the probability of the on-time delivery of critical items. Each time the SRA is run, the completion-date probability distributions for each activity of interest are extracted from the SRA run and plotted with respect to both the current plan date and the need date to produce a "BandAid" Chart. Examples of *Probability of On-Time Delivery of Critical Items Reports* are shown in Figure 7-40 and Figure 8-54.

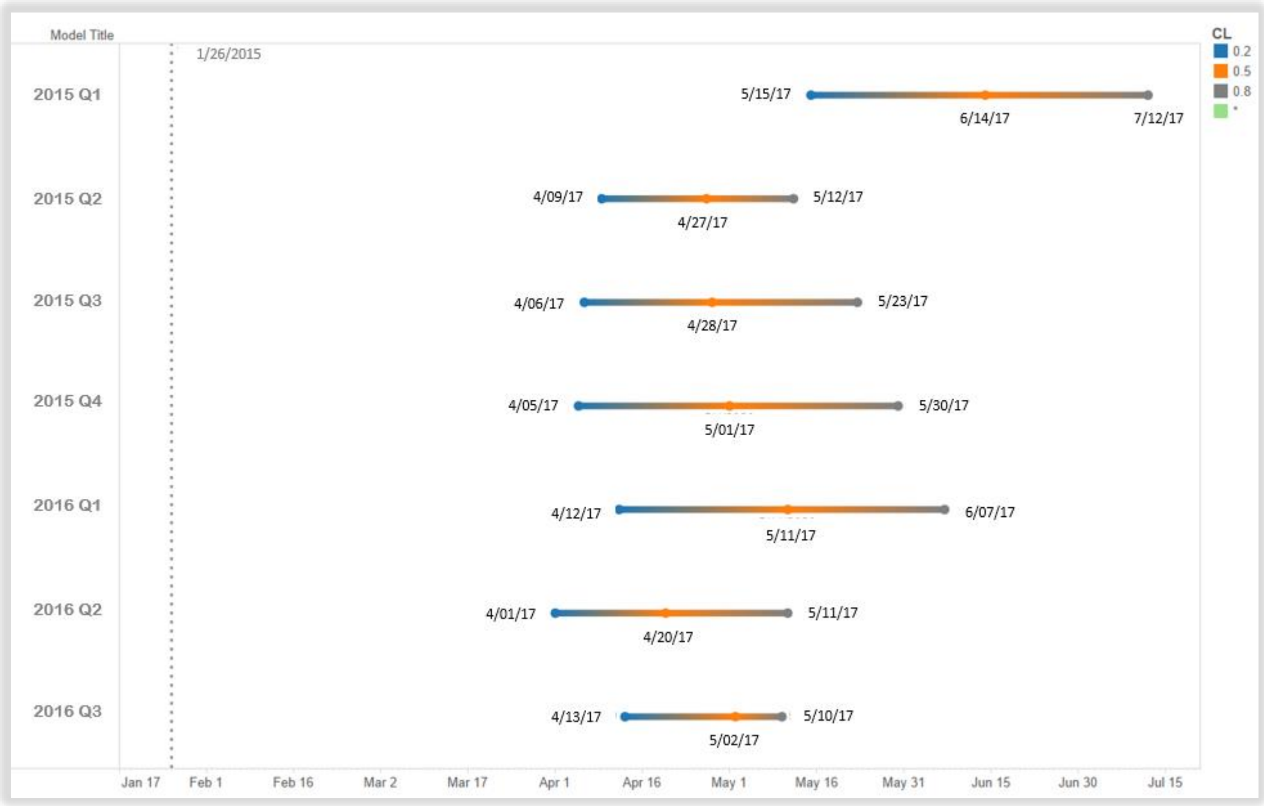


Figure 8-54. An example of a Probability of On-Time Delivery of Critical Items Report.

Stochastic Critical Path Report

Critical path reports may reflect stochastic (or probabilistic) critical path(s), such as those generated from probabilistic SRA. A *Stochastic Critical Path Report* helps to identify the most likely critical schedule drivers for the P/p due to the potential impact of uncertainties and risks. They are often outputs of SRA tools and are presented in the form of a table showing the "criticality" associated with specific activities as a result of the SRA, as shown Figure 8-55.

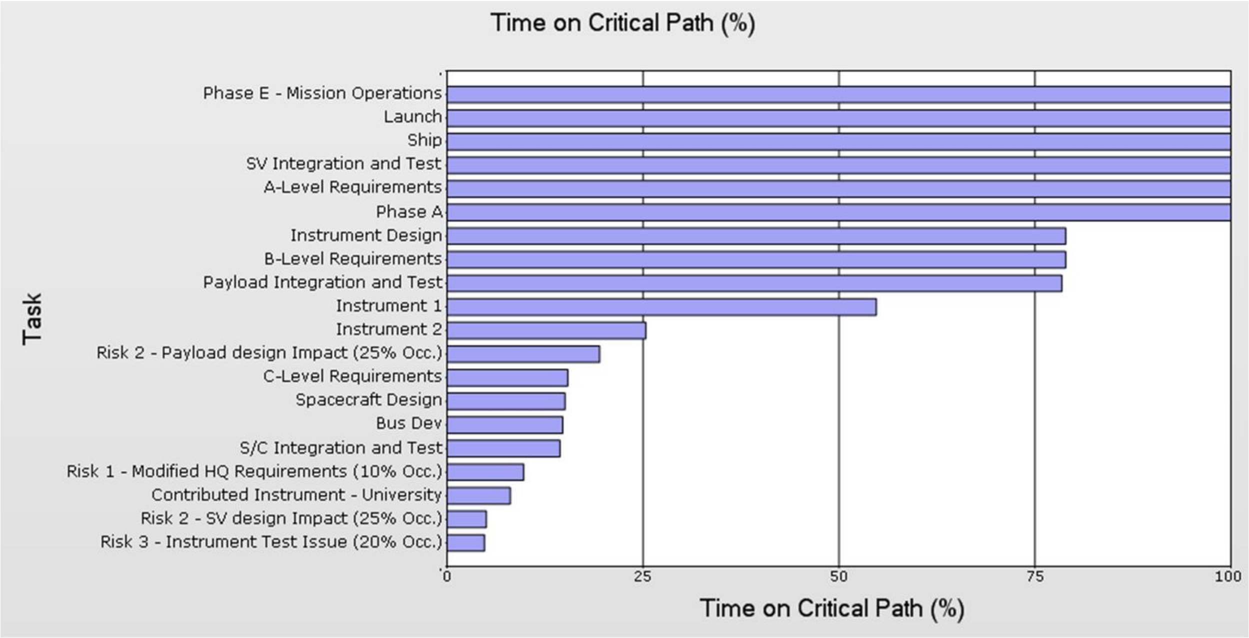


Figure 8-55. A stochastic Critical Path Report generated from a probabilistic SRA.

Sensitivity Report

"Tornado" charts are typical outputs of Monte Carlo simulation tools and can illustrate sensitivity or cruciality for activity durations, costs, and risks, as described in Section 6.3.2.5.2.3. Figure 8-56 shows an example of a *Risk Sensitivity Report* used in risk prioritization.

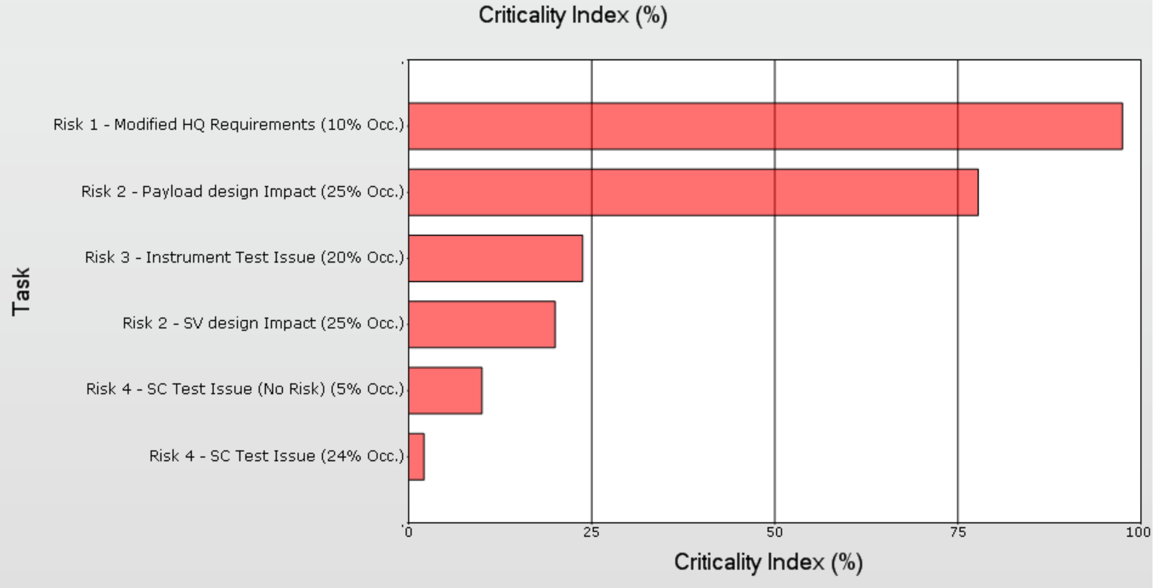


Figure 8-56. An example of a tornado chart showing risk sensitivity.

Confidence Level Report

A *Confidence Level Report* is composed of a CDF, which is used to plot the confidence levels associated with possible dates and/or costs resulting from an *SRA/ICSRA*, as described in Section 6.3.2.5.2.1 and illustrated in Figure 6-50. Figure 8-57 shows another example of a schedule *Confidence Level Report* with the underlying histogram.

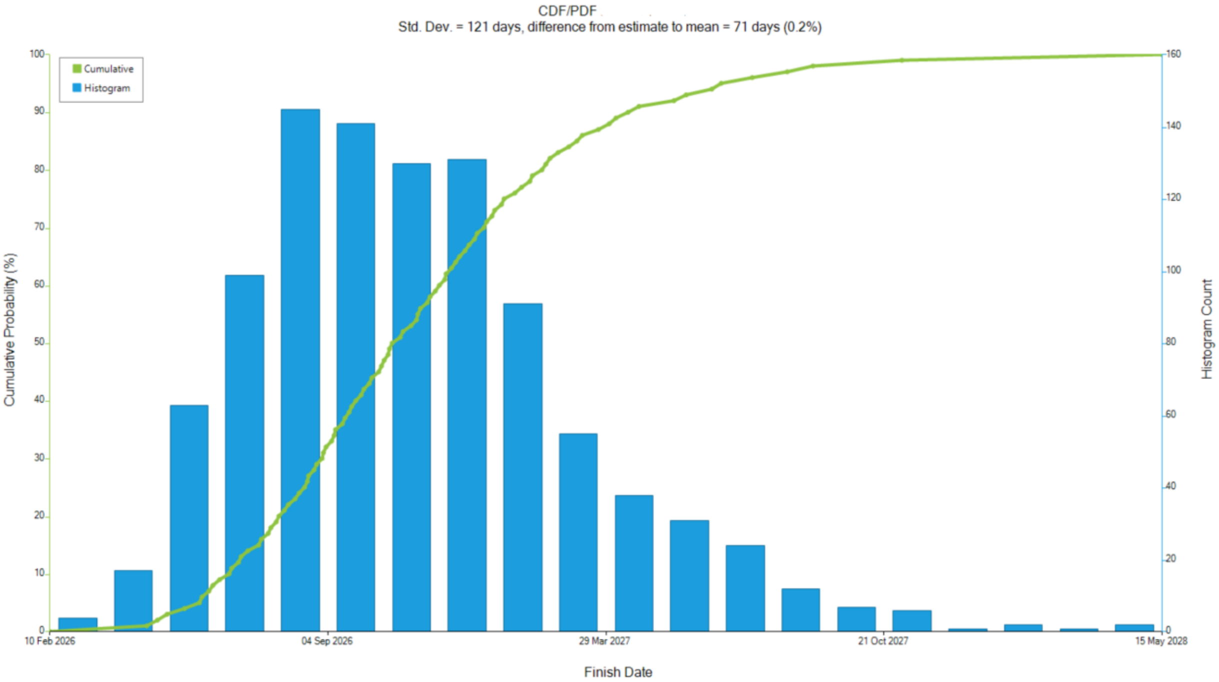


Figure 8-57. An example of a schedule confidence level report.

SRA Reports

A CDF, or S-curve, can be used to communicate information about *SRA/ICSRA* simulation runs for reporting as follows:

- *Analysis of Alternatives Reports* are usually generated early in the P/p life cycle as described in Section 6.3.2.5.3.1 and illustrated in Figure 6-55
- *Completion Range Reports* are developed prior to baselining as described in Section 6.3.2.5.3.4 and illustrated in Figure 6-59.
- *Margin Sufficiency Reports* help to track and evaluate whether the P/p is carrying enough margin throughout the lifecycle, as described in Sections 6.3.2.5.3.6 and 7.3.3.2.3, and illustrated in Figure 6-63 and Figure 6-64.
- *Trade Studies/Risk Sensitivity Analysis Reports* can be generated as part of routine P/p assessments or to support SRB assessments at LCRs, as described in Section 6.3.2.5.3.3 and illustrated in Figure 6-57.

JCL Report (Scatterplot)

A *JCL Report* is composed of a scatterplot drawn from the simulation data table, which is produced from the *ICSRA*. The *JCL* is determined from the scatterplot by finding those cost-schedule pairs that have the specified confidence level, i.e. 70%, per the NASA requirement. The scatterplot and *JCL* are further described in Section 6.3.2.4 and illustrated in Figure 8-58.

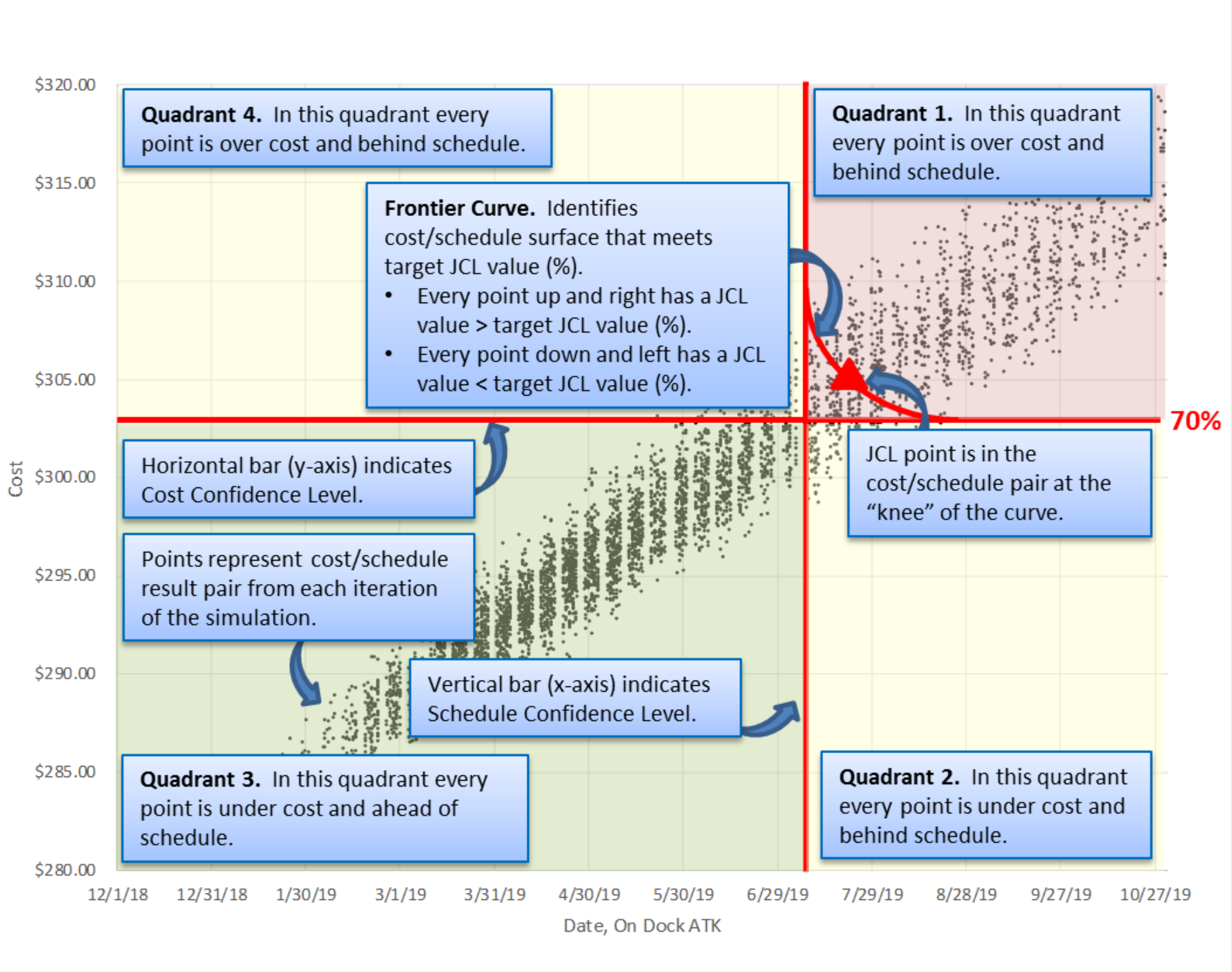


Figure 8-58. An illustration of the characteristics of a JCL Scatterplot.

8.3.3 Schedule Information and Knowledge Capture

Electronically available schedules and associated schedule data can provide a wealth of information. Routinely backing up schedule data helps to ensure important schedule information is not lost and is also retrievable when needed. The archival process is the process of documenting P/p data in a timely manner, as well as formally accepting the P/p's product and lessons learned. It includes verifying scope, archiving or maintaining P/p information, and producing summary information about items such as cost, work accomplished, risks, issues, problems, and schedules. This summary information may be included in P/p reports, or other reports generated for major P/p reviews (e.g., LCRs, IBRs, etc.). Care should be taken to properly label and store these datasets. The backup, archive, and retrieval process should address all phases of the P/p and be coordinated with the Configuration Manager and documented in the *SMP*.

8.3.3.1.1 Informal Backups

Informal backups ensure important schedule information is not lost from one status period to the next. It also allows for more time-sensitive traceability between specific *IMS* iterations and other schedule-related data, such as P/p risks and issues, or specific schedule assessments or analyses.

Integrated Master Schedule Backups

It is a best practice for the P/p schedule and associated BoEs to be routinely backed up throughout the P/p lifecycle, starting even before the schedule is baselined. Schedules should, at a minimum, be backed up by the P/S on a monthly basis or prior to any major changes in the schedule (e.g., logic sequence, task/milestone additions, and deletions). This practice ensures that a record of changes is maintained for a number of beneficial reasons. Backup may include electronic and hard copies, but electronic copies at a minimum are recommended. Backup files should be verified periodically and stored in a secure location with controlled access.

Schedule Data Backups

It is a best practice for schedule performance data, as well as assessment and analysis inputs, models, and results to be routinely backed up for easy recovery, repeat analysis, and development of trends. Maintaining records that explain all changes in activity durations or logic as changes are made, or especially at life cycle reviews can prove to be invaluable at later stages of the P/p. Activity log notes are often used for the purpose of capturing logic when changes occur. Both activity log notes and information captured at life cycle reviews will provide valuable data if it becomes necessary to reconstruct what happened and why. Backed-up schedule data is essential for performing assessment, analysis, and control processes, such as trending schedule performance over time and forecasting completion dates. It is also invaluable in estimating efforts on future P/ps, providing information to support the *BoE* for overall P/p schedule duration, specific task durations, task duration uncertainty, and schedule margin.

8.3.3.1.2 Formal Archives

Properly following through with knowledge capture activities on current P/ps can positively impact the success of future P/ps by providing continuous improvement in Schedule Management processes. Formally archiving schedule information facilitates the retention of records generated and collected throughout the P/p life cycle. It also provides a means by which communicate important schedule information with stakeholders and the broader schedule community. For P/p’s with contracted efforts, archiving also occurs at contract closeout and ensures that the contractors' final scheduled work is completed and delivered, and that billings or invoices are complete. It is important to review and document contractor performance to the schedule, including any changes that occurred throughout the P/p life cycle and the rationale for the changes. Archived data should be organized according to the CM/DM function requirements at each level of management (e.g., Agency-level Schedule Repository, CADRe, and EVM Repositories, as well as MD/Center/P/p-level repositories).

Integrated Master Schedule Archives

It is a best practice for the original baseline IMS, any significant replan IMSs, all rebaseline IMSs, and as-built IMSs, along with schedule versions at each major life cycle review milestone to be the minimum for P/p schedule archives. Perhaps the two most important versions of the P/p schedule are the original schedule baseline (discussed in Chapter 7) and the “as-built” schedule. The schedule baseline is the original, approved, time-phased P/p schedule plan of the work to be performed that serves as the basis for performance measurement during P/p implementation. The “as-built” schedule is the completed set of schedule data after all P/p work and represents what actually was implemented and how long each task took. Additionally, schedule versions that reflect phase changes or those that capture significant workflow or duration changes, such as replans or rebaselines, represent key status points. These iterations of the schedule are essential for estimating, trending, forecasting, and analysis efforts on both current and future P/ps and should be archived within a master database or commonly-accessible repository. Historical schedules can also be used for future P/ps by saving schedule files as templates.

Archived schedules should be placed within a P/p schedule database, as well as in or commonly-accessible repository, when appropriate. Formally archiving schedules in the Agency-level Schedule Repository, described in Section 5.5.9, is required for all 7120.5 and 7120.8 P/p's with LCCs of $50 Million dollars or greater. These P/ps are required to submit the *IMS* in its native scheduling tool formats (e.g., MS Project .mpp files and/or Primavera P6 files). Specific Schedule Repository requirements can be found on the Schedule Community of Practice (SCoPe) website.[176] P/ps not subject to the Schedule Repository requirement should maintain an archive of *IMSs* in the highest-level repository appropriate as determined by their organization, whether it's the Agency Schedule Repository or a MD- or P/p-level schedule repository.

Historical Schedule Narrative Archives

It is a best practice for narrative associated with the original baseline IMS any significant replan IMSs, all rebaseline IMSs, and as-built IMSs, along with schedule versions at each major life cycle review milestone to be the included in P/p schedule archives. A historical narrative presents past P/p schedule information in a meaningful format with content defined and documented for the complete life cycle. The historical narrative should present a story of the P/p from beginning to end that highlights the major events. It includes figures and diagrams that note significant changes between milestones. The narrative should not capture every single detail but provide others with enough information to determine how the P/p scope of work was accomplished and what implementation strategies were used. Historical narrative is often captured as part of the CADRe, described in Section 5.5.9.[177]

Schedule Actuals Archives

It is a best practice for a schedule (and cost) data package associated with the original baseline IMS, any significant replan IMSs, all rebaseline IMSs, and as-built IMSs, along with schedule versions at each major life cycle review milestone to be documented and archived. Archiving schedule (and cost) data packages facilitates the use of the P/p "actuals" data by others in the organization, and in some cases across the Agency, which facilitates for more-informed planning at all levels of the Agency. For example, "CADRe developers are able to quickly upload the documents and information and customized reporting is available for analysts and users."[178]

The intent of the archive is not to include every iteration of every assessment, analysis or model run, rather the iterations at key events in the P/p lifecycle, as well as final products. All supporting data for

---

[176] Agency Policy Guidance to Enhance Earned Value Management (EVM) and Create a Schedule Repository. June 4, 2019. https://community.max.gov/display/NASA/Schedule+Community+of+Practice

[177] CADRe/ONCE – Data Collection and Database. https://www.nasa.gov/offices/ocfo/functions/models_tools/CADRe_ONCE.html

[178] CADRe/ONCE – Data Collection and Database. https://www.nasa.gov/offices/ocfo/functions/models_tools/CADRe_ONCE.html

the results should be archived. This information can include, but is not limited to: *BoEs*, the baseline *IMS*, LCR *IMSs*, the as-built *IMS*, *Analysis Schedules*, routine (i.e., monthly, etc.) schedule metrics, uncertainty, risks, parametric models, model assumptions, cost and schedule benchmarks, as well as other specific communication/reporting documents discussed in Section 8.3.2.4. Detailed data may be referred to, including direction regarding how to retrieve that data, if not part of the formal archive. The following types of schedule-related reports should be considered a minimum set for archiving purposes:

- Schedule Reports:
  - *IMS*
  - *Summary Schedule*
  - Performance Trend Report (Tasks/Milestones Planned vs. Actuals)
  - EVM Metrics, if applicable
  - Critical Path Report
  - Total Slack Report
  - Schedule Margin Report
  - Performance Trend Report
- Cost Reports:
  - Performance Trend Reports (Budget vs. Actuals)
  - EVM Metrics
  - Over-budget Tasks
  - Over-budget Resources
- Technical Reports:
  - Technical Scope Changes
  - Technical Parameters (Planned vs. Actuals)
  - Risks/Issues Reports (e.g., Risk Waterfall (burn-down) charts, etc.)

Archived schedule data should be placed within a master database or commonly-accessible repository. The P/S should coordinate with the Configuration Manager to ensure that Schedule Documentation files are archived at the appropriate levels. For instance, while some P/ps may not be required to provide schedule (and cost) data packages for archive purposes at the Agency level (e.g., CADRe, Schedule Repository, EVM Repository), there may be a P/p-, MD-, or Center-level requirement for such data. The P/p repository is typically maintained by the Configuration Manager (whether this be in the P/p business offices, systems management offices, or P/p analysis offices), whereas a Center-level repository is maintained by a specific point of contact at a given Center. At the Agency level, the CADRe, Schedule Repository, and EVM Repository are maintained by the OCFO's Strategic Investments Division (SID).

Schedule Analysis Archives

It is a best practice for analysis input data, analysis models, and analysis results to be formally archived throughout the P/p lifecycle for easy recovery, repeat analysis, and development of trends. Whether performed routinely or as part of an Agency-level requirement, analysis data often proves invaluable in helping to tell the P/p's "story". For instance, analysis data can be trended over time, which necessitates uncomplicated access to past analysis files. Figure 8-59 illustrates an example archival structure.

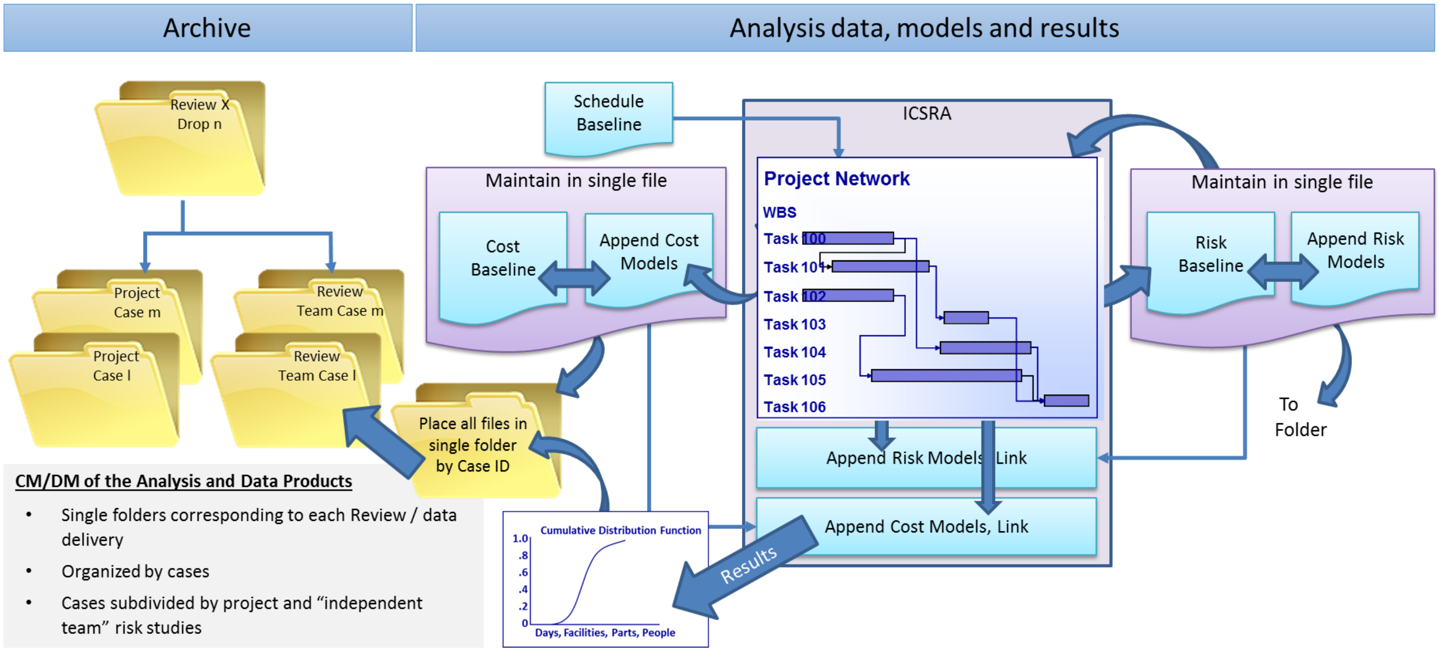


Figure 8-59. Archival of the entire data set input, the models and the results is critically important to support repeat analyses and examination of trends.

The top-level folder should contain a Review Plan and a ToR (Terms of Reference) if an SRB review. If it is a major milestone, it may be appropriate to capture and archive any cases done specifically for the SRB. Trial versions, preliminary versions and final versions should be clearly marked. A recommended hierarchical structure follows:

1 **Analysis/Review Name and Date.** Contents: Analysis instructions and the final report (text version and presentation version).

1.1 **Analysis Versions:** Trial, Preliminary, Final, Final Update, etc.

1.2 **Read Me File:** Describes content of folder. Specifies the Monte Carlo simulation tool used and version number.

1.2.1 **Input Data:** Copies of P/p baseline data provided for the analysis.

1.2.2 **Modeling Data/Worksheets:** Spreadsheets or other formats with input parameters for uncertainties, risks, and costs, etc.

1.2.3 **SRA Model:** The native SRA file that opens in the simulation tool or in the schedule software with the statistical package add-in and includes all statistical distribution parameters required to repeat the analysis if necessary.

1.2.4 **Post-process Files.** Excel Files with exported statistical data used to generate results/plots. Must include case identification and description. If multiple files, label with case names.

1.2.5 **Reports and Presentation Files.** Interim files used for the various versions. Final version goes in the top-level folder.

Lessons Learned Archives

It is a best practice for P/p schedule management lessons learned to be routinely developed and archived throughout the P/p life cycle, at a minimum at the end of each life cycle review milestone. Capturing lessons learned throughout the P/p life cycle facilitates a review of P/p best practices during the life cycle, which aids in on-going schedule control. Maintaining documentation on how the P/p is progressed, including information gathered from reports, discussions, and meetings, also provides insights to new P/ps. As new P/ps begin, reviewing the lessons learned from analogous missions allows for more informed planning and better knowledge capture, supporting the *BoE*. Examining lessons learned provides an opportunity to answer questions such as:

- Was the P/p objective completed?
- Was the work on time, within budget, and by specifications?
- What can be done to improve future P/ps?
- Were the stakeholders satisfied?

Effective P/p management, as well as schedule management, techniques should be carefully recorded and replicated throughout the P/p life cycle, where practical. Just as carefully, ineffective practices should be noted and avoided in the future. This includes information about a P/p's successes and failures, including any risks that were effectively mitigated or realized, which can be used to aid in the management of current P/p issues or training on similar future or recurring P/ps.

Schedule statistics are also often useful to future P/ps and may be included in a current P/p’s lessons learned archive. Most of these statistics can be gleaned from routine data backups and change control documents, if properly maintained. One approach in this area is to communicate with NASA’s Schedule Community of Practice (SCoPe), in order to ascertain the types of statistics that would be most useful for future P/p efforts. Preparation and dissemination of a summary document during closeout is often a much more efficient use of time than later researching archives. Another good practice is to make a “wish list” throughout the P/p life cycle, recording the types of schedule-related statistics that P/p personnel would have found helpful had they been available. During the course of the P/p, part of the effort should be directed toward, or at least cognizant of, accommodating this type of data collection at specified intervals. Yet another good practice to efficiently and effectively capture lessons learned is to follow the best practices mentioned elsewhere in this handbook. Specifically, the use of change control, data structure, common naming conventions, and consistent data coding enhance the collection, analysis, and future P/p use of schedule data statistics. As the P/p proceeds to completion, this information facilitates final P/p team meetings, as well as administrative closure and contract closeout.

As is the case with the schedule data archives, P/p Schedule Management lessons learned should be placed within the P/p's schedule repository and an Agency-level repository, such as the Schedule Repository and/or CADRe, as appropriate. This information will help in the collection of best practices and P/p data that can be communicated through reports, white papers, conferences or other distributions for SCoPe and broader PP&C knowledge sharing.[179]

8.4 Skills and Competencies Required for Schedule Documentation and Communication

The skills and competencies required for Schedule Documentation and Communication can be found on the SCoPe website.[180]

9 Appendices and Supporting Information

Supporting information for the NASA Schedule Management Handbook will be living documents maintained on the Agency's Schedule Community of Practice (SCoPe) website, https://community.max.gov/x/9rjRYg.

9.1 Acronyms

AA	Associate Administrator
ABC	Agency Baseline Commitment
AC	Actual Cost
ACWP	Actual Cost of Work Performed
ADM	Arrow Diagramming Method
AI&T	Assembly, Integration, and Test
ALAP	As Late As Possible
ANSI	American National Standards Institute
AO	Announcement of Opportunity
AoA	Activity on Arrow
AON	Activity on Node
APAC	Agency Programmatic Analysis Capability
APPEL	Academy of Program and Project Leadership
ASAP	As Soon As Possible
AT	Actual Time
ATP	Authority to Proceed
BCR	Baseline Change Request

---

[179] The NASA Cost and Schedule Symposium website has links to white papers presented at the Symposium from individuals in NASA's cost, schedule, and EVM communities. https://www.nasa.gov/offices/ocfo/cost_symposium

[180] SCoPe website, https://community.max.gov/x/9rjRYg

BCWP	Budgeted Cost of Work Performed
BCWS	Budgeted Cost of Work Scheduled
BEI	Baseline Execution Index
BoE	Basis of Estimate
BOM	Bill of Materials
BP	Best Practice
CA	Control Account
CADRe	Cost Analysis Data Requirement
CAIV	Cost As an Independent Variable
CAM	Control Account Manager
CBS	Cost Breakdown Structure
CCB	Configuration Control Board
CCM	Critical Chain Method
CDF	Cumulative Distribution Function
CDR	Critical Design Review
CDRL	Contract Data Requirements List
CEI	Current Execution Index
CER	Cost Estimating Relationship
CFOU	Chief Financial Officer University
CLIN	Contract Line Item Number
CMC	Center Management Councils
CM/DM	Configuration Management and Data Management
COTR	Contracting Officer’s Technical Representative
COTS	Commercial-Off-The-Shelf
CPFF	Cost Plus Fixed Fee
CPI	Cost Performance Index
CPLI	Critical Path Length Index
CPM	Critical Path Method
CPR	Contractor Performance Report
CPTF	Critical Path Total Float
CR	Continuing Resolution
CV	Coefficient of Variation
CWBS	Contractor Work Breakdown Structure
DA	Decision Authority

DDE	Dynamic Data Exchange
DDT&E	Design Development Test and Evaluation
DID	Data Item Description
DM	Decision Memorandum
DQI	Data Quality Indicator
DR	Data Requirements
DRD	Data Requirements Description
EAC	Estimate at Completion
EIA	Electronic Industries Alliance
ES	Earned Schedule
EV	Earned Value
EVM	Earned Value Management
EVMS	Earned Value Management System
FAD	Formulation Authorization Document
FAR	Federal Acquisition Regulations
FFRDC	Federally Funded Research and Development Center
FNET	Finish No Earlier Than
FNLT	Finish No Later Than
FRR	Flight Readiness Review
FTE	Full Time Equivalent
FY	Fiscal Year
GAO	Government Accountability Office
GFE	Government Furnished Equipment
GFP	Government Furnished Property
GPMC	Governing Program Management Council
GR&A	Ground Rules & Assumptions
GSFC	Goddard Space Flight Center
HMI	Hit or Miss Index
HOT	Hands-On Training
HQ	Headquarters
I&T	Integration and Test
IA	Independent Assessment
IBR	Integrated Baseline Review
ICD	Interface Control Document

ICSRA	Integrated Cost Schedule Risk Analysis
IMP	Integrated Master Plan
IMS	Integrated Master Schedule
IPMD	Integrated Program Management Division
IPMR	Integrated Program Management Report
IPT	Integrated Product/Project Team
IRT	Independent Review Team
IT	Information Technology
ITAR	International Traffic in Arms Regulations
JCL	Joint Confidence Level
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
JSCC	Joint Space Cost Council
KDP	Key Decision Point
LCC	Life Cycle Cost
LCR	Life Cycle Review
LOA	Letter of Agreement
LOE	Level of Effort
LRD	Launch Readiness Date
LxC	Likelihood x Consequence
MA	Management Agreement
MDAA	Mission Directorate Associate Administrator
MDR	Mission Definition Review
MFO	Must Finish On
MOA	Memorandum of Agreement
MOU	Memorandum of Understanding
MR	Management Reserve
MS	Microsoft
MSFC	Marshall Space Flight Center
MSO	Must Start On
MSOD	Mission Support Office Director
MSR	Monthly Status Review
NAFCOM	NASA Air Force Cost Model
NASA	National Aeronautics and Space Administration

NAMS	NASA Access Management System
NDIA	National Defense Industrial Association
NICM	NASA Instrument Cost Model
NID	NASA Interim Directives
NOA	New Obligation Authority
NPD	NASA Policy Directive
NPR	NASA Procedural Requirements
NSM	NASA Structure Management
OBS	Organization Breakdown Structure
OCE	Office of the Chief Engineer
OCFO	Office Chief Financial Officer
ODBC	Open Database Connectivity
OIG	Office of Inspector General
OJT	On-the-Job Training
OMB	Office of Management and Budget
ONCE	One NASA Cost Engineering Database
OoE	Office of Evaluation
ORR	Operational Readiness Review
P/p	Program/project
P/S	Planner/Scheduler
PAR	Program Assessment Review
PCA	Project Commitment Agreement
P-CAM	Project Control Account Managers
PCM	Project Control Milestone
PDF	Probability Density Function
PDM	Precedence Diagramming Method
PDR	Preliminary Design Review
PE	Principal Engineer
PERT	Program Evaluation Review Technique
PFA	Program/project Formulation Agreement
PIR	Program Implementation Review
PM	Program/Project Manager
PMB	Performance Measurement Baseline
PMBOK	Guide to Project Management Body of Knowledge

PMC	Program Management Council
PMI	Project Management Institute
PMT	Performance Measurement Techniques
PP&C	Project Planning and Control
PPBE	Program Planning Budget Execution
PPR	Periodic Project Review
PRR	Preliminary Requirements Review
PSR	Program Status Review
QSR	Quarterly Status Review
R&T	Research and Technology
RBS	Resource Breakdown Structure
Rec/Del	Receivable/Deliverable
REDSTAR	Resource Data Storage and Retrieval
RFA	Request for Action
RFP	Request for Proposal
RID	Review Item Discrepancy
RMS	Risk Management System
RP	Recommended Practice
SATERN	System for Administration, Training, and Educational Resources for NASA
SCoPe	Schedule Community of Practice
SDR	System Definition Review
SER	Schedule Estimating Relationship
SID	Strategic Investments Division
SIR	System Integration Review
SMART	Schedule Management and Relationship Tool
SMD	Science Mission Directorate
SME	Subject Matter Expert
SMH	NASA Schedule Management Handbook
SMP	Schedule Management Plan
SNET	Start No Earlier Than
SNLT	Start No Later Than
SOPI	Standing Operating Procedure Instructions
SOW	Statement of Work
SPG	Strategic Planning Guidance

SPI	Schedule Performance Index
SPI_t	Time-Based Schedule Performance Index
SRA	Schedule Risk Analysis
SRB	Standing Review Board
SRR	System Requirements Review
SS	Subsystem
SSI	Schedule Sensitivity Index
STAT	Schedule Test and Assessment Tool
SV	Schedule Variance
TA	Task Agreement
TBD	To Be Determined
TBR	To Be Resolved
TD	Time Dependent
TF	Total Float
TFCI	Total Float Consumption Index
TI	Time Independent
TSC	Technical Schedule Cost
ToR	Terms of Reference
UFE	Unallocated Future Expense
UID	Unique Identifiers
WAD	Work Authorization Document
WBS	Work Breakdown Structure
WP	Work Package
WYE	Work Year Equivalent