National Aeronautics and
Space Administration

Program Planning and Control

In Major Acquisition Programs

What is it? How does it work?

An invitation to apply what we learned to what you do

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About the Authors

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Lucy V. Kranz is a senior executive service manager with degrees from Texas Tech and University of Texas, San Antonio. She is an originator of PP&C in major acquisition programs, starting as a leader in the Business Office to address cost and schedule growth in the ISS Program, extending into SSP operations—including Return to Flight, and culminating with formal definition in the Orion Program. She has held the positions of deputy Space Shuttle Program manager and assistant JSC center director for Management. Her work has been widely acknowledged most recently with the Rotary National Foundation Stellar Award for achievement in space programs and previously with, among others, Space Flight Awareness Management Award, NASA Outstanding Leadership Medal, and NASA Exceptional Service Medal.

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Preface

The word "NASA" is immediately recognized around the world as a symbol of cutting-edge technology and space exploration. The National Aeronautics and Space Administration's acronym instantly conjures images of breakthroughs including the Apollo moon landings, the space shuttle, Hubble Space Telescope, and the International Space Station. All profound technological achievements, yet none were accomplished without overcoming significant management and business hurdles in addition to technological ones.

NASA has struggled with the overwhelming challenges of delivering programs on time and on budget nearly from its inception as the nation's space agency in 1958. The 1960s are recalled nostalgically as the era of "sky's the limit" NASA funding, when the agency's share of the federal budget reached as high as approximately 4.4 percent in 1966 (as compared to less than one percent by the end of the 1970s, and falling to one half of one percent in 2009).[1]

However, even during the Gemini Program (1965-1966), NASA's second administrator, James E. Webb, felt compelled to take action in order to counteract the program's budget overruns and schedule delays. Only two years into the Gemini Program, NASA's estimated cost to complete the program had tripled. Instead of fighting for more funding from Congress, Administrator Webb instituted management and business reforms. Webb sought the assistance of U.S. Air Force personnel with experience working on intercontinental ballistic missiles—expensive and technologically complex rockets—that could help transfer their knowledge to the similarly advanced realm of human spaceflight.[2]

Webb assigned Dr. George E. Mueller, a former project executive for an Air Force contractor (and later dubbed "Father of the Space Shuttle"), as the NASA associate administrator for all human spaceflight in order to institute systems engineering and configuration management reforms. Since then, these intricate management systems, instituted with the aim of delivering programs on time and on budget, have formed a cornerstone of NASA operations.[3]

However, even decades later, NASA's James Webb Space Telescope, named for the former NASA administrator, remained plagued by cost and schedule issues. Originally assigned a baseline launch date of June 2013, this planned replacement for the aging Hubble Space Telescope underwent a major independent review to correct problems in 2010 and is currently expected to launch in 2018.[4]

Unfortunately, the case of the James Webb Space Telescope does not represent an anomaly in the past fifty-plus years of programs since the Apollo moon landings. Growth in NASA's International Space Station Program and action taken to revise business management practices is a prerequisite to this monograph. Subsequent legislation established roles and responsibilities for oversight of NASA programs along with thresholds for reporting to Congress.[5]

Cost and schedule growth problems are not unique to NASA. In 2008, the Department of Energy (DOE) pursued its own root cause analysis process—with some noteworthy parallels between that agency and NASA. For example, the DOE identified its "portfolio of projects" as "large, complex, and technically challenging." They continued, "Many are unique, one-of-a-kind initiatives that involve cutting-edge technology."[6] In another parallel with the space agency, the DOE recognized the need for effective contractor management in light of the fact that "the Department continues to rely predominantly on contractors to operate the laboratories and sites and to carry out diverse missions."[7]

Similarly, in the Department of Defense (DOD), the Weapons System Acquisition Reform Act of 2009 (PL 111-23) included the establishment of the Office of Performance Assessments and Root Cause Analyses (PARCA), responsible for the "policies, procedures, and guidance" for DOD acquisitions.[8] Just one year later, the Improve Acquisition Act of 2010 (PL 111-383) defined the responsibilities for acquisition functions and performance assessments in DOD, along with the requirements for acquisitions. It again called for "improvements to the management of the defense acquisition system."[9]

The 2013 Annual Report on the Performance of the Defense Acquisition System noted that "Our ultimate measure of performance is providing effective systems to the warfighter … at costs that are affordable, while ensuring taxpayers' money is spent as productively as possible"—the goal of all government programs. The report continued, "Only through rigorous analysis and clear reporting will we be able to separate and account for acceptable and unacceptable types of cost growth, informing our discussions within DOD, Congress, our Allies, and the American public."[10]

Program Planning & Control

The term Program Planning & Control (PP&C) emerged circa 2000 from action taken by the International Space Station Program to address the cause of cost and schedule growth that nearly toppled the program. The report issued by the International Space Station (ISS) Management and Cost Evaluation (IMCE) Task Force to the NASA Advisory Council documented seven findings of inadequate planning, cost estimating, and budget control.[11]

To correct inadequacies, the ISS Business Office changed its operations to better align budget with schedules and estimation with assessment. This new approach significantly expanded the scope of both planning and control over what had been performed previously. Personnel reported that this change, the identification of PP&C as a collective unit, became a much more proactive way to identify the work being performed.[12] The ISS Program Office organization today includes a separate PP&C office, as do the other NASA human spaceflight programs.

Implementation of PP&C in the ISS and Space Shuttle Programs and the Orion Project followed a common practice of assembling the disciplines needed to produce the data used to plan and measure program performance. Under this system, each discipline is a separate service that produces individual data reports using discipline-specific tools. These reports are presented directly to program management at regularly scheduled management review forums that can take up to two days to complete as subject matter experts present activity reports while showing graphics displaying individual sets of data. (Note: The Orion Project initiated in 2004 became a project within the Constellation Program in 2005 and was reauthorized as the Orion Program in 2010. This monograph makes references to both the Orion Project [2004-2009] and the Orion Program [2010-present]).

However, because expertise and data reports are stove-piped, budget status doesn't necessarily align with a scheduled baseline, which doesn't correspond to the latest contract scope, which doesn't match the information in the risk system, etc. A program manager has to integrate multiple data reports in near real-time in order to discern current program performance status and glean an impression of the trajectory of future program performance.

This was common PP&C practice until Mark S. Geyer, the Orion project manager, provided feedback that forced a re-evaluation of assumptions and approach for performing PP&C: "I see all this data and I see all these reports, and I hear you, but I don't understand our status." He continued, "I have no idea what you want me to do with all this."[13] Around the same time, after its reauthorization in 2010, the Orion Program received 70 percent of its previous funding, and the Program Planning & Control function was cut an additional 20 percent. The Orion PP&C team, headed by Lucy V. Kranz, recognized the gravity of the situation and endeavored to find a definitive solution to the perpetual issue of cost overruns and schedule delays in government-run programs.

Re-evaluating assumptions and approach led to a series of insights about how PP&C could be performed. This monograph explores those insights, with the aim of communicating how a more effective form of PP&C can help programs maintain their budget and schedule commitments while delivering quality products, using the experience of Orion PP&C as an example.

Alignment

This monograph is an implementation of Strategic Goal 3 of the 2014 NASA Strategic Plan, to "Serve the American public and accomplish our mission by effectively managing our people, technical capabilities, and infrastructure," particularly the following two objectives:

- Objective 3.2: "Ensure the availability and continued advancement of strategic, technical, and programmatic capabilities to sustain NASA's Mission."
- Objective 3.4: "Ensure effective management of NASA programs and operations to complete the mission safely and successfully."[14]

It also addresses a key lesson learned from the Constellation Program:

> While the Agency is renowned for its technical prowess, senior managers in programs can be faced with a multitude of nontechnical challenges for which they have far less training or preparation.[15]

Addressing this nontechnical challenge within the context of a technical federal agency has proven to be a formidable challenge throughout NASA's history. As once articulated by rocket pioneer Wernher von Braun, "We can lick gravity, but sometimes the paperwork is overwhelming."[16]

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A new paradigm is a result of numerous encounters and exchanges leading to and refining insights that evolve into clarity suitable for writing it down so others can understand what we have done, and perhaps use it and make it better. The authors gratefully acknowledge the following persons for their contributions to the evolution:

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CHAPTER 1

Introduction

Space programs are exciting. To some, the allure of developing new technologies for space travel and exploration is irresistible. Teams of educated and highly trained persons in government, industry, and academia are eager to make contributions. The opportunity to build new land, air, and space vehicles tempers any initial concerns about the conditions in which the building will occur. Let the work begin.

Space programs are challenging. Requirements, resource commitments, and environmental conditions are all subject to change. Plans become casualties of encounters with reality as assumptions fail and improbable things happen. But throughout this volatile environment, accountability remains. Regardless of prevailing conditions throughout a program's life cycle, management is accountable for resources consumed, the work accomplished, and the results achieved. Managers manage performance; they consume information and issue direction so outcomes can be achieved.

This chapter provides background, including key terminology, for how major acquisition programs are carried out and reported in the space agency.

Concepts and Definitions

This work begins with the observation that:

> Words are important.

Words when accompanied by jargon and the use of acronyms can significantly complicate meaning and hinder communication. The following descriptions are provided to establish meaning and context for understanding the concepts fundamental to Program Planning & Control. The word "program" is used predominately, reflective of government program experience of the authors; however, the word "project" may be substituted to describe the same concept of coordinated efforts to develop new facilities, plants, or technology systems.

Orion Multi-Purpose Crew Vehicle

In January 2004, President George W. Bush announced a bold new Vision for Exploration, a plan to extend humanity's presence in the cosmos with a mission to the moon and then on to Mars. Part of this Vision included plans to:

> … develop and test a new spacecraft, the Crew Exploration Vehicle, by 2008, and to conduct the first manned mission no later than 2014. The Crew Exploration Vehicle will be capable of ferrying astronauts and scientists to the Space Station after the [space] shuttle is retired. But the main purpose of this spacecraft will be to carry astronauts beyond our orbit to other worlds. This will be the first spacecraft of its kind since the Apollo Command Module.[17]

Named Orion, the new project to acquire the Crew Exploration Vehicle (CEV) formed part of the new Constellation Program. The CEV would be launched on the Ares rocket being developed at NASA's Marshall Space Flight Center in Huntsville, Alabama. In August 2006, NASA awarded a contract to Lockheed Martin to build the CEV. The plan was to develop different CEV capsules for specific missions. The first vehicle was for crew rotation and resupply for the International Space Station; subsequent vehicles would be designed and developed for deep-space exploration.

Although the Constellation Program was cancelled in February 2010, the NASA Authorization Act of 2010 reauthorized the Crew Exploration Vehicle project as the Multi-Purpose Crew Vehicle (MPCV) Program. The act also cancelled the Ares rocket to focus on the heavy-lift Space Launch System (SLS).[18] Orion CEV Project became Orion MPCV Program, and more simply the Orion Program. Both Orion and SLS Programs are grouped under the Exploration Systems Development Division of the Human Exploration and Operations Mission Directorate at NASA Headquarters in Washington, DC.

In 2013, the Orion Program partnered with the European Space Agency (ESA) to acquire a service module to support mission flights of the MPCV. The service module is located directly below the crew capsule and contains the in-space propulsion capability for orbital transfer, attitude control, and high-altitude ascent aborts. It also will generate and store power and provide thermal control, water, and air for the astronauts.[19]

The first flight of the vehicle, Exploration Flight Test (EFT)-1, is currently scheduled for late 2014. The test will launch an un-crewed MPCV spacecraft atop a Delta IV Heavy rocket and fly to an altitude of 3,600 miles above Earth's surface, farther than a human spacecraft has gone in 40 years. In 2017, Exploration Mission-1 will be the first integrated flight test with both the MPCV spacecraft and NASA's new Space Launch System. It will be followed by Exploration Mission-2, which will launch an MPCV and a crew of four astronauts into space.

Major Acquisition

Orion is a government major acquisition program, as is SLS. An acquisition is a process for obtaining products and services. A major acquisition is an acquisition with a price tag greater than $250 million. Major acquisitions are performed over a life cycle that begins with an idea aligned with a strategic plan, fulfills an identified need or mission, and ends many years later with the final disposition of the product acquired.[20]

Variables

Values for three independent variables define an acquisition: cost, schedule, and technical.[21] Information about all three provides input to program control. The functional relationship between cost, schedule, and technical variables is not mathematical. There is no formula that can be used to calculate new values for one variable based on changes made in the values of one or both of the other two variables. For example, new values for technical content cannot be calculated directly by a formula relating cost, schedule, and technical variables. Rather, the relationship between variables is established by a plan, and values of variables are quantified using tools such as strategic assessment, cost estimating, integrated schedule management, and risk management.

Life Cycle

Human spaceflight products are developed over a life cycle. The development of new vehicles for spaceflight is not linear with time; a new vehicle does not accrete from standard building blocks of knowledge and content, but rather it evolves iteratively over multiple cycles of analyses, trade studies, designs, development, and testing. Initial work formulates the product, a next phase implements it, and subsequent phases operate it.[22]

Formulation Phase

The purpose of a Formulation phase is to convert visionary technical-capability requirements into vehicle design and specifications and to define cost and schedule requirements for its implementation. Work performed during a Formulation phase matures the technical components into a vehicle with a form, fit, and function that meets customer and stakeholder requirements and can be produced within fixed values for cost and time.

Work performed to establish a vehicle design that is both affordable and meets "minimum capability requirements" is iterative, that is, repeated in a continual cycle. Definition requires cycles of detailed analyses and trade studies, technology development, design, and the building and testing of various engineering units. Technology development is especially complex, not only to achieve the performance necessary to meet new capability requirements but also in the amount of resources required to realize that new capability.[23]

Beginning stages of a program establish a work breakdown structure for technical content and an organizational structure for management and governance. Strategic assessments, along with cost and schedule estimating, are initiated to bracket life cycle values for cost and schedule as work to define and design the technical content of the flight product proceeds. Early in the Formulation phase, a program plan is developed to document vehicle architecture, program organization, implementation approach, baseline, and governance.

Contracts and supplier agreements are also established early in a Formulation phase of a program. In NASA, about 90 percent of developmental work is performed by a supply chain comprised of a prime contractor and a network of agency centers, each with its own set of contractors, subcontractors, and suppliers.[24] Contracts are awarded to industry following a competitive procurement process governed by federal law and regulations.[25]

Agreements are executed with government suppliers, and contracts with industry are awarded based on an evaluation of proposals for performing work and data requirements prescribed by the government. Requirements—together with associated milestones, schedules, and costs—are all codified in a contract. Contracts can only be changed by following a prescriptive and time-consuming formal sub-process of the procurement process.

Implementation Phase

Work performed during the Implementation phase executes approved plans for the development and operation of the new flight vehicle. Transition from a Formulation phase into an Implementation phase is controlled by a formal process of review and decision. The Preliminary Design Review (PDR) ensures that the design is mature; the maturity of required technologies has been demonstrated; the cost and schedule estimates are credible; and technical and resource margins are adequate to complete vehicle development within the agreed-to values of life cycle cost, date(s) for launch, and risks.[26] Following PRD, the Decision Memorandum executed by agency management and technical authorities, host-center management and the program manager establishes cost and schedule values and assumptions for implementation. A successful PDR with documentation constitutes authorization to transition into the Implementation phase, and sets the program baseline at those agreed-to values. Control systems are used throughout the Implementation phase to ensure performance in accordance with governing documents and resources, and in alignment with the agency's strategic goals.

Baseline

Combined, any set of linked values for cost, schedule, and technical variables agreed to in writing by the affected parties can be called a "baseline." Accordingly, there is more than one definition, as shown in Appendix B, Glossary. A baseline is established by an authority and can be changed only by approval obtained formally through a tightly controlled process.

Formulation Phase

During the Formulation phase, the baseline comprises estimates for cost and time needed to develop the new flight product. The benchmark for performance is set by the annual Execution Plan and budget established by the Program Planning Budget & Execution (PPB&E) process; the planned outcome is the evolving program baseline for implementation.[27]

In theory, cost overruns and schedule delays are not possible during the Formulation phase because there is no baseline set of cost and time values to benchmark change, and the purpose of work performed is to determine the values that will make up the program baseline. In the Formulation phase, work performance is controlled by the funds provided. Therefore, as technical requirements change, or as problems in developing new technology or in re-purposing heritage technology emerge, schedules for completing future work have to slip because annual budgets are constrained.

Accordingly, growth in value for program cost or schedule to accommodate changes in technical requirements is a result of applying best practices and following agency and industry standards to work performed. Similarly, changes in contracts with industry and agreements with suppliers to accommodate change are a consequence of an acquisition strategy that involves industry early in a life cycle and a complex procurement process for both award and change.

Change and growth occur within a tightly controlled work environment for analysis and governance. Regardless, within a public setting, change and growth presents vulnerability not only for a program but also for the persons managing the program. Public reaction to growth to accommodate change made during the Formulation phase for both the International Space Station Program and the Orion Project is the genesis of this monograph.

Implementation Phase

During the Implementation phase, the program baseline established by the Decision Memorandum following PDR is termed the Agency Baseline Commitment. In Congress, the program baseline is termed the Baseline Report. Baseline values of life cycle cost and annual budget with reserves, launch date, and schedule with margin, and technical capability with margin comprise the benchmark from which change is measured and reported. Accordingly, cost overruns and schedule delays do happen but only when the reserves and margins provided are exceeded, and by specified amounts.

The NASA Authorization Act of 2005 (PL 109-155) defined a major program as an activity approved to proceed into the Implementation phase that has an estimated life-cycle cost of more than $250 million. The agency is required to report cost and schedule baselines as benchmarks against which growth in the baseline can be measured. The law also requires NASA to report to Congress when development cost is likely to exceed the baseline estimate by fifteen percent or more or when a key milestone is likely to be delayed by six months or more.[28]

Further, the NASA Authorization Act of 2008 (PL 110-422) requires the Comptroller General of the Government Accountability Office (GAO) to review NASA programs with annual funding greater than $50 million that are "similar in scope and purpose to other activities within the Federal government."[29] The explanatory statement of the House Committee on Appropriations accompanying the Act further directs the Comptroller General to prepare project status reports annually on selected major NASA programs.[30]

Cost Overruns and Schedule Delays

In the case of the Orion Program, the initial "planned" relationship between variables was established by the NASA Authorization Act of 2010 (PL 111-267). The act authorized the Multi-Purpose Crew Vehicle Program and authorized funds to be appropriated in the amounts of $1.12 billion for fiscal year (FY) 2011, $1.4 billion for FY 2012, and $1.4 billion for FY 2013—a total of $3.92 billion for three fiscal years.[31] The law also specified that the MPCV should be completed "not later than December 31, 2016" with "full operational capability."[32] Note that appropriations do not extend beyond FY 2013 to reach the December 31, 2016, completion deadline.

Authorization bills create or continue a program as well as authorize the subsequent enactment of appropriations. The appropriations bill provides the funding needed for the program authorized by the enacted authorization bill. Programs must have been authorized before they can have funds appropriated to them. Budget via agency process follows appropriations.[33] Appropriated funds can be less than authorized amounts and budgets can be less than appropriated funds. Hence commentary about cost growth or cost overruns depend on what amount (authorized, appropriated or budget) is cited as the basis for comparison. Words are important.

The "baseline" for the Orion Program was defined by a technical value (a multi-purpose crew vehicle for missions beyond low-Earth orbit), a schedule value (December 31, 2016), and a cost value ($3.92 billion through FY 2013). A public perception could be that starting in 2017 NASA will be conducting human exploration missions beyond low-Earth orbit using a new vehicle that will cost the American tax payers approximately $4 billion. The fact that no costs for FY 2014 through FY 2017 are specified is generally overlooked; the fact that actual budgets may be different from appropriations is a detail not usually noted. Hence, for major acquisition programs:

> ***Public expectations that can never be realized are set before work begins.***

Orion Program received authorization for a $3.92 billion appropriation through the 2013 fiscal year. The Formulation Authorization Document for the Orion Program approved in FY 2011 set the total value for the cost of the program at approximately $6 billion.[34] Subsequently, after reviewing Formulation phase work in progress, the Orion Program Decision Memorandum issued in FY 2013 estimated that achieving "full operational capability" would require a cost of $8.5 billion to $10.3 billion, and that completion would occur from the fourth quarter of FY 2021 to the second quarter of FY 2022.[35] The increase in values happened because: 1) requirements changed, 2) the funds budgeted to date were significantly less than appropriated, 3) vehicle configuration, fabrication, and production were better understood, and 4) technology development and reuse was more complex than assumed.

It is important to note that the difference in program costs from $4 billion to $6 billion to $10 billion is neither a cost growth nor a cost overrun. The $4 billion amount was three years of appropriation only and not an estimate at completion. Likewise, the change in date for operational capability from 2016 to 2022 is neither a schedule growth nor a schedule delay, although each could be misrepresented as such.[36] Rather, each is an output from normal work performed in a Formulation phase of a program driven by the realities of changes in requirements, annual budgets, and technical complexity. Note also that the addition of an International Partner in 2013 will further impact the above cited values for the cost and schedule of the program as work in the Formulation phase continues.

Baselines also apply to the chain of suppliers that perform the work. The contract to design, develop, test and evaluate, and produce multiple CEVs to perform missions from low-Earth orbit to deep-space exploration consistent with the 2004 vision was initiated early in the Formulation phase of the Orion Project. It took more than one year to develop. Subsequently, a contract was awarded to Lockheed Martin in 2006. The contract established a contract baseline that specified technical requirements and associated values for cost and schedule. The contract baseline was a subset of the program baseline in existence at the time the contract was awarded.

During the Formulation phase, however, there is no program baseline; there are only multi-year authorized-to-be-allocated funds along with estimated values for the cost and time required for developing a capability to meet visionary technical requirements. Vehicle design and the resources required for implementation evolve as work in the Formulation phase proceeds. Hence, a contract baseline is overcome by work performed under that contract, and contract change is guaranteed.

Further, in the case of Orion, both the vehicle and reference missions for MPCV are different from those of CEV, further reinforcing the need for contract change. The resulting change in contract cost value to implement MPCV is not a cost overrun. Similarly, the resulting change in schedule for implementation is not a schedule delay. Rather, each is an output of normal work performed in a Formulation phase driven by the realities of development: requirements change, technical complexity, assumptions, and annual funding.

Organization

Change is an expected outcome of the Formulation phase. Congressional, agency, and public reaction to change in both the ISS program and the Orion Project during the Formulation phase, however, exceeded expectations. A detailed investigation of PP&C and how it is performed in NASA programs was performed. The result is a new paradigm for performing PP&C and Program Performance Management (PPM) that was implemented in the Orion Program in 2010. This monograph explores the process of causal analysis and corrective action that resulted in improved performance in the Orion Program.

This book is divided into two parts to explain the journey of research, analysis, and implementation. Part I, Discovery and Change, documents the history of cost overruns and schedule delays in major acquisition programs, analyzes why changes made at congressional-, agency- and discipline-expert levels did not eliminate them, and prescribes corrective action.

Part II, Discovery Continues, documents work in progress to address the effects of uncertainty on program performance. This part is the more academic of the two and is based on the scholarly research currently in progress to develop knowledge and methodology for incorporating the effects of emergence into predictions of program performance.

Audience

The manuscript was developed from the authors' experience with NASA programs. However, literature from other federal agencies—namely the Department of Energy and the Department of Defense—was also reviewed for an understanding of applicability across government major acquisition programs. The series of reports issued by the National Research Council on program performance management at the Department of Energy were studied as were reports issued by the Government Accountability Office on program performance management in the Department of Defense.[37] The authors have discussed ideas about program planning and control and program performance management with peers in the congressionally established DOD Performance Assessment and Root Cause Analysis (PARCA) Office and with faculty at the DOD Defense Acquisition University.

The information provided in this monograph is intended to be of use to organizations responsible for the development of major acquisitions by government agencies as well as for large-scale projects conducted by industry. The authors reviewed literature about project management in the building industry.[38] Any feedback from the construction industry, or other industries and from government agencies conducting large-scale projects, on the utility of our findings would contribute significantly to the application of the theories presented for their effective practical use.

PART I
Discovery and Change

Part I focuses on the work performed to document the root cause of perennial cost overruns and schedule delays in major acquisition programs and to define corrective action to eliminate the problem. It follows the progression of work that began with a simple question of “Why?” asked in 2009 through organizational and work changes made first in 2010 and again in 2013 to implement corrective action.

The Introduction began with the key observation that “words are important.” Part I is based on the observation that “scope is important.” The size or scale of a program determines not *what* program management work is performed but rather *how* that work is performed: the law of diminishing returns applies to adding and expanding disciplines—and tools—to accommodate the increasing needs of large-scale programs.

Chapter 2: The Problem documents the more than 20-year effort to control cost and schedule growth in government major acquisition programs. It includes a review of the path-finding work of the International Space Station Program to improve what was then called “business management” after a near fatal breakdown in program control at the turn of the millennium that severely compromised stakeholder confidence.

Chapter 3: Causal Analysis, defines the problem’s cause. An understanding of root cause is arrived at by identifying external and internal forces that have historically impacted program control. Application of the traditional “five whys” leads to an identification of root cause.[39]

Key insights lead to the realization that program control**s** (with an “s”) is not the same as program control (without the “s”), and PP&C is a system of interdependent, interrelated, and interacting elements. PP&C must address both the controls and control parts. Chapter 4 discusses the two-part corrective action necessary to eliminate root cause: the structural change to improve program controls, and the management change necessary to improve program control.

Chapter 5: Program Planning and Control describes the structural change made within the Orion Program PP&C Office to improve program controls by producing integrated, actionable information to inform—as opposed to reams of incoherent data to brief—program management. Comments from persons directly affected by the change are included. Work, data, and key personnel requirements are provided to facilitate use by others.

Chapter 6: Program Performance Management describes program control as a corrective action and develops the notion that Program Performance Management is a system that operates within a three-dimensional "trade space." This chapter also discusses the relationship of Program Performance Management to GAO requirements for creating knowledge and establishing a sound business case.[40]

Chapter 7: Effectiveness presents the operational improvement achieved to date from the changes made to both program controls and program control. Although the process of change encountered significant resistance—first at the local level, and then exacerbated by upheavals within the agency—it did eventually succeed and result in measurable improvement in Orion Program operations.

CHAPTER 2

The Problem

Historical Background and Literature Review

This chapter begins with an overview of how the concept of Program Planning & Control has evolved over time, in parallel with the efforts taken within the space agency to address lingering cost and schedule issues in its major acquisition programs. A review of previous recommendations and attempts to ameliorate those negative outcomes sets the stage for the Orion PP&C causal analysis and corrective action.

Seminal Works

In the 1960s, NASA Administrator James E. Webb introduced systems management and configuration control to the agency's human spaceflight programs in attempt to reign in the skyrocketing costs and schedule delays already plaguing the Gemini Program.[41] These early efforts represented the NASA application of what was, at the time, the newly emerging professional practice of program and project management. Although all programs and projects must include some degree of forethought, it was not until the middle of the twentieth century that the practice of project management began to be recognized as an independent discipline.

Throughout the 1960s, project management remained largely the domain of the aerospace, defense, and construction industries. In 1967, the DOD developed the set of 35 Cost/Schedule Control Systems Criteria (C/SCSC) in an attempt to systematically monitor program performance. The 1970s saw the development of several new management tools and techniques, including Work Breakdown Structure and Earned Value Management, as the discipline grew and was increasingly applied in other industries. By the 1980s, project management approaches expanded to encompass virtually all sectors of the economy.[42]

As theories proliferated, multiple organizations began to record this knowledge in written manuals. The Project Management Institute (PMI) was founded in 1969 and in the 1980s began to codify its set of rules and standards as the Project Management Body of Knowledge (PMBOK). The official *Guide to the Project Management Body of Knowledge* was first published in 1996. Updated regularly, the fifth edition of the PMBOK was released in 2013.[43]

Several of the founding participants of PMI had experience in government projects and programs, and defense and aerospace needs often provided the impetus behind important project management initiatives and organizations. In 1984 (around the same time period that the PMBOK was being developed), the Department of Defense established the Software Engineering Institute (SEI), a federally funded research and development center, at Carnegie Mellon University. The SEI was tasked to provide, among other things, "research in … process improvement and performance measurement."[44] In 1987, the SEI first developed its Capability Maturity Model (CMM) for software and a "methodology for assessing the process maturity of defense contractors."[45] By 2000, these ideas had been more fully developed and were published as CMM Integration (CMMI), the third version of which (v. 1.3) was released in November 2010.

Both the *CMMI for Development* and the *PMBOK Guide* define a series of tasks necessary for program control, including the need for integration. Version 1.3 of *CMMI for Development* states that the volume "provides an opportunity to avoid or eliminate these stovepipes and barriers,"[46] and "Integrated Project Management" is defined as one of the *CMMI's* twenty-two core process areas. Similarly, "Integration Management" is listed as one of the ten PMBOK Project Management Knowledge Areas acknowledged in the Fifth Edition.

In addition to these volumes, many, many books and guides on program and project management have been published by individual authors. James P. Lewis and David G. Carmichael, respectively, wrote the two books with the words "planning and control" in their titles.

In 1991, James Lewis, an engineer and former project manager at ITT Telecommunications, published his book, *Project Planning, Scheduling and Control*, in which he developed what was later trademarked as the Lewis Method® of project management, targeted to practitioners in the field. Drawing on PMBOK and the established Earned Value Management (EVM) and Work Breakdown Structure (WBS) tools of project management, the Lewis Method places a substantial emphasis on individual psychology and the behavioral components of management, i.e., people skills. As Lewis stated in the preface, "without good skills in dealing with people, the tools will do nothing but help [managers] document their failures with precision."[47] The fifth edition of Lewis' book was published in 2010, nearly twenty years after the first.

Second, David G. Carmichael's *Project Planning and Control* was published in 2006. It proposes an alternative prescription for an integrated system of project management. Carmichael asserts that the planning problem is best addressed by approaching it as a systems synthesis, or inverse, problem. In other words, if the planner understands "the model of the system" and has reliable cost and schedule data, the planner can "evaluate the control[s]" needed to reach project targets.[48] Ideally, controls will be selected that "extremise the objectives," that is, result in the achievement of aims such as lowest possible cost or fastest possible completion.[49]

These management guides and books recognize the need for, and the value of, integration of management tasks, but they vary widely in the methods espoused for realization. Both PMBOK and CMMI define a series of tasks necessary for program control but lack an effective prescription for how to integrate each of the functions into a coherent system, despite their surface acknowledgement of the need for program integration between different components. Although the two publications do use the terms "project planning" and "control," neither defines PP&C as a unified concept nor uses PP&C as an acronym.

The varying theories for Project Planning & Control highlight the lack of definition that, up to this point, has characterized the body of work. Even Carmichael states that although most people profess the need for and importance of planning, "everybody has a different idea of what planning is." He continued, "Therein lays the source of most of the troubles preventing the advancement of the understanding of planning"[50]—and also to the integrated concept of Program Planning & Control.

1969	PMI founded
1984	SEI founded
1987	CMM published
1991	Lewis PPS&C, 1st Edition
1996	PMBOK Guide 1st Edition
2000	CMMI published
2006	Carmichael PP&C published
2010	CMMI V 1.3 released
2013	PMBOK Guide 5th Edition

Table 2.1a Timeline: Seminal Works.

U.S. Congress and NASA (1990-2009)

1990s

Despite the advances in the field of project management that took place in the 1960s, 70s, and 80s, the first years of the 1990s continued to see government programs in both NASA and the Department of Defense plagued by cost and schedule issues. In January 1990, in response to concerns voiced by Congressman John J. Conyers and Senator and former Astronaut John H. Glenn, the Government Accountability Office released its first High Risk List identifying those "agencies and program areas that are high risk due to their vulnerabilities to fraud, waste, abuse, and mismanagement, or are most in need of transformation." Both NASA Contract Management and DOD Major Systems Acquisition were identified as "vulnerable areas" in government programs in what would become a continuing series reviewed biannually at the start of each new Congress.[51]

Three years later, Congress passed the Government Performance and Results Act of 1993. The Act attempted to "initiate program performance reform" by "setting program goals, measuring program performance against those goals, and reporting publicly on their progress."[52] Federal agencies were required to submit annual performance plans with "objective, quantifiable, and measurable" performance indicators, which would then provide the basis for an annual report on how well those goals were executed.[53] These performance measures were intended to "improve congressional decision-making by providing more objective information."[54]

International Space Station Management and Cost Evaluation Task Force

In 1993, the then Space Station Freedom Program underwent a crisis over budget issues.[55] The problem was so severe that legislators on Capitol Hill threatened to cancel the program, in the end approving its continuation by only one vote. But, seven years later, problems persisted. The case of the International Space Station Management and Cost Evaluation (IMCE) Task Force is particularly instructive and relevant, as some of its lessons would later be applied to Orion PP&C under the leadership of Lucy V. Kranz.

In 2000, the International Space Station Program identified a resource shortfall.[56] Former Space Station Procurement Office Manager Lucy Kranz recalled how, as requirements for modules and needed capabilities had increased over the previous five to six years, particularly with the addition of International Partners, the resulting additional technical scope was not accounted for in the program's budget or schedule. "At the time I didn't question more requirements without the additional budget, or the additional schedule," Kranz said. But after years of scope creep, she said, "It was all piling up to be problematic."[57] The cumulative effect of this gradual buildup was significant overruns and delays when compared to published values for program cost and schedule.

The program notified NASA Headquarters, and the Office of Management and Budget (OMB) responded by chartering the International Space Station Management and Cost Evaluation Task Force to conduct an independent external review and assessment of the ISS cost, budget, and management. After several months of fact finding and interviews, in November 2001 the IMCE Task Force reported that the existing program plan and multi-year budget were not credible. Overrun estimates ran in the range of $2 billion to $3 billion.[58] Kranz recalled that she initially reacted to the findings with skepticism: "I was in denial over whether that was truly an overrun. Looking back on it, all of that was true, and the facts were there, and we were just not putting the inputs together to understand the implications."[59]

Kranz went on to describe the severity of the situation: "That was a significant event, a cataclysmic event, really, that we had lost our stakeholder trust and confidence. It was in that environment that we started thinking through the program control aspects."[60]

The IMCE concluded that "the existing deficiencies in management structure, institutional culture, cost estimating, and program control must be acknowledged and corrected for the program to move forward in a credible fashion."[61] IMCE recommended that financial and program control be strengthened at both the program and headquarters.

In response, NASA temporarily moved program control to headquarters, and the ISS Business Office spent months "putting the facts together" to determine: "What had just happened here?" The team then began to look at options for corrective action. However, Kranz was careful to distinguish that the ISS fact-finding process was not the same as a causal analysis. Instead of root cause, the team was assigned to look for information and "put it together in talking points" in order to regain the trust of the congressional stakeholders as quickly as possible.[62]

The program developed a Program Management Action Plan for ISS. The plan "to ensure more effective program content and resource management" assigned responsibilities and accountability. It called for improvement in management and resource controls and in cost estimating including: the development of predictive measures of cost, schedule, and technical performance; the use of independent assessments to provide an "early warning" of potential cost growth; and the establishment of a capability to perform integrated assessments.[63]

As a result of this process, the ISS Business Office and NASA Comptroller implemented fundamental changes at a local level:

- Established control account managers
- Established a program assessment function
- Established Work Breakdown Structure (WBS) and Cost Analysis Requirements Description (CARD)
- Revised funding and accounting structure
- Developed and certified a life-cycle cost estimate
- Developed and implemented a quantitative risk assessment of threats
- Developed and implemented program-wide performance management based on earned value management concepts
- Streamlined contract management through a consolidation strategy
- Improved management of reserves
- Established formal quarterly cost, schedule, and technical reviews

And at the agency level:

- Established the Integrated Financial Management Program (IFMP)
- Established full-cost budgeting and full-cost management
- Established cost estimating capabilities and standards

To perform the new work, the ISS Business Office increased the number of staff by 38 percent. These changes became the foundation of what, for the first time, was called "Program Planning & Control."

Kranz noted that, also for the first time, General Michael C. Kostelnik, the Air Force major general who had been named NASA deputy associate administrator for Space Station and Space Shuttle Programs at headquarters, established a single, authoritative management information system as a tool for managers at all levels, and initiated the use of dashboards so he could have access to performance data "at his fingertips."[64] However, years later (2009), Kranz received feedback from the then Orion Project manager indicating that he still needed a more complete picture of authoritative management information, as opposed to the data overview provided by a dashboard.

Kranz later cited the IMCE review as a "turning point" for her professional development as she first began to learn how "these functions go together."[65] Geyer said, "That was the first time I saw how that can get you into trouble, and how the program tried to react by putting more of a process of managing all those pieces together, to get a better handle on future projections."[66] The experience of the IMCE findings together with ISS corrective action would inform the organization and structure of Orion PP&C just a few years later.

2000s

The remainder of the decade continued to see multiple efforts to reform how program control was implemented at the agency in an attempt to alleviate the symptoms of what remained as seemingly intractable cost and schedule issues in NASA programs. The impetus for reforms often resulted from concerns expressed by OMB, Congress, and GAO.

Just a few years after the findings of the IMCE initiated by OMB—and two years after the *Columbia* Accident Investigation Board recommended a series of cultural reforms following the 2003 Space Shuttle *Columbia* disaster—the U.S. Congress again added explicit requirements for program control. The 2005 NASA Authorization Act included a section on "Baselines and Cost Controls" that required the NASA administrator to report to Congress if a program was "likely to exceed the [cost] estimate provided in the Baseline Report of the program by 15 percent or more, or whether a [schedule] milestone is likely to be delayed by six months or more."[67]

Even with this extra measure of congressional oversight, often referred to as the "15 percent rule," in January 2007 NASA Contract Management (along with DOD Major Systems Acquisition) was again named by GAO as a continuing high-risk area. GAO found that despite some improvements made by the space agency, "the system still does not provide cost information that program managers and cost estimators need to develop credible estimates and compare budgeted and actual cost with the work performed." The report continued, "In addition to establishing an integrated financial management system, much work remains to ensure effective program management and contractor oversight."[68]

In October 2007, NASA responded with an official plan for improvement, a corrective action plan that proposed an "agency-wide coordinated approach" that focused on life-cycle cost estimates, business processes for contractor assessment, and internal assessment of performance issues.[69] The plan recognized the challenge by stating that "it is not reasonable to expect that cost/schedule growth can be entirely controlled."[70]

Still, some efforts expanded upon work that had been started in response to IMCE. These included revisions in NASA Policy Directive (NPD) 7120.4, NASA Engineering and Program/Project Management Policy. In addition to policy, procedural requirement documents were also bolstered, including the documents NASA Procedural Requirement (NPR) 7120.5: NASA Space Flight Program and Project Management Requirements, and NPR 7123.1: NASA Systems Engineering Processes and Requirements.

These changes resulted in a new governance structure within the agency and were expected to establish "a standard of uniformity in NASA program/project management" that would help better control cost and schedule growth.[71] Kranz later noted, although NPR 7120 series provides clear expectations of management, it still falls short on how to fit all the different components together in an effective way.[72]

But one year after these changes, another piece of legislation, the NASA Authorization Act of 2008, required the GAO to provide Congress with a report on the status of any NASA program with a budget greater than $50 million, indicating not all cost and schedule issues had been satisfactorily addressed.[73]

In November 2009, the Exploration Systems Mission Directorate that oversaw the Constellation Program made a point to identify Integrated Program Management as a "top priority," including the use of earned value management, integrated scheduling, and schedule risk analysis.[74] However, as described in the next section, this priority from the top was not necessarily implemented equally at the agency's ten centers across the country where the work for programs and projects was carried out.

Note that items in bold italics correspond to new timeline content discussed above.

1969	PMI founded
1984	SEI founded
1987	CMM published
1990	***GAO identified NASA Contract Management in first high-risk list***
1991	Lewis PPS&C, 1st Edition
1993	***Government Performance and Results Act (PL 103-62)***
1996	PMBOK Guide 1st published
2000	CMMI published
2000	***ISS notifies headquarters and OMB of resource shortfall; IMCE chartered***
2001	***IMCE report: strengthen financial and project control at program and headquarters***
2001	***OSF 7120.1 ISS Program Management Action Plan***
2002	***Corrective action to IMCE at ISS and headquarters: Origin of PP&C***
2003	***Columbia Accident Investigation Board, Report Volume 1, August 2003***
2005	***NASA Authorization Act of 2005 (PL 109-155) Sec 103(d): 15% rule***
2006	Carmichael PP&C published
2007	***GAO High-Risk Update (GAO-07-310): NASA, DOE and DOD all for contract management***
2007	***NASA Plan for Improvement in the GAO High-Risk Area of Contract Management***
2008	***NASA Authorization Act of 2008 (PL 110-422) Sec 1122(a) GAO report to congress***
2009	***Weiler requested NRC perform independent assessment of cost growth***
2009	***ESMD identified Integrated Program Management (IPM) as a top priority***
2010	CMMI V 1.3 released
2013	PMBOK Guide 5th Edition

Table 2.1b Timeline: U. S. Congress and NASA.

NASA Centers (1990-2010)

Over the same period as the above activities were occurring in Washington, D.C., the problem of budget and cost control was also being examined at individual NASA centers. Throughout the 1990s, initiatives at NASA centers were undertaken to train managers in project management techniques like PMBOK, CMMI, Total Quality Management (TQM) and Quality Management Systems (QMS).

In 1993, the Program Development and Control Office at NASA's Johnson Space Center (JSC) embarked on a cost containment study to determine how the center could more effectively meet its budget commitments, noting the difficulties of "the economic and political environment under which JSC and NASA operates" and the resulting poor credibility with program funders in Congress as important reasons for preventing cost overruns.[75] The study identified unrealistic cost estimates at the beginning of programs, requirements growth due to inadequate program definition, and funding instability due to the system of fiscal-year appropriations as contributing causes.[76]

As remedies, the study recommended improvement measures such as more accurate cost estimates, freezing requirements, and requesting multi-year funding from Congress. However, despite this attempt, performance issues first identified in the 1970s and again in the 1990s continued to persist into the 21st century.

In 2006, support contractor Booz Allen Hamilton examined program control issues at JSC. The contractor team compared Integrated Planning & Control (IPC) practices at JSC to those in industry. The study found that some of the issues identified in the 1993 Cost Containment Study—such as inadequate front-end planning, increasing technical complexity (i.e., added requirements), poor cost estimates, inadequate management of contingency (or reserve) funding, and conflict between institutional and program needs—had not been resolved. Overall, the team concluded that "IPC is not an institutional practice at JSC" and that "IPC execution falls below industry in most areas."[77]

In February 2010—the same month the Constellation Program was cancelled—Booz Allen Hamilton completed another such study, this one entitled Project

Excellence. The final presentation reiterated the need for a formal system of project management and the application of system engineering best practices. According to the study, "over 70% of the time, projects fail due to poor management of PM [program management] related issues."[78] The nontechnical challenge of project management, as articulated by Dr. Wernher von Braun, director of the George C. Marshall Space Flight Center during the Apollo Program in 1962 remains after almost fifty years: "The task of the project office is not to do any part of the technical job in the various disciplines but rather to assure that all effort required by the project has been planned for, budgeted for, and is actually being accomplished in a coordinated, effective and efficient manner."[79]

In fact, throughout 2010—an uncertain year for the agency when major programs were in flux—multiple other NASA centers also evaluated their Program Planning & Control practices as part of dealing with cost and schedule performance problems in the programs they hosted. NASA's Johnson Space Center, Kennedy Space Center, Goddard Space Flight Center, and Jet Propulsion Laboratory all responded to the same set of questions regarding planning and control at each of the respective centers. Topics included center organizational structures and best practices, as well as the answers to key questions such as "How often are planning and control products reviewed?" and "How well do engineers and program managers understand planning and control?" Comparing the results of these benchmarking initiatives revealed that each center had a different definition and approach to Program Planning & Control.[80]

The final presentation of the study performed at NASA's Marshall Space Flight Center found more of the same commonly observed issues of "unrealistic [budget and schedule] commitments early in the project," a lack of integration and the planning and control function being undervalued by project managers.[81] It also noted that because of a focus on cost, "integrated analysis skills have been diminished over time" while "great program control personnel possess skill, natural curiosity, and the ability to translate data to decisional information."[82] This last feature especially would prove important in the Orion PP&C causal analysis and corrective action.

Note that items in bold italics correspond to new timeline content discussed above.

1969	PMI founded
1984	SEI founded
1987	CMM published
1990	GAO identified NASA contract management in first High-Risk list
1991	Lewis PPS&C, 1st Edition
1993	***JSC Implementation of cost containment at JSC***
1993	Government Performance and Results Act (PL 103-62)
1996	PMBOK Guide 1st published
2000	CMMI published
2000	ISS notifies headquarters and OMB of resource shortfall; IMCE chartered
2001	IMCE Report: strengthen financial and project control at program and headquarters
2001	OSF 7120.1 ISS Program Management Action Plan
2002	CA to IMCE @ ISS and headquarters: origin of PP&C
2003	Columbia Accident Investigation Board, Report Volume 1, August 2003
2005	NASA Authorization Act of 2005 (PL 109-155) Sec 103(d): 15 percent rule
2006	Carmichael PP&C published
2006	***JSC Integrated Planning & Control Implementation Team (IPCIT) Decision Package (BAH)***
2007	GAO High-Risk Update (GAO-07-310): NASA, DOE, and DOD all for contract management
2007	NASA Plan for Improvement in the GAO High-Risk Area of Contract Management
2008	NASA Authorization Act of 2008 (PL 110-422) Sec 1122(a) GAO report to congress
2009	Weiler requests independent assessment of cost growth
2009	ESMD identified Integrated Program Management (IPM) as a top priority
2010	CMMI V 1.3 released
2010	***NRC (2010), Controlling Cost Growth of NASA Earth and Space Science Missions***
2010	***JSC project excellence study (BAH)***
2010	***JPL benchmarking trip***
2010	***MSFC improving program, planning & control at MSFC***
2010	***KSC benchmarking study***
2010	***JSC program control capability study***
2010	***GSFC benchmarking summary***
2013	PMBOK Guide 5th Edition

Table 2.1c Timeline: NASA Centers.

Continuing Saga (2010-present)

Despite earlier critiques and agency responses, issues with budget overruns and schedule delays in NASA programs continue to occur.

In response to the NASA Authorization Act of 2008, in 2009 NASA associate administrator for the Science Mission Directorate, Dr. Edward J. Weiler, requested an "independent external assessment to identify the primary causes of cost growth" in NASA's space science missions and to "make recommendations as to what changes, if any, should be made to contain costs."[83] The resulting 2010 report by the National Research Council found the most common causes of cost growth in NASA's science programs included "overly optimistic and unrealistic initial cost estimates" and "project instability and funding issues." The report also described how schedule growth "magnifies total mission cost growth."[84]

While agreeing with the Report's findings, Weiler noted that several of the report's recommendations, including integrated analysis and multiple cost reviews, had already been applied to other NASA programs but without results. Weiler said, "There must be another factor we're missing." He continued, "Is it the number of unknown unknowns? Is it human behavior? Because I'm at a loss. I'm looking for help."[85]

These issues were also widely noted in the media. In the wake of the cancellation of Constellation in February 2010, one reporter noted that: "Year after year, NASA's biggest projects are way over budget and way behind schedule." Further, reports by external auditors such as the GAO were "sadly predictable in listing the problems, the causes, and that NASA and its contractors are 'making progress' on reform."[86]

Nor did these problems escape the attention of policy makers on Capitol Hill, who continued to express criticism of NASA programs and projects in progress. A month before the NRC report was released, longtime NASA advocate Senator Barbara A. Mikulski requested an "independent and comprehensive" review of the James Webb Space Telescope (JWST). In her letter to Administrator Charles F. Bolden, Mikulski stated, "I am deeply troubled by the escalating costs for the JWST … Simply put, NASA must manage the cost and schedule of its large-scale programs to the highest standard."[87]

The final report of the resulting Independent Comprehensive Review Panel (more often referred to as the Casani Report) was released on October 29, 2010. It found that "the problems causing cost growth and schedule delays on the JWST Project are associated with budgeting and program management, not technical performance"—again emphasizing the issue of dealing with nontechnical challenges in NASA programs.[88] Because of poor estimates of cost and schedule baselines, the panel found the project "was simply not executable within the budgeted resources."[89] The report echoed more than fifteen years of similar findings.

That fall, NASA Headquarters conducted (yet another) study of how Program Planning & Control was executed within the agency.[90] Co-led by the Office of the Chief Engineer and the NASA Office of Independent Program and Cost Evaluation (IPCE), the study consisted of a literature review of both NASA and non-NASA planning and control sources, stakeholder interviews, and a series of focus group meetings of experts from across the agency. One significant finding of the study was that "there was confusion as to the actual definitions, functions and skills associated with PP&C."[91] Earned value management, cost estimation, and integrated PP&C capabilities were similarly found to be lacking.[92] Also, as a result of the study, the NASA associate administrator of the IPCE office was named as the agency "champion" of PP&C and charged with ownership of NASA PP&C efforts. After the study was officially concluded on March 2, 2011, the role of "champion" was not fulfilled.

In October 2011, a Project Tracking and Reporting Team Study was conducted at headquarters in response to the findings of the Casani Report on the state of the James Webb Space Telescope, "but also in response to general questions of why NASA overruns cost and schedule in its programs and projects."[93] Approximately forty interviews were conducted with personnel who had planning and control experience both inside and outside the agency.

Many of the results continued to parrot earlier conclusions. The study noted that "program office roles and responsibilities aren't clearly defined," confusing issues of accountability.[94] And the large volume of reporting processes "diverts a project manager's attention, impacts timely decision making, and inhibits forward program/project progress to mission success."[95] Another recommendation was that authority and responsibility be clarified by "defining the center as the sole responsible party for programs/projects."[96]

The parallel efforts at NASA's Johnson Space Center had arrived at similar conclusions, while also reiterating several of the same findings from the studies that had occurred in past years. The 2010 benchmarking effort had identified the need for high-level sponsorship or "champion" of PP&C at the center or agency level, and earlier that spring, just such a suggestion had begun to take shape at JSC.

In May 2010, an office within the Constellation Program presented a proposal for the establishment of an Integrated Project Management Support Office as a core JSC competency. The office would exercise primary responsibility for performing data analysis, providing training, conducting audits, and improving tools by tracking and implementing best practices research.[97] Six months later, JSC conducted a Program Control Capability Study. This effort similarly concluded that a central, consolidated JSC organization was needed for PP&C in order to address the perpetual "gaps" in program control capabilities. It called for JSC "centers of excellence" to be established for the functions of schedule and performance measurement and to develop a formal JSC training program for PP&C.[98]

A little less than a year later, around March 2011, JSC began developing proposals for reorganization as NASA prepared for the end of the thirty-year Space Shuttle Program. (The last space shuttle flight would take place in July 2011.) In addition to the establishment of the Orion Program Office (since the Orion Crew Exploration Vehicle was reauthorized in October 2010), that summer the JSC center director chief of staff proposed a center office dedicated to PP&C.[99] This new office would help address the PP&C shortcoming identified by the 2010 study. In consideration of the proposal, officials noted that each individual program and project established independent processes, and as a result of this disorganization was prone to react to PP&C issues rather than proactively address them.[100] Also addressed was the "value of corrective action" and decisions "based on data."[101] A Performance Management and Integration Office was established within the JSC Center Director's Office in September 2011.[102]

Two years later, the considerable number of efforts that had taken place in the past two decades finally seemed to have had a positive effect on budget and schedule control within the agency. The GAO's 2013 Assessment of Selected Large-Scale Projects at NASA reported that:

> Of the twelve projects in implementation, nine reported no development cost growth and or launch schedule delay in the past year, but two of these are currently facing cost and/or schedule pressures. Three projects reported development cost growth or a launch delay, but for two projects, the impetus was outside of the project's direct control. A number of factors appear to contribute to NASA's improved performance. For example, in prior reviews, a majority of projects exceeded their cost and schedule baselines. Most of these projects, however, have launched and are no longer affecting the portfolio.[103]

In other words, underlying problems continue to persist. As GAO stated in its 2014 assessment:

> NASA's total portfolio of major projects saw cost and schedule growth that remains low compared to GAO's first review of the portfolio. Within the context of (today's) constrained budgets, a primary challenge for NASA is effectively managing competing priorities, while completing a series of complex projects: 74% of the major project budget is consumed by only four projects—Space Launch System, Orion, James Webb Space Telescope and Commercial Crew.[104]

The challenge is real. In the words of SLS Program Manager Todd A. May: "The technology of this thing, to get it to fly, is not our biggest challenge right now. Doing things in a new, more efficient way to enable exploration is our challenge."[105]

Note that items in bold italics correspond to new timeline content discussed above.

1969	PMI founded
1984	SEI founded
1987	CMM published
1990	GAO identified NASA Contract Management in first High-Risk list
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1996	PMBOK Guide 1st published
2000	CMMI published
2000	ISS notifies headquarters and OMB of resource shortfall; IMCE chartered
2001	IMCE Report: strengthen financial and project control at program and headquarters
2001	OSF 7120.1 ISS Program Management Action Plan
2002	CA to IMCE @ ISS and headquarters: Origin of PP&C
2003	Columbia Accident Investigation Board, Report Volume 1, August 2003
2005	NASA Authorization Act of 2005 (PL 109-155) Sec 103(d): 15% rule
2006	Carmichael PP&C published
2006	JSC Integrated Planning & Control Implementation Team (IPCIT) Decision Package (BAH)
2007	GAO High-Risk Update (GAO-07-310): NASA, DOE and DOD all for contract management
2007	NASA Plan for Improvement in the GAO High-Risk Area of Contract Management
2008	NASA Authorization Act of 2008 (PL 110-422) Sec 1122(a) GAO report to congress
2009	Weiler requests independent assessment of cost growth
2009	ESMD identified Integrated Program Management (IPM) as a top priority
2010	CMMI V 1.3 released
2010	NRC (2010), Controlling Cost Growth of NASA Earth and Space Science Missions
2010	JSC Project Excellence study (BAH)
2010	JPL benchmarking trip
2010	***JSC Integrated Project Management Support Office 5/1/2010***
2010	***Mikulski requested independent review of JWST***
2010	***Weiler "There must be another factor we are missing" Space News V21, I29***
2010	MSFC Improving Program, Planning & Control at MSFC
2010	***JWST Independent Comprehensive Review Panel (ICRP) Final Report (Casani Report)***
2010	KSC benchmarking study
2010	JSC Program Control Capability Study
2010	***NASA OCE PP&C Study kick off 11/16/2010***
2010	***JSC Program Control Capability Study***
2010	GSFC benchmarking summary
2011	***NASA OCE PP&C Interim Report released 3/2/2011***
2011	***JSC chief of staff request for JSC PP&C staff office Aug. 19, 2011***
2011	***JSC PP&C Office Charter Sept. 2, 2011***
2011	***Project Tracking and Reporting Team (PTRT) Study Oct. 5, 2011***
2013	PMBOK Guide 5th Edition
2013	***GAO-13-276SP, NASA, Assessment of Selected Large-Scale Projects***
2014	***GAO-14-338SP, NASA, Assessment of Selected Large-Scale Projects***

Table 2.1d Timeline: Continuing Saga.

The Problem

To date, years of study, improved tools and restructured governance have not solved the problem of cost and schedule growth in major acquisition programs. Previous studies presented a common approach: they captured the opinions of recognized authorities in space science, aerospace engineering, program management, and related fields through interviews and group interaction. The findings documented in published reports and briefings were remarkably similar, and findings were accompanied by recommendations that were notably consistent.

Also common was what the studies were missing. The shortcomings of previous studies include a lack of problem definition, analysis, peer review, assigned responsibility, and follow-up. A lack of definition and accord for integration of project management tasks resulted in the unintended consequence of a wide variation in the outcomes produced by and from the same work. Managers of development programs (and their projects) each became independent authorities on how management tasks were to be performed, including Program Planning & Control. Hence, each program—and even projects within a program—performed these common management functions differently.

Analysis of expert opinion or group interaction appeared limited to editing pronouncements and deliberations into lists of findings and recommendations. Little, if any, analysis of cause was found in the studies. Rather the cause was assumed endemic to the environment in which these major acquisition programs performed. The absence of analytical rigor meant that there were no results that could be peer reviewed; mostly peers were included as participants in the studies.

Some studies did assign responsibility for implementing recommendations. However, responsibility was usually distributed across multiple authorities. Generally, findings and recommendations were compound, inclusive of the multiple disciplines involved with program management. Accordingly, responsibility was assigned to each organization responsible for its part of the finding (discipline): there is no one authority for the multi-disciplinary work of PP&C. In the one instance where a singularity was recommended (PP&C Champion), that position has not been fulfilled as of the time of this writing.

Previous studies did not determine the root cause of technical requirements growth, and concomitant cost overruns and schedule delays in NASA programs. Therefore, the problem for causal analysis and corrective action is stated as follows:

> ***Problem Statement***
>
> ***With all of the improvements that have been made, why do cost overruns and schedule delays persist in NASA major acquisition programs?***

The answer to this question is developed in the following chapter.

CHAPTER 3
Causal Analysis

Having identified the problem in Chapter 2, this chapter continues by investigating the root cause of the cost and schedule growth problem so corrective action to eliminate it can be identified.

Traditional Model

The historic pattern of cost and schedule performance in NASA programs is associated with implementation of Program Planning & Control, which evolved from the changes made in response to IMCE recommendations in the ISS Program Business Office. A model of this "Traditional PP&C" is provided as Figure 3.1.

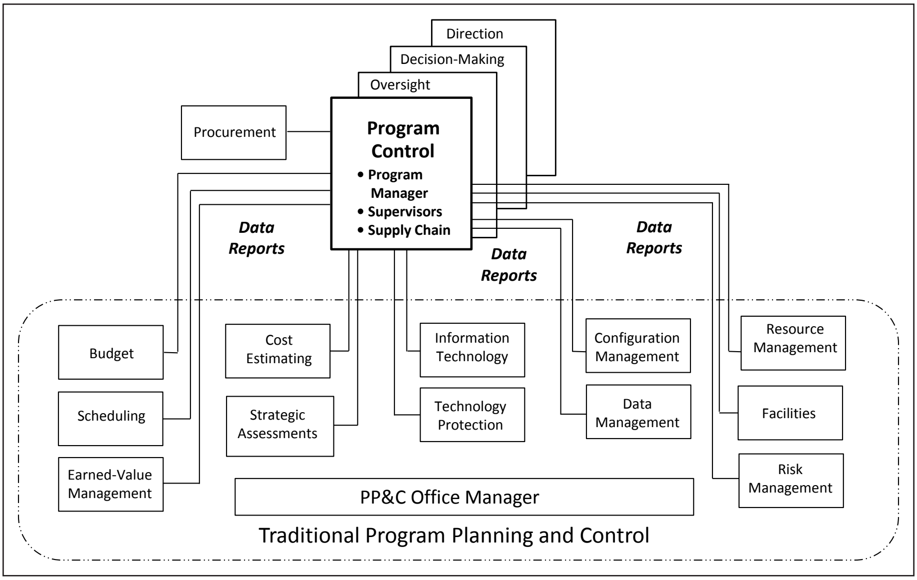

Figure 3.1 A Model of Traditional PP&C.

PP&C as traditionally implemented in NASA programs is a collection of disciplines overseen by an office manager. Separate offices for each discipline—such as procurement, financial management, and some professional services, especially configuration and data management and information technology—are common. And there may be more than one office manager (one for each discipline), as each is not necessarily co-located within any one organization.

Under this system, each discipline constitutes a separate service that produces individual data reports using discipline-specific tools. These data reports are presented directly to program management at regularly scheduled management reviews. Kranz reported how these reviews could sometimes take days to complete, as representatives from each individual discipline presented their activity reports along with data.[106]

Services provided by each PP&C discipline also include responding directly to managements' request for additional information. This working relationship sets up a direct link between a subject-matter expert and a program manager independent of the PP&C manager, compromising the manager's ability to produce and communicate any integrated and coherent program status. The program manager (and not the PP&C office manager) integrates data reports in near real-time into a perception of current program performance status and an impression of future program performance.

Orion Project PP&C featured a somewhat unique organization for NASA because of Geyer's decision to group all but one of the individual discipline offices together under one organizational umbrella—what Kranz later described as "a shock to the system."[107] Still, the different disciplines often failed to communicate with one another. Kranz focused on her previous expertise of budget and schedule and trusted the other functions to execute their jobs as they had been previously trained. One employee noted, "They were still all teams of people who were experts in that area and who really only did that stuff. You'd have a whole bunch of earned value specialists doing all of their things, and you'd have schedule specialists doing projections from that. You'd have cost analysts doing it from the accounting system."[108]

The twelve disciplines making up the Orion Project PP&C Office (see Figure 3.1) produced an almost overwhelming number of products and services. A total of 115 unique items were presented to the program manager each month, which he would then need to analyze and interpret in order to decipher program status. Additionally, in monthly and quarterly status review forums, the program manager received data sets from the prime contractor and each participating center organization supplying CEV and Orion Project Office content. After one monthly meeting in 2009, 563 individual items of data and information were counted. Of these 563 items, the majority pertained to activities performed by suppliers, with perhaps 25 percent providing information about the actual flight vehicle being developed.[109] Geyer described the quarterly report he received, remarking on how by the time it was published, "that data was so old, and we'd had to reformulate because of these external influences, that that 500-page report was totally useless to me."[110]

Additionally, in traditional versions of PP&C, there is no mechanism for balancing the demands of competing disciplines, for example the need for improved tools or larger staff of schedule management versus those same needs for cost estimating. And, PP&C resources are limited. As one staff member explained regarding his experience in risk management: "Controlling the portfolio ends up being much more trading priorities, some performance or some objectives versus the others."[111] In the development environment, budget and priority for "planning work" or for "business functions" do not fare well when in competition with technological challenges for program resources.

This discipline-view of PP&C, with continuous improvement of individual discipline expertise and tools had limited success in controlling cost, schedule, and technical growth. The tool set of individual disciplines were improved and operating costs for each became more expensive. Over almost two decades of accumulation, as individual, stovepipe disciplines strove for individual improvement, the total cost to perform PP&C also increased.

Though NASA PP&C had functioned in this stovepipe, "silos" way, for decades, the operation became less and less tenable, especially for large-scale development programs. Each instance of PP&C did manage to get the job done, as evidenced by the many flight products that were produced, but what was the cost of operating under this uncoordinated system?[112] Are there limits?

Kranz described the critical juncture when she knew it was necessary to re-assess PP&C operations. Although Kranz administered the PP&C office as she had previously been trained, and thought the review meetings were communicating information the program manager needed, the feedback she received from Geyer indicated just the opposite. She recalled how, after a monthly program review, Geyer approached her and said, "I see all this data and I see all these reports, and I hear you, but I don't understand our status." In other words, the onslaught of numbers and figures was ultimately not helpful for decision making. For her, this was "significant feedback" that it was necessary to re-think the approach to PP&C.[113]

Causal Analysis

Two decades of recurring program performance problems and investigative studies did not produce a way to eliminate cost overruns and schedule delays in major acquisition programs. Although study findings and recommendations were quite consistent, implementations had not been effective. Either the recommendations of previous studies had not been implemented correctly, or the recommendations implemented by organization were only locally, and not globally, effective in resolving program control issues.

Previous studies of PP&C problems within the agency had been performed by support contractors. Their approach was to benchmark industry and work performed by NASA centers to produce reports of findings and recommendations. Kranz emphasized that this time she wanted to use a quality management approach of causal analysis followed by corrective action. She sought help independent of those groups that had studied the problem before. She explained, "I think contractors were putting the job together the way [they had approached it before]; I wanted to put the job together [differently] … Someone should have challenged me years ago."[114]

Kranz hired H. Lawrence Dyer as her Technical Assistant to analyze the problem, primarily because of his systems engineering and quality management background in both government and industry. They had previously worked together on related problems at the JSC center level, and Kranz reported she could rely on his straightforward approach. She knew he would study the problem, and based on objective evidence, identify cause, prescribe corrective action, and follow up to ensure resolution—or repeat the process until a resolution could be demonstrated.

In contrast to previous efforts, the Orion PP&C Office implemented a quality management approach of causal analysis and corrective action, including the use of audit to ensure the effectiveness of the corrective action taken to eliminate the identified problem. This process aimed to articulate the root cause of recurring overruns and delays in NASA programs as a response to a well-posed problem for which a unique solution could be found. Only in this way could managers treat the disease instead of alleviating the symptoms. Summarized Kranz, the reason for a root-cause analysis is "so that we don't repeat those mistakes."[115]

The root-cause analysis performed by the Orion PP&C Office included extensive literature reviews (research), discussions with participants (learning), independent analysis and discussions with peers (validation). In March 2010, a series of investigative interviews were conducted with more than a dozen members of the (then) Orion Project Office. Leads and staff were queried for their perspectives on the definition of PP&C, reasons for continuing schedule delays and budget overruns, performance of existing PP&C work processes, and project management. Interviewee responses, complimented the literature review, and identified findings driven by both external and internal forces. Note the similarity in the findings presented below with those of previous studies documented in Chapter 2.

External Forces

Several of the interviewees approached for the causal analysis made note of forces that were outside of a program's immediate control. These included unsolicited input and changing requirements from politicians in the administration and on Capitol Hill (presidential administration and Congress), as well as other NASA authorities such as headquarters and the Constellation Program to which Orion was then a fully-owned project. Orion Project PP&C staff members remarked that many past NASA programs had been cancelled as a result of political machinations—the same type the Orion Project would experience when in February 2010 the Constellation Program was cancelled.

Further, the annual "use it or lose it" fiscal year budget process was found to be incompatible with highly complex space exploration programs that span multiple years and cost billions of dollars to complete. As early as 2001, the ISS Management and Cost Evaluation (IMCE) found that program cost and development schedule varied from year to year as the agency focused on executing the ISS Program within the constraints of annual budgets.[116] The issues to this approach were also noted by James P. Lewis, who observed that not only does this system create waste by encouraging unnecessary spending at the end of the fiscal year; it also demonstrates a failure to understand the dynamic nature of projects. In his words, "Project budgets typically have tolerances of ± 10 to 20 percent, so to expect them not to vary is ludicrous."[117]

This observation is particularly true in the field of cutting-edge space exploration. A NASA Headquarters official explained, "You don't know what your budget's going to be from year to year, which means you're going to have to shift content, you're going to have to shift schedule." She added, "The external stakeholders have an amazing impact on us. If we could have some kind of stability in our budget where, 'All right, for the next five years, you will get this,' we could actually plan better, but it's very hard with so much oscillation."[118]

In addition, interviewees further observed that, partly as a result of the political system within which the agency operates, budgets for NASA major acquisition programs were often set too low from the beginning. Costs were frequently "low-balled" because of the lack of consistent cost-estimating techniques, inaccurate information, or simply bad decisions. Furthermore, reserves were set too low to be able to address issues that manifested in the course of program execution. Some participants also found management at fault for accepting these business shortfalls.[119]

In addition to budgets being set too low from the outset, Orion Project PP&C Office staff also noted that cost growth was a logical response to continual changes in scope, that is, technical requirements, from entities outside the Orion Project's control, particularly headquarters and the Constellation Program. Interviewees observed that technical requirements were not well-enough defined at the beginning of a project, and should have more definition before a contract was awarded to perform development work.

Geyer later described how NASA had been subject to outside political influences for decades, citing as an example the addition of the Russian Federal Space Agency as a partner on the space station. Geyer said, "Every time there's a new guy, they all wanted to put their thumbprint on [the space program]."[120] Deputy Orion Program Manager Mark A. Kirasich added that because of fluctuations in the economy, "the external factors move quicker sometimes than the project can mature."[121]

As frustrating as they may be, these and other external factors were outside the direct control of the Orion Project. However, some of the factors identified by the causal analysis, which reinforced findings of the 2001 IMCE study, were internal and within a program manager's ability to change: the organization and operation of a PP&C within both a program and project office.[122]

Internal Forces

Multiple personnel noted that, within program offices, problems were rarely addressed as they occurred. The habit to "kick the can down the road" ultimately culminated in a crisis of budget and schedule growth. This was a legacy problem, as was the concomitant practice of only addressing a problem when it became "too big to ignore." One staff member described the role of planning personnel under traditional PP&C as constantly "firefighting."[123] Although the fallacy of this approach has been known since the medieval period, it persists into the 21st century.[124]

According to many of the persons interviewed, potential reasons for this failure to take prompt action included that:

- PP&C was neither well understood nor well executed.
- PP&C was "not particularly valued" by project managers.
- PP&C was often perceived as a "burden" that imposed unnecessary paperwork.

In the development environment, budget and priority for "planning work" or for "business functions" often suffered when in competition with technological challenges for program resources. "We're all engineers it seems like, so everybody likes the technical,"[125] said Cris Guidi, director of Programmatic & Strategic Integration at NASA Headquarters.

Even when managers were more positively disposed to the idea of Program Planning & Control, the structure of PP&C often undermined its ability to successfully execute the function. The root cause analysis identified the underlying structural reasons for these failures, and its findings were used to re-define PP&C.

Root Cause

The observations gleaned from interviews, a review of literature, and a review of past studies of cost and schedule growth provided substance for the causal analysis that through a succession of "questions and answers" identified a root cause:

- Why do cost overruns and schedule delays persist in major acquisition programs?
- Because alignment between cost, schedule and technical is not maintained; why?
- Because PP&C work is performed independently by discipline; why?
- Because integration across disciplines is not happening; why?
- Because the need was not addressed; why?
- Because technical work has priority over non-technical work.
- Because there are external factors beyond a program's control.

Put succinctly, the root cause of cost overruns and schedule delays in major acquisition programs is PP&C work does not officially exist:

Cost overruns and schedule delays continue to happen because Program Planning & Control does not formally exist. It has no D.O.B.:

- ***No Definition***
- ***No Ownership***
- ***No Benchmark***

Corrective action to eliminate root cause requires prescription of definition, ownership, and benchmark for PP&C work, followed by implementation and testing for effectiveness. Analysis and prescriptions for each of the three components is described in the next chapter, including a description of pre-work required for implementation. Implementation is described in Chapters 5 and 6, and results are presented in Chapter 7.

CHAPTER 4

Corrective Action

Corrective action to eliminate root cause is providing definition, ownership, and benchmark for PP&C. Each is developed below as analysis followed by a concluding statement. The vision for implementing corrective action in Orion is then presented.

Definition

The first part of the root cause of cost overruns and schedule delays in major acquisition programs is the lack of a commonly recognized definition of PP&C. Within NASA, roles and responsibilities for program managers are documented as an Appendix in the NASA Handbook for Program Management.[126] Each program aims to independently provide what program management and discipline experts agree is necessary and sufficient for the program to measure, manage, and control program performance within available resources. This one-by-one situation could be found throughout the agency, where PP&C becomes a program-unique adaptation of existing, common requirements and capabilities.

This situation was not unique to the space agency. Within other federal agencies also, each program administered its own interpretation of policy, requirements, and procedures for the work performed by each of the individual PP&C disciplines. For example, a 2008 Root Cause Analysis at the Department of Energy found that the inconsistencies between various roles, responsibilities, and authorities resulted in "competing and conflicting project direction, ineffective use of resources, a lack of accountability, and limited authority."[127] Congressional action in 2009 and 2010 sought to remedy similar problems in DOD major acquisition programs.[128]

Even in professional program management literature, each book or volume presents its own glossary and terminology usage based on the author or organization's preference and convention. No single, common definition of the words "Program Planning & Control" or of the acronym PP&C was found, and each of the two books with Project Planning & Control in its title proved quite different in content.

It became clear that in all of the literature reviews and interviews conducted to date, the actual work performed by PP&C had not been defined. In order for PP&C to perform effectively, Orion Program would have to provide a functional definition.

Analysis

The work to develop a definition for PP&C began with three key insights that would be vital to how corrective action was defined and executed.

Insight 1: Work ≠ Tools

During the causal analysis, the question was asked: "What work do discipline experts perform with their tools?" This question led to the realization that, historically, the work performed under the PP&C umbrella was identified by the name of a discipline used to collect and produce information (e.g., financial management, cost estimating, earned value, etc.). However, the expertise and tools used by these disciplines are not the same as the work itself.

This insight helped to explain a limitation of traditional PP&C: the work had not been defined, and the unique expertise was with each discipline. Put another way, the role of the traditional PP&C office manager was more custodian than manager—and it was certainly not integrator.

As shown in Figure 4.1, PP&C work is iterative; it is continually repeated. Plan Work, Acquire Resources, and Document Baseline are annual events associated with the Program Planning Budget & Execution cycle. During a Formulation phase, Plan Work is re-planning the execution plan each year to accommodate results of work performed to date, as well as expected funding for the current year. Then, during an Implementation phase, Plan Work means performing the annual portion of the Agency Baseline Commitment (a.k.a. Program Baseline), which is funded in annual increments each fiscal year.

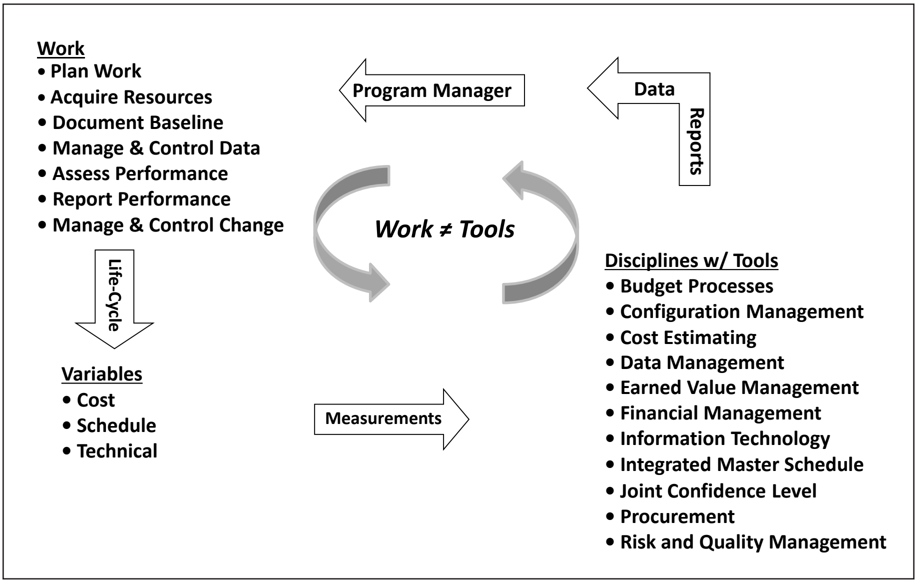

Figure 4.1 The work performed by PP&C is not defined as the tools used to perform that work.

Manage and Control Data, Assess Performance, Report Performance, and Manage and Control Change are repetitive, usually on a monthly cycle. Manage and Control Data work is the mechanism for how "official" cost, schedule (business), and technical data and information are incorporated into the program. Its purpose is to maintain and preserve the integrity of the data and information so it can be used as a source for assessing and reporting program performance. Manage and Control Change ensures that changes and trends are traceable. Maintaining data traceability and using consistent methods of analysis yields a time stream of quality-assured performance measurements and trends that can be used to monitor change over time and enable a more informed decision-making process.

Insight 2: Data ≠ Analysis

An examination of the work and data flows shown in Figure 4.1 led to the additional insight that traditional PP&C did not assess program performance. One employee explained, "I think a lot of the NASA systems have been built for particular individuals to analyze and research their information, but very little has been done to look at how [one] particular [discipline] integrates with another [discipline]."[129] Each discipline produces data reports for that discipline only, which are then presented directly to a program manager. Analysis and integration are performed by a program manager in near-real time as a stream of data is being reported.

A program manager could be overwhelmed by incoherent sets of data, each developed with its own set of tools and presented in its discipline-unique language, jargon, and context. As a result, the data and information used to inform program management varied and was not (necessarily) actionable; it was of limited usefulness for informing decision making.

Guidi explained how, for example, Earned Value Management "is great as one data set, one data point, but is not the end all, be all." In order for the information to be useful, it must be combined with other data and experience to form a comprehensive analysis. On its own, "the number tells me nothing." Instead of one data point separate from any context, "you've got to take everything into consideration" in order to understand "the big picture of what's the health of the program."[130]

In fact, this was the exact feedback Kranz had received earlier from Geyer. Echoing Guidi's comments, Geyer later reflected that "sometimes those tools got in our way." He also commented that tools "won't help you actually manage. They're just tools with output." Put another way, PP&C operations centered around a "tool empire" that was "very focused on process, and not necessarily goals."[131] The causal analysis found that the different disciplines were not even communicating with each other, so Orion PP&C began to re-think how the office was structured in order to remove some of the barriers that prevented PP&C from being more collaborative.

In order to perform the Assess Performance and Report Performance work, PP&C would have to include an analysis function not previously performed, as shown in Figure 4.2. This new PP&C analysis work would provide information about performance at the *program* level, rather than just data at the discipline level; the results would address feedback received and enable a better informed decision-making process.

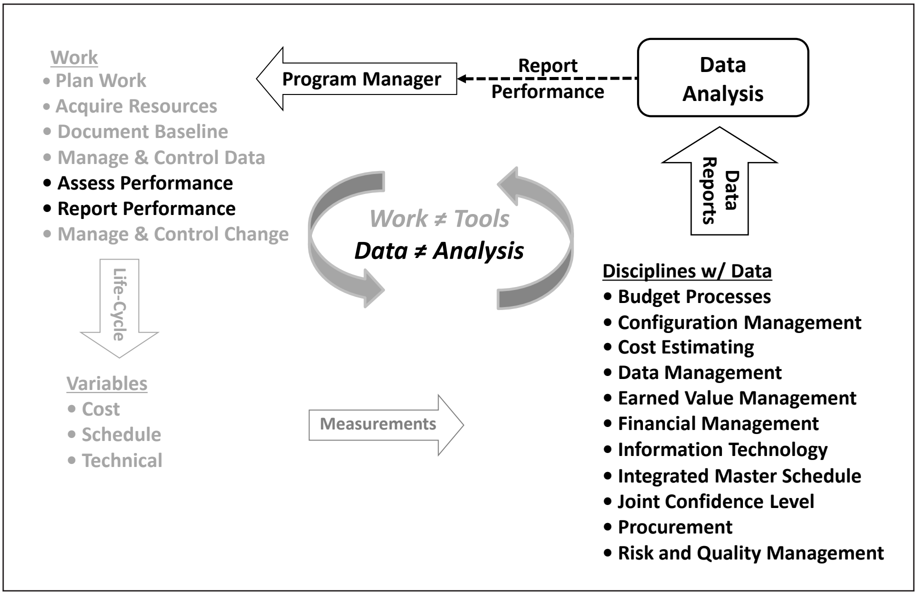

Figure 4.2 The work of PP&C includes analyzing data reports and reporting results to program management.

Insight 3: Control ≠ Controls

What is the meaning of the letter "C" in the acronym, "PP&C"? Common usage establishes that the "C" stands for *control*. However, the positions of PP&C Office manager and subordinate leads do not have authority for making program-level decisions (See Appendix D, Position Descriptions). Program control is performed by a program manager and other positions with authorization to make program-level decisions. PP&C develops the *controls* used to inform control; control is external of the PP&C organization. Therefore, the acronym PP&C includes controls and control; the definition of PP&C to eliminate the "definition part" of root cause must address both.

Insights 1 and 2 provide a basis for defining PP&C as a system for developing program controls. Insight 3 provides a basis for defining Program Performance Management as a system for exercising program control. A conceptual relationship between controls and control is shown in Figure 4.3.

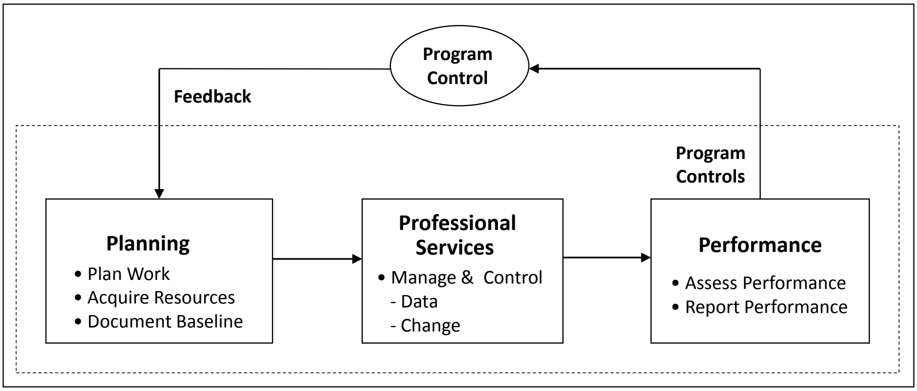

Figure 4.3 PP&C work produces program controls that inform program control.

Controls

The work of PP&C is a subset of a program manager's roles and responsibilities. Because of the size of major acquisitions programs, the volumes of data and information required and the importance of program controls in managing program performance, the subset is performed as a collective by a dedicated group of highly trained people with analytical tools. PP&C (controls) is a group of interdependent, interrelated and interacting elements that form a complex whole.[132]

Examination of the seven items of PP&C work shown in Figures 4.1 and 4.2 reveals a group of three elements: planning, professional services, and performance. Put simply, "Planning" establishes the cost, schedule, and technical relationship; "Professional Services" manages the flow of data and information throughout the program; and "Performance" compares planned with actual performance to inform program control. Program control provides feedback, and the process repeats.

As reviewed in Chapter 2, government and industry standards exist for the work performed by many of the disciplines comprising the three elements of PP&C. A list of selected CMMI, PMBOK, and NASA requirements and standards for disciplines comprising PP&C is provided as Table 4.1. These lists were used as a starting-off point to define the work performed by PP&C in developing program controls.

CMMI V1.2 Process Area	PMBOK Knowledge Area	NASA Requirements
• Requirements Management • Project Planning • Project Monitoring & Control • Supplier Agreement Management • Measurement and Analysis • Quality Assurance • Configuration Management • Risk Management • Integrated Project Management • Organizational Process Definition • Quantitative Project Management • Causal Analysis & Resolution	• Integration Management • Scope Management • Time Management • Cost Management • Quality Management • Communication Management • Risk Management • Procurement Management	• Program and Project Management • Earned Value Management • Schedule Management • Risk Management • Work Breakdown Structure • Systems Engineering • Financial Management • FAR Procurement Notices • Configuration Management • Quality Management • Quality Assurance

Table 4.1 List of selected disciplines in industry and NASA standards.

Similarly, a review of GAO reports and testimony identified management functions considered key to managing risk in major acquisition programs. The GAO reported that effective performance of the following eight disciplines of management is necessary for creating and sustaining high-performing organizations:

- Strategic Planning
- Budget Formulation and Execution
- Organizational Alignment and Control
- Performance Measures
- Human Capital Strategies
- Financial Management
- Information Technology
- Acquisition[133]

Using these lists of selected disciplines and GAO criteria as a basis, subset roles, and responsibilities comprising PP&C were extracted from the Program Manager's Handbook and mapped into each of the three PP&C system elements.[134] The results are shown in Table 4.2.

PP&C Planning	Subset of Program Manager's Roles and Responsibilities
	• Conduct concept studies • Develop cost and schedule estimates • Develop workforce and facilities plans • Provide annual budget submission • Support development of the Agency Baseline Commitment • Support development of agreements with international and other government agencies • Provide proposed program management agreement, cost and schedule estimates for Key Decision Points (KDPs)

Table 4.2a PP&C is responsible for the performance of a number of program managers' Planning roles and responsibilities.

PP&C Performance	Subset of Program Manager's Roles and Responsibilities
	• Implement program consistent with budget • Assess program technical, schedule, and cost performance and identify action to mitigate risks • Provide assessment of program and project readiness to enter next phase

Table 4.2b PP&C is responsible for the performance of a number of program manager's Performance roles and responsibilities.

PP&C Professional Services	Program Infrastructure required to fulfill Program Manager's Roles and Responsibilities
	• Configuration Management • Control Board Administration • Data Management • Export Control • Facility Management • Information Technology • Records Management • Supply Management • Technology Protection

Table 4.2c The PP&C is responsible for providing the infrastructure and Professional Services for program operation.

Control

As with controls, the control work under the conventional banner of PP&C is also a subset of a program manager's roles and responsibilities. Accordingly, using the same criteria as for controls, the subset of roles and responsibilities comprising program control were extracted from the Program Manager's Handbook. The results are shown in Table 4.3.

Program Manager Program Control	**Subset of Program Manager's Roles and Responsibilities** • Originate requirements for the program • Develop and approve the Program Plan • Implement program consistent with budget • Execute Program Plan • Manage program resources • Assess program and project technical, schedule, and cost performance and take action, as appropriate, to mitigate risks • Communicate program performance, issues, risks to center and headquarters management • Conduct readiness reviews leading to KDPs for program • Present program and project readiness to proceed past KDPs

Table 4.3 Program Control is a subset of a program manager's roles and responsibilities.

Concluding Statement – Definition

PP&C is defined as:

> ***PP&C is the name given to the body of multidisciplinary work performed under a single authority to fulfill a subset of a program manager's roles and responsibilities for producing the controls (data and information) that inform program control.***

To minimize confusion with controls, program control is re-named Program Performance Management (PPM) and is defined as:

> ***PPM is a system for 1) determining a program's actual status relative to its planned performance at any point in time, 2) assessing the probable impact of the current status on a) where the program wants to be in the near-term, b) where the program needs to be in the long-term, and 3) making decisions to fulfill commitments and achieve the required outcome.***

Implementation of *program controls*, PP&C, in the Orion Program is described in Chapter 5. Implementation of *program control*, PPM, in the Orion Program is described in Chapter 6. Both are required to eliminate the complete scope of the "definition part" of the root cause of cost growth (and concomitant cost overruns) and schedule growth (and schedule delays) in major acquisition programs.

Ownership

The second part of the root cause of cost overruns and schedule delays in major acquisition programs is lack of ownership of PP&C.[135] The owner is the single person accountable for the consistent operation of PP&C in conformity with governing policy and procedural requirements, and the person delegated authority to ensure PP&C operations are correct and cost effective, both within and across programs.

Causal analysis found that a program exercises its own unique PP&C, as does each of its chain of suppliers providing program content.[136] Previous studies in NASA recommended ownership based at Headquarters in Washington DC, either within one office, or split among multiple business, administrative, and technical functions. Suggestions have included the Office of the Chief Engineer, the Office of the Chief Financial Officer, the Procurement Office, and the Independent Program and Cost Evaluation Office.

Previous NASA studies recommended a center hosting a program. And, in fact, many of the NASA centers did institute their own offices for performing PP&C work, for example the JSC Performance Management and Integration Office created in 2010. So just as with definition, "ownership," is, and remains, individual. This individual ownership compromises data integrity and increases operating cost.

All the different levels of agency governance need the same types of informational data to make decisions. What differs is the scope of detail required: requirements for data detail decrease with increasing organizational hierarchical level. For example, the budget for an enterprise responsible for a portfolio of programs is obtained through the same work process used to fund each of its programs, but the values are less granular. The amount of data and information detail required by an enterprise to manage its programs is less than that required by a program to manage its projects, etc. Finely detailed project numbers are an input to a program number, and medium-detail program numbers are an input to a broader Enterprise number.

Integrity is maintained most easily when each element in a supply chain uses a system that implements common work and data requirements. Each level does not need to duplicate the results produced at a lower level. Rather it needs to have confidence in the accuracy of the data and information provided by its subordinate. This is especially true at the program level where content from a portfolio of projects is integrated into a flight vehicle and at the enterprise level where content from a portfolio of programs is integrated into a mission capability.

A patchwork of individual procedures and tools makes information exchange expensive when both data systems and exchange procedures vary. Under such conditions, detailed requirements to interface data systems are needed and rework is required to integrate information from lower levels into higher-level representations. As data interpretations are "translated" across different organizational levels, quality control is compromised.

As data are captured, manipulated, analyzed, and then integrated by a second party removed from the original source, data can be corrupted; responsibility has shifted from provider to analyst. One staff member reported, "Nine times out of ten, the person who's inputting the data knows everything there is to know about the data, understands what they intended to say or didn't say, or how they meant to say it, or, 'well, this really means this.'" She explained how it was therefore important to identify and retain the "authoritative source."[137]

The same staff member also pointed out that because of a lack of standardized tools, the various levels of enterprise, program, and project management could not effectively communicate with each other. She explained how under the CEV Project she had to learn three different risk systems: one for Orion, another for Constellation, and a third for the headquarters-level Exploration Systems Mission Directorate.[138] What's more, time can be lost because of the time required to learn all the different tools: "Every time we start a new project, we're losing between three to nine months of everybody's time to learn the system tool."[139]

Analysis

Ownership was determined by identifying the agency organization most ideally positioned to facilitate a seamless exchange of information throughout the hierarchy of projects, programs, enterprises, and mission directorates while still maintaining integrity and minimizing expense. To start, the responsibilities of ownership were defined on the basis of research and observations.

Ideally, an owner would:

- Have a position of authority.
  Position of authority argues for an agency-level owner in order to establish policy and procedural requirements, as well as to require implementation by all major acquisition programs, including audit.
- Have a systems perspective.
  A *systems perspective* would be a component of an individual's knowledge base, ideally a required capability of persons qualified for a management position within an organization.
- Have an understanding of component disciplines;
  PP&C work is multidisciplinary and an *understanding of component disciplines* requires both ability and a willingness to support work in one discipline over another as necessary to maintain and preserve an overall functional capability.
- Optimize PP&C performance.
  Optimize functional performance would mean that decisions are based on improving the overall operation at the expense of any one component discipline.
- Facilitate the flow of data and information.
  The primary product of PP&C is a *flow of data and information* that is both accurate and timely throughout a hierarchy of suppliers for product integration and for governance, regardless of physical location.
- Address affordability objectives.
  Affordability is especially important in an environment where budgets are constrained. Data require personnel and time to be collected and are therefore expensive to acquire. Quantity is controlled primarily by cost.

Each supplier provides data in accordance with contract or agreement provisions. Calls for data outside of contracts are generally not used in cost-constrained programs; they are prohibitively expensive because of both availability of data sought, and mostly because of approvals required for releasing it to a second party.

- Continuously improve PP&C.
  Continuous improvement of PP&C by audit improves product and service quality, and it reduces operating cost through standardization of work product, leaning of processes, or innovation. Continuous improvement directly implements affordability.

Based on these criteria, candidate owners of PP&C were identified as agency, center, program, and project. Table 4.4 illustrates the evaluation of the various NASA offices for their suitability as owner of PP&C.

	Position of Authority	System Perspective	Understand Component Disciplines	Optimize PP&C Performance	Facilitate the Flow of Data and Information			Affordability	PP&C Function Continuous Improvement
					Flight	Mission	Governance		
Mission Directorate	Agency	More Likely	More Likely	More Likely	X	X	X	More Likely	More Likely
Mission Support Directorate	Agency	Less Likely	Less Likely	Less Likely			X	Less Likely	Less Likely
Administrator Staff Office	Agency	Less Likely	Less Likely	Less Likely			X	Less Likely	Less Likely
Center Director	Center	More Likely	More Likely	More Likely	X	X	X	Likely	More Likely
Program Manager	Program	More Likely	Likely	Less Likely	X	X	X	Likely	Likely
Project Manager	Project	More Likely	Likely	Less Likely	X	X	X	Less Likely	Less Likely

Table 4.4 Evaluation of ownership.

The PP&C and PPM systems are defined as a subset of a program manager's roles and responsibilities in Tables 4.2 and 4.3. Therefore, the authority responsible for establishing and maintaining policy, requirements, and procedures for program management is the logical owner for the policy, requirements, and procedures for PP&C. As noted by one headquarters official: "There are very distinct personalities of each center, but what tends to happen is the program manager sets the tone."[140] Applying the above criteria for ownership shows that both mission directorates and centers are the strongest contenders.

Pros and cons were applied to these two contenders. Because the work for NASA programs is frequently distributed across multiple centers, center ownership presents the risk that the PP&C systems across a program, an enterprise and a mission directorate would be different. For example, independent authorities for PP&C at JSC, MSFC, and KSC could complicate the efforts of the Orion, SLS, and Ground Systems Development and Operations (GSDO) Programs to pool information at the Exploration Systems Development (ESD) Enterprise level. This difference equates to additional expenses because:

- Extra work is required to prescribe in detail data requirements and interface requirements for the exchange of data and information between participating program organizations and information technology at different centers.
- Re-work of delivered data is required to perform higher-level (enterprise, program) performance management analysis; governance becomes more complicated as questions of ownership of re-worked data became an issue.

Data integrity and affordability are the deciding factors between mission directorate and center ownership. During the causal analysis interviewees observed that dividing the work between multiple NASA centers resulted in higher costs for the overhead required to coordinate between all the different parties and information technology systems involved.[141] Individual center standards and systems for data exchange would increase the work and costs required to communicate and manage across programs (and projects). Therefore, a mission directorate is the most-well suited level to exercise ownership of PP&C.

Guidi noted that at a time when NASA is increasingly focused on meeting cost objectives, "we're not just setting up processes for processes' sake, and we're not collecting data just for the sake of collecting data. We're using every piece of data because we don't have the resources" to collect extraneous pieces of information. In other words, "every penny that we spend has to be absolutely justified."[142]

Ownership at the mission directorate level would eliminate superfluous and costly data hand-offs, in addition to reducing the risk of errors caused by faulty communications. A common definition for the PP&C system means that the work performed is the same for all organizations, regardless of level: enterprise (portfolio of programs), program (portfolio of projects), center (parts of programs or projects), or project. Ownership should also be common so PP&C can be common throughout an enterprise-program-project supply chain, including governance.[143]

Concluding Statement – Ownership

Based on the above analysis, Orion PP&C determined that in order for PP&C to function effectively throughout a hierarchy of governance:

> ***Ownership of PP&C is bifurcated: The owner of PP&C, its requirements, procedures, operation, and improvement is the mission directorate responsible for a portfolio of major acquisition programs.***[144]

> ***The manager of the "book" documenting PP&C policy, requirements, and procedure is the NASA Administrator's office responsible for program management documents.***

The owner of PP&C is responsible for requirements and procedure. Each mission directorate will capture work, data, and key personnel requirements. The owner will capture these agency-level requirements, integrate them by consensus of mission directorates, and provide them to the book manager for issuance as a controlled directive within the NASA Procedural Requirements (NPR) 7000 series for program formulation.[145] The directive will include requirements for audit of compliance and for controlling change and provisions for tailoring to individual program needs. Mission directorates will flow PP&C system requirements down to enterprise, program, and project levels, regardless of host NASA center. The "book manager" is responsible for quality control of content.

Tailoring is performed at the enterprise level. Enterprise managers within a mission directorate, in consultation with program managers, will tailor agency-level PP&C requirements for major acquisition programs within its portfolio. However, traceability and rationale are required. Guidi, said, "There's that balance. You want to put some structure, but you don't want to make the structure so rigid, where then the program manager itself doesn't have the flexibility."[146]

Common ownership at the mission directorate level would also facilitate the annual PPB&E process. For programs in the Formulation phase a mission directorate and an enterprise could, for example, trade off schedule for budget to balance between funding priorities. For programs in the Implementation phase, it would provide for continuity within a baseline commitment as a trade-off with other programs within a Formulation phase.

Benchmark

Lastly, the third part of the root cause of cost overruns and schedule delays in major acquisition programs is lack of a *benchmark*. The causal analysis did not find any documented set of best practices and standards for benchmarking the effectiveness of an overall PP&C system.[147] A benchmark is a standard or point of reference used in measuring value or judging quality.[148] As defined by PMBOK, benchmarking is "comparing actual or planned project practices to those of comparable projects to identify best practices, to generate ideas for improvement, and to provide a basis for measuring performance."[149] Guidi said, "Benchmarking [point of reference] to me, is just looking at different industries, different entities and how they manage their portfolios."[150]

Within NASA and other federal agencies, some requirements and guidance for performing PP&C were found, but no evidence was found that the measurement of overall PP&C (system) performance within or across multiple programs was being performed.[151] The lack of a standard for benchmarking follows directly from the lack of both definition and ownership; without these first two components, it is impossible to address a common standard. Like definition and ownership, benchmarking of PP&C performance, if performed, is individual.

Some industries utilize recognized, independent standards of performance that provide points of reference for determining quality. In finance, for example, the National Bureau of Economic Research has classified common stocks as a leading indicator of business cycles. Two standards for benchmarking are the Morgan Stanley Capital International (MSCI) index and the S&P 500. The

MSCI World is a stock market index of 1,612 world stocks.[152] It is maintained by MSCI Inc., and is often used as a common standard for benchmarking world or global stock funds.

The S&P 500, or the Standard & Poor's 500, is a stock market index based on the market capitalization of 500 large companies having common stock listed on the NYSE or NASDAQ.[153] The S&P 500 Index is one of the most commonly followed equity indices, and many consider it a bellwether for the U.S. economy.

Financial managers compare the performance of the individual portfolios they manage with published values for the MSCI World Index and/or the S&P 500 Index at comparable time periods. The objective for an individual portfolio (analog to a program) or for a financial manager (analog to an enterprise manager) is to meet or exceed reported performance for that index. Performance scored at or above the standard for benchmark achieves the objective. Performance below the reported index value is cause for taking corrective action. Since the sectors and companies comprising each published index are known, comparison of performance with the standards can be used to identify where change is needed to bring about improvement.

Analysis

Agencies and managers of federal programs are responsible for the quality and timeliness of program performance, for increasing productivity, controlling costs, mitigating adverse aspects of operations, and assuring that programs are managed with integrity and in compliance with applicable law. The U.S. government defines *management controls* as the standard for benchmark, and results are reported annually by agency.

The Office of Management and Budget defines management controls as "the organization, policies, and procedures used to reasonably ensure that (i) programs achieve their intended results; (ii) resources are used consistent with agency mission; (iii) programs and resources are protected from waste, fraud, and mismanagement; (iv) laws and regulations are followed; and (v) reliable and timely information is obtained, maintained, reported and used for decision making."[154]

Similarly, the Federal Managers' Financial Integrity Act of 1982 (FMFIA) requires the GAO to issue standards for *internal control* in government.[155] The standards provide the overall framework for establishing and maintaining internal control and for identifying and addressing major performance and management challenges and areas at greatest risk of fraud, waste, abuse, and mismanagement. The term internal control is synonymous with the term management control that covers all aspects of an agency's operations.[156]

GAO uses five standards to benchmark internal control. The five standards applied at a program level are documented as Table 4.5. Performance in each standard is evaluated at operating levels, such as centers, programs and projects, and reported annually at an agency level. Because the evaluations reported are subjective and do not include the objective data behind the evaluations, using them as a standard for benchmarking PP&C is problematic. They do not provide the level of detail necessary to identify precursors of poor performance as cost overruns and schedule delays have occurred while programs, centers, and the agency have conformed to GAO standards. Therefore, internal control is a necessary—but not a sufficient—agency-level standard for benchmarking PP&C operational performance.

Standard	Definition at a program level (edited from GAO, 1999)
Control Environment	Establish and maintain a program environment that sets a positive and supportive attitude toward managing and controlling cost, schedule, and technical performance.
Risk Assessment	Assess program cost, schedule, and technical performance risks from both external and internal sources.
Control Activities	Establish and operate boards, panels, and management review forums to control change, review cost, schedule, and technical performance, and ensure that management's directives are carried out.
Information and Communications	Record and communicate information to management and others who need it in content, form, and time frame that enables them to carry out their responsibilities.
Monitoring	Monitor and assess the quality of performance over time and ensure that the findings of audits and other reviews are promptly resolved.

Table 4.5 GAO Standards for the internal control of programs.

As reported in Chapter 2, Federal law establishes values for cost and schedule variables as benchmarks for measuring and reporting program performance during an Implementation phase.[157] Federal law also requires GAO to annually document agency performance in controlling cost and schedule growth.[158] Available GAO data for cost and schedule growth in NASA programs in the implementation phase is summarized in Table 4.6.[159]

GAO Assessment of NASA		2009	2010	2011	2012*	2013*	2014*
GAO Assessment of NASA		09-306SP	10-227SP	11-239SP	12-207SP	13-276SP	14-338SP
Number of Projects Reviewed		18	19	21	21	18	18
	LCC ($B)	>50	>66	>68	>43	NR	>21
Number in Implementation Phase		13	14	16	15	12	15
	Number with Cost Growth	11	9	7	5	2	6
	Percent with Cost Growth	85%	64%	44%	33%	17%	40%
	Average Increase (%)	13%	19%	15%	15%	4%	3%
	Number with Schedule Growth	11	10	5	5	3	4
	Percent with LRD Growth	85%	71%	31%	33%	25%	27 %
	Average Delay in LRD (months)	11	15	8	8	4	3
*	Excludes JWST values						
NR	Not Reported						

Table 4.6 Range of average cost and schedule variance in NASA programs.

Average Growth in LCC = 12% (which is below the 15% threshold)

Average Growth in LRD = 8 months (which is above the 6 month threshold)

These data could be used to prescribe standards (≤ 12% as the bound for cost growth and < 6 months as the bound for schedule growth) for benchmarking program performance during the Implementation phase, for which the source data apply. Controlling program performance to values below historic averages would be the objective.

While values for the cost, schedule, and technical variables of a program compared to planned values provide a standard for benchmarking the performance of a program overall, they do not provide a standard for benchmarking the performance of the PP&C system alone.[160] That is, there is a necessary distinction between the program controls that inform program management (PP&C work), and the program control responsible for decisions made based on those controls (PPM work). Likewise, a standard for benchmarking PP&C system performance distinct from PPM performance is needed: a standard for benchmarking PP&C system operational performance must only address program controls and exclude any evaluation of management decisions informed by those data and information.

Concluding Statement – Benchmark

A standard for benchmarking PP&C performance independent of PPM performance is needed. Using internal controls as a standard would apply at an agency level only, and using historic GAO measurements as a standard would apply at a program level. Only PP&C applies to a PP&C level; the standard for benchmarking PP&C performance must be PP&C itself. Since PP&C deals with both near real-time program performance and future time projected program performance, the standard for benchmarking PP&C performance is consistency, which can be measured by comparing predicted program performance with actual program performance at the same time period. The objective would be for computed actuals to be within "acceptable" variance of predicted at any comparable time.

$$\text{Variance} = \frac{[(\text{Predicted Performance})_t - (\text{Real-Time Performance})_t]}{(\text{Real-Time Performance})_t}$$

with t = time ,
and Objective: Variance ≤ TBD %

Program performance values projected for a future time period are testable against actual program performance. This is true for any life cycle phase of a program. The standard for benchmarking PP&C work within and across a hierarchy of projects, programs, and enterprise is internal consistency.

> ***The standard for benchmarking the performance of the overall PP&C system operation is internal consistency. It is measured by comparing the values of program controls projected to be present at some future time period with actual values achieved when that time period occurs. Variance in cost, schedule, or technical variable provides guidance for making improvements to performance calculations and analysis methods used by PP&C.***

Vision

Quality management requires that the effectiveness of corrective action to eliminate cause be demonstrated. If elimination of root cause cannot be established, then further cycles of analysis and action are required until elimination can be confirmed. With corrective action known, the next step was implementation as a prerequisite for determining effectiveness. The definition of PP&C and PPM as systems was expanded to a next-level of detail to support a reorganization of the disciplines of traditional PP&C (Figure 3.1) into the systems model of PP&C for implementation in the Orion Program (Figure 4.3).

Orion PP&C envisioned a re-structuring of the PP&C office, in which program controls would be developed by discipline experts working interactively and interdependently within and across PP&C system elements to produce data reports and actionable information. As an employee noted in the causal analysis, it was the job of PP&C to “connect the dots.” Another staff member reflected later: “That’s what project planning and control is—it’s an integration function of all of these silos of data, to be able to answer questions at the project, program, and agency level that come up.”[161]

In this vision, PP&C would improve predictions of future performance and be able to inform program management of issues and drivers so problem areas could be addressed before they spiraled out of control.[162] One staff member said, “If we make some predictions about where we’re heading, then hopefully … we can be proactive on those things.”[163]

A restructured PP&C would be a consolidation and integration of products and services from multiple disciplines working under a single authority in order to ensure:

- Coordination of disciplines.
- Integrity of data and information.
- Consistency of work products and services.

And once established, the single authority would allow for reduced operating costs thereby implementing agency objectives for affordability and cost savings by:

- Eliminating duplication.
- Standardizing products and services.
- Improving continuously.[164]

Figure 4.4 depicts the model of the PP&C system for implementation into the Orion Program, a.k.a. PP&C Second Generation. According to the model, configuration-controlled requirements for the flight vehicle are input to the "Planning" element. The planning element captures the program baseline and program plan, and obtains annual budget. Together, these captured data and information are stored as the Planning Data Set. Baseline, plan, and budget are all input to a supply chain that comprises contracts with aerospace industry, agreements with government agency organizations, protocols with international governments, and grants to academia.

The PP&C "Professional Services" element provides the infrastructure, control, and security for data and information exchange throughout the entire program supply chain. Supplier data received by professional services is input to the "Performance" element that calculates discipline-specific and integrated-program performance at regular intervals in time. These data, information, and analysis results, a.k.a. program controls, are captured as the Performance Data Set.

Integrated analysis, together with performance measures and source data, comprise the program controls that are reported to program control to inform decision-making. Decisions made and feedback can change planning information, which in turn would change supply chain input and output, and hence program performance in repeat cycles throughout a program life cycle.

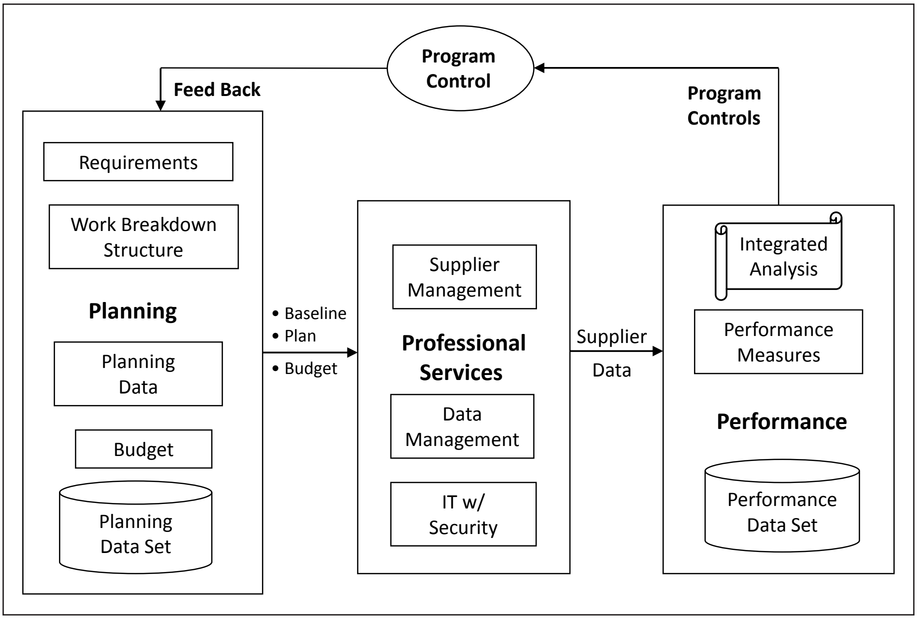

Figure 4.4 PP&C is a system of three interdependent, interrelated, and interacting elements.

Implementation of this vision is the subject of the next chapter.

CHAPTER 5

Program Planning & Control

Chapter 3 described the causal analysis performed to identify the root cause of cost overruns and schedule delays in major acquisition programs as no definition, ownership, and benchmark. Chapter 4 described the analyses performed to determine corrective action. Chapter 5 describes implementation in the Orion Program.

In the Orion Program, *definition* is PP&C Second Generation and PPM. *Ownership* is the program manager, who also provides budget. Linking ownership to budget authority eliminates cost growth caused by multiple individual and sometimes conflicting discipline authorities operating independently. B*enchmark* is internal consistency, feedback, and best practices. Consistency is measured by comparing predictions of performance with actual performance for comparable time periods. Feedback is obtained monthly, and work processes incorporate best practices, which are audited as part of applicable certifications.[165]

This chapter addresses implementation of PP&C in the Orion Program. It provides a description of the transition of PP&C from a model of traditional operations to a systems model of execution. Its purpose is to facilitate future implementation by sharing experience in managing change. Chapter 6 then addresses implementation of PPM. It provides a description of the management forums and performance management concepts of trade space and business case fundamental to controlling program performance.

Implementation

By early FY 2010 (starting in October 1, 2009), the Orion CEV Project was ready to share the findings and conclusions of its investigation into PP&C with Orion PP&C office staff, many of whom had been working on Orion since its inception in 2004. A year of study and analysis had led to the incontrovertible conclusion that PP&C needed to pursue a more integrated approach, in which employees would look beyond their individual tools and discipline-specific processes in order to provide a coherent picture of program status to the program manager. Kranz described how she coined the term "Next Gen" to signal "a significant impact to the work of this team." She stated, "I wanted it to look, be, and sound different."[166]

Retreats

Because most of the Orion PP&C team had continued their activities under the traditional PP&C paradigm while the root cause of the cost overrun and schedule delay problem was under investigation, PP&C leadership organized a series of retreats to introduce and discuss the Next Gen approach. These one- to two-day, off-site meetings allowed time for discussion away from the distractions of the office. Six off-site retreats were held over a one-year period from April 2010 through April 2011 to build consensus for a new way of performing PP&C in the Orion Program.[167]

Overall, the information presented to office staff—each of them an expert in their respective discipline—on the results of their interviews during the Causal Analysis (Chapter 3) was well received. Staff volunteered verbal feedback to add detail or provide clarification of statements made about their own work and input, demonstrating that employees were engaged with the process. Information presented on insights about the vision of PP&C as a system was mostly met with interest and intellectual curiosity.

However, this involvement was also balanced with a discernable, growing concern that the imminent change would have a personal and potentially negative effect. This became clear when the plan to reorganize the Orion PP&C Office into the three elements of the systems approach was met with significant resistance.

Kranz recalled that some staff members were more open to the new approach than others; some individuals saw the new approach as a risk that deviated from all their prior knowledge and experience, while others were excited about the opportunity for improvement. One staff member noted that responses to the proposed changes fell into three main categories. First were those who "never really grasped on to the concept," followed by those who immediately accepted it "and went moving full-steam ahead." The third group in the middle took the more cautious stance of going "with the flow to see where it was going to lead."[168]

The reluctance to embrace a new PP&C paradigm—one that seemed to upend all of their previous training and experience—was partially the result of a natural human resistance to change. Time and discussion would help overcome some of the pushback, but some aggravating circumstances also impacted how the implementation of the reorganization was executed.

Resistance

For the more skeptical employees, their concerns were largely based on the idea that traditional PP&C as it was being performed in Orion was in fact meeting needs. Therefore, there was no reason to change it. Their perspective was, to put it basically, "If it ain't broke, don't fix it." For these members of staff, the proposal to fundamentally change Orion's approach to PP&C was perceived as a threat, not only to being able to do their job (as they understood it), but also to their personal careers and roles as data owners and presenters to the program manager.

Kranz noted how, within each of the twelve PP&C disciplines, "Our individuals in our teams were highly successful. They were doing the products they felt, in their traditional sense, were critical, important, and of significance to the program manager because they got to present it." Kranz added, "That's very satisfying. You can do your work, and it can be great"—but ultimately that work did not serve the program manager's needs.[169] Geyer also recognized the issue. He said, "There were hundreds of people invested because they thought it was the right thing to do."[170]

And, members of staff were concerned that their future opportunities for career advancement would be limited. The Orion assistant manager described the problem: "It's very, very difficult to find this kind of individual—a broad perspective, inclined to the synthesis of data in a broad picture inside an organization that … prides itself and rewards people for being experts in what they know."[171] Kranz recalled that at the time of Next Gen implementation, "there [was] no such thing as PP&C in the HR [Human Resource] systems. There were no position descriptions that matched the work performed by PP&C [personnel]."[172]

As a result, employees feared for their future employment potential. However, Kranz ensured that all members of the team were able to take additional training in other areas of expertise—training that would actually increase their value as future employees, particularly once it was combined with the ability to integrate data to provide a coherent, comprehensive picture of vital program information.

Furthermore, Kranz explained that from some employees' perspective, the feedback from the program manager was directed only to the PP&C Office manager (Kranz) and not the team as a whole. She said, "That's *your* feedback from the program manager to *you*."[173] Therefore, PP&C leadership made an effort in the retreats to communicate that in order for Kranz to be more effective in her role as PP&C Office manager, PP&C as a whole would need to adapt and evolve.

Some staff also expressed concern that the new approach would be incompatible with the agency's operations, specifically the difficulties of standardizing a system that needed to respond to what is a politically driven bureaucracy. For example, employees sometimes needed to respond to an unexpected request for information from Congress. And some employees thrived on the "rush" generated from constantly "putting out fires." To routinize their jobs seemed, by comparison, boring.[174]

Kranz later identified overcoming the hurdle of seeing traditional methods as successful as being the biggest challenge for PP&C, and the process did not occur overnight. Rather it was a gradual transformation as, one by one, individuals were converted to the new approach. Reported one lead:

> We had a series of several meetings. At first it was, "This is what we're thinking," then feedback and we got some buy-in. We went at that for a little bit. Then we came back with another retreat and the same sort of thing, feedback and more buy-in. Then finally, I think, we came back to the last retreat, and this was how we were going to do it.[175]

For some it was a matter of seeing the results in action.[176] However, some personnel were simply too entrenched in the traditional way of thinking, and eventually had to be "shed" and transferred to other offices "because they could not participate in this new PP&C approach."[177] Geyer said, "It's being able to adapt to an environment. You may not like it, but it is what it is, and you adapt. There's people that mentally can get around that and some that cannot. You can definitely see within the team who could handle it."[178]

As she later reflected on the experience, Kranz noted that she could have done more to implement planned change management—she wondered aloud if she had made the transition "too cold turkey." However, from her perspective, the need for an altered approach in order to effectively execute PP&C was obvious, and the plan needed to be implemented as soon as possible.[179]

Upheavals

Complicating the reorganization, around the same time that Kranz and Dyer completed their analysis of traditional PP&C, other broader events took place in the political arena that also shaped how the reorganization was executed. It was throughout these months of tumult that Orion PP&C held retreats and individual discussions with staff to help improve their understanding of PP&C's role.

First, in the FY 2010 PPB&E exercise that began in March 2009, agency guidelines for budget planning cut the Orion Project budget by 30 percent and Orion PP&C by an additional 20 percent. That meant a 50 percent total reduction: Orion Project PP&C would have half the previous year's operating budget. Starting in FY 2010 (beginning on October 1, 2009) speaking generally, either half the disciplines would be eliminated, or more likely, half of the PP&C Office staff would be cut and each discipline would have increased competition for getting budget and staff.

This was common knowledge throughout Orion Project, civil servants, and contractor personnel, especially in the PP&C Office that managed Orion's input to PPB&E. Therefore, part of the angst experienced in the retreats was driven by a realization that business-as-usual was at an end, and a reduction in the level of integrating-contractor staff was already in progress. The assistant program manager explained, "At the same time that we're transitioning, we're also operating on half the budget that we were before on an annual basis. Every part of the program feels that. PP&C very much feels that as an organization."[180]

Even more dramatic than these already significant budget cuts, in February 2010 the Constellation Program (the parent program of the Orion Project) was cancelled altogether. The Orion PP&C budget was even more tightly constrained when the program manager decided to push more of the available funds towards tangible hardware. This was a strategic move designed to demonstrate to stakeholders—those who would ultimately decide whether or not Orion would be continued—that the Orion Project was making tangible progress.[181] A staff member stated, "We cut all of these teams in half, and then down to less than that."[182]

On October 1, 2010 (the first day of FY 2011)—and when the fate of the Orion Project was still undecided—the Orion PP&C office formally reorganized into a three-element systems approach. Just ten days later, on October 11, 2010, the NASA Authorization Act of 2010 (PL 111-267) reinstated the Orion Crew Exploration Vehicle as the Orion Multi-Purpose Crew Vehicle. Now a Program under the Exploration Systems Development Division, the Orion Program continued development of the hardware necessary to transport a crew beyond low-Earth orbit, though with a new paradigm of PP&C operating with half the previous resources.

Outcome

Eventually, over months of retreats, many of the initial skeptics among the PP&C leads came to understand the rationale behind the new organization of PP&C as a system. Discipline leads began to bring information from the retreats back to their respective offices in order to put Next Gen PP&C into action.

The leads of the twelve disciplines reorganized their efforts to encourage "cross pollinating" of information between personnel from different areas.[183] In other words, the task was to encourage employees to communicate with each other. In order to make these new connections work, analysts were required to "translate" their data into a unified and easily-understood format.[184] One lead said, “Getting past those things—like sibling rivalry, to get the brothers and sisters to play together—was a big challenge.”[185]

Another staff member observed that sometimes resistance within the teams was less motivated by reason than by emotion: “Any time that people are talking about tools, we tend to get very emotional. ‘I don’t like that tool, I like this tool.’” She further noted that “it’s easy and comfortable” to focus on the routine input of data rather than analysis because “I know how to do that, I don’t have to think.”[186]

Over time and with continued persistence, PP&C Next Gen was able to establish a “mosaic” approach to judiciously select those “focus areas” that were “best for putting together an overall picture.”[187] The planning lead described how the different disciplines collaborated:

> Now, those interact with each other prior to coming to a presentation. You know that this is your budget. You align it with the guys on the schedule and say, “Well, you guys look like you’re way behind on schedule. We’re over our budget by three times, and we’ve still got all of these risks against that schedule and that budget still is lying out there.” You can integrate it, and then you get that big picture of where you actually stand versus just getting one, one, and one … We can come up with that whole story now with the teams organized the way they are.[188]

A shift to a new way of thinking about their roles continued to take place, particularly as results started to become more apparent. In March 2014, the data management and IT lead described the status of the reforms as a “battle zone” between the new way and the old.[189] Kranz said, “It does take a while to turn a ship.”[190]

In retrospect, the retreats did provide a means for working together to accommodate some very difficult realities of government programs. Kranz noted that the threat to Orion PP&C allowed an opportunity to examine past practices and address areas in need of attention. She explained, “Looking back on it, we had a perfect opportunity when we were cancelled to take a look at ourselves and our process and really put this PP&C under a microscope.”[191] Marshall added, “In my opinion, there is no change—no radical change—that any organization undergoes without this kind of pressure.”[192]

Second Generation PP&C

PP&C Second Generation was established as a system of interacting elements. It reorganized the disciplines of the traditional paradigm as was shown in Figure 3.1 into the three elements of the PP&C system as was shown in Figure 4.4. This reorganization is a shift from the *services-based* traditional model into a *product-based* systems model to provide the program manager with integrated products, along with source data and information, to inform decision making. The result of this reorganization by Element is shown as Figure 5.1 and by Product in Figure 5.2.

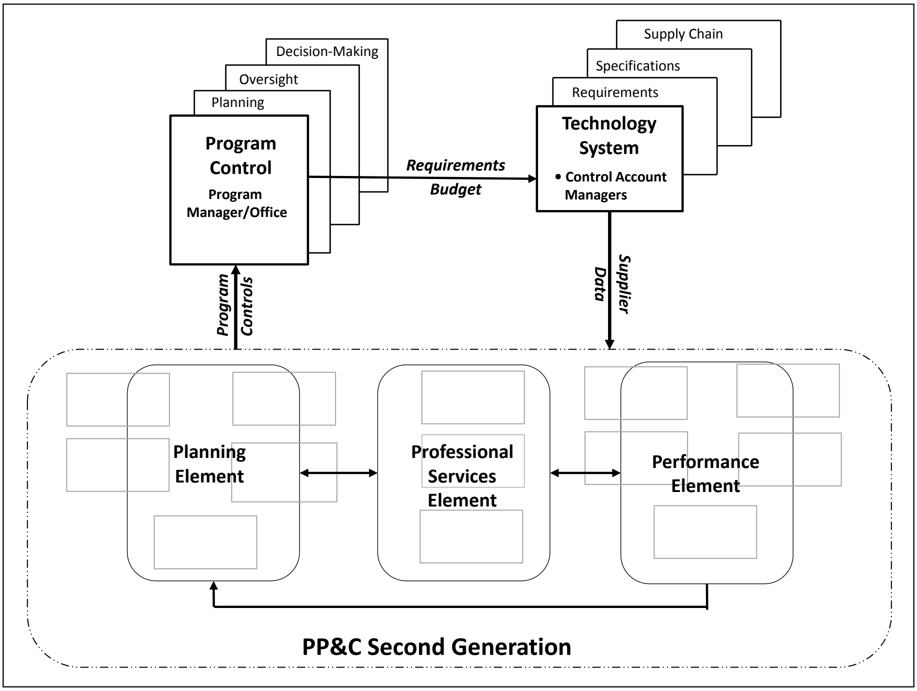

Figure 5.1 Model of the Second Generation PP&C, by Element.

Note, program control includes providing feedback for planning, performing oversight of the supply chain, and making decisions to manage and control program performance. The technology system is the new flight vehicle being acquired, and suppliers of technology system content are the primary sources of data for measuring performance. Lastly, in the bottom portion of each figure, PP&C Second Generation develops the program controls that are regularly reported to program control.

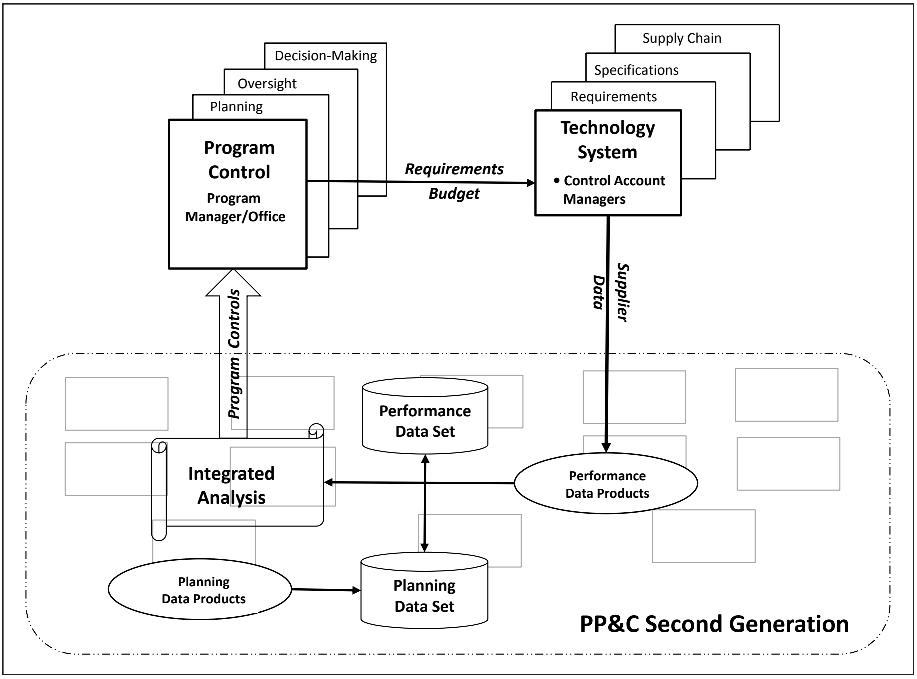

Figure 5.2 Model of the Second Generation PP&C, by Product.

Requirements

In 2012, Orion PP&C had the opportunity to formally codify the requirements for PP&C Second Generation. The Orion Project Integration Contract (OPIC) was about to reach its period of performance and the contract would be re-competed. The new MPCV Program Integrating Contractor (MPIC) procurement that took place in the summer of 2012 provided the opportunity to define and document work and data requirements for PP&C Second Generation as one part of the contract's Statement of Work.[193] Position descriptions for key persons leading each PP&C element were also written to codify responsibilities for collaboration and integration to develop multi-discipline products. Kranz noted the fortuitous timing of the contract expiry and subsequent re-compete. She said, "It was the perfect timing to fully implement the PP&C Next Gen approach."[194] With the reorganization of the Orion PP&C office complete and with a new contract in place for the integrating contractor, implementation could be completed.[195]

Together, these new work, data, and key personnel requirements reflect how the data reports of independent disciplines of traditional PP&C are now integrated into work performed by one or more system elements, and provide both data input and expertise to Planning Element and Performance Element data products (see Figure C.1). Requirements are summarized below. Detailed descriptions of all the requirements are provided as appendices to facilitate implementation by others.

Work Requirements

Work requirements are provided as Appendix C; and they are summarized in Table 5.1 and described below.

Planning Work Requirements	Professional Services Work Requirements	Performance Work Requirements
• Maintain program baseline and attributes • Prepare cost estimates • Prepare schedules • Perform strategic assessments • Execute the agency PPB&E process • Operate and maintain the planning data Set • Develop and report planning data products • Support preparation of supplier agreements	• Perform data and records management • Perform configuration management • Manage program information technology • Provide program security management • Provide risk management systems • Perform supply management • Provide administrative support to management forums	• Capture data and information reported by suppliers • Mine supplier data • Operate and maintain the performance data set • Develop and report functional data products • Perform risk management • Calculate program EVM • Perform and report program integrated analysis • Provide data packages for milestone reviews

Table 5.1 Summary of work requirements.

Planning Element

Work performed within the Planning Element develops the planned relationship between cost, schedule, technical variables, and obtains annual budget. Work captures and maintains the baseline and baseline attributes, including planned values for cost, schedule, and technical variables. Values for cost are estimate-at-completion and budget with reserves, values for schedule are a vehicle launch readiness date along with milestones and events for key development work and margin, and values for technical include technology system requirements (such as crew size, vehicle power, volume, and mission duration) with margins, technology development plans, assumptions, and risk. Strategic assessments of program alternatives are made. Cost and schedule estimates along with confidence levels are produced. The annual PPB&E submission is administered by the Planning Element. Note that discipline experts perform both Planning Element and Performance Element work as the disciplines are common, but the data products are not.

Professional Services Element

Work performed within the Professional Services Element provides the infrastructure for the program that links government and supply chain resources and systems into a logically singular system for data and information storage and exchange, including the important aspects of security management, technology protection, and export control. Supplier data reports and information enter the PP&C system via data management, which is responsible for storing data, for maintaining data integrity, and for data exchange throughout the entire program network.

Work performed also manages configuration control of data and information to ensure that any change has been approved by management and is communicated and available throughout the program's geographically diverse hierarchy of governance and supply chain. Although these professional services are performed at the Orion Program office located at NASA's Johnson Space Center, they extend to program participants throughout the United States and Europe. PP&C Second Generation innovations include performing configuration control using digital and electronic communication. For example, instead of formal, paper-based directives—each of which requires an official signature—PP&C Second Generation communicates changes through approved change requests electronically through e-mail.[196]

Performance Element

Work performed within the Performance Element analyzes supplier-reported data against planned performance data for a comparable time period. Analytical tools and methodologies generate variance and other data reports that are integrated into a characterization of current program performance, and into predictions of both near-term and long-term future performance.[197] Analysis includes assessing the continuing validity of assumptions and changes in risk posture, and reviewing trends in the program earned value indices. This element integrates current performance with forecasts of performance and independent assessments to provide the program manager with another innovation PP&C Second Generation: integrated analysis.

An integrated analysis is interpreting current program performance based on planning data, discipline data reports and strategic assessments, and then predicting future program performance based on forecast and independent assessments. It is performed collectively by PP&C civil servant and contractor staff. Initial results are reviewed with control account managers to verify accuracy and to obtain feedback, and then—after further PP&C coordination—are presented to the program manager at quarterly, monthly, and weekly review forums. The analysis includes both a summary of current program status, as well as the projected trajectory for future performance relative to program commitments made to the agency—and, by extension, the agency's stakeholders on Capitol Hill.

Data Requirements

The shift from a traditional services-based approach to a product-based systems approach in PP&C Second Generation is also reflected in revised data requirements. In order for PP&C to be effective, data products had to be defined and standardized, and the work processes to develop them had to be documented and subject to continual improvement in order to achieve targets for affordability as annual cost savings. Data requirements are provided with work requirements by element in Appendix C; and they are summarized alphabetically in Table 5.2 and described below.

Planning Element Planning Data Set	Professional Services Element User Reports & Metrics	Performance Element Performance Data Set
• Baseline Attributes • Budget Submit • Change Request • Cost Estimates • Program Baseline • Schedule Products • Strategic Assessments	• Cost-Benefit Reports • IT Management Reports • Process Improvement Metrics • Security Management Reports • Supplier Management Administration Reports • User Status Reports	• Forecasts • Functional Data Products • Independent Assessments • Integrated (Program) analysis • Mined Data Reports • Supplier Data Reports

Table 5.2 Summary of data requirements.

Planning Element

The Planning Data Set is the single, authoritative source of official planning information in the program. It is accessible by authorized program participants, including the prime contractor and its supply chain, NASA participating organizations and their supply chain, and international partners, and their supply chain. The data set supports data exchange throughout the Orion Program and its operating environment; and it also facilitates data reporting throughout the program and into NASA Headquarters.

Professional Services Element

Data products for the Professional Services element comprise measurements and metrics of system availability and utilization, quantity and quality of user services, and discipline-specific reports required by an authority such as system security, technology protection, and export control. Products include status of contracts and agreements with suppliers and contract administration including the tracking of undefinitized contract actions from inception to closure.

Performance Element

The Performance Data Set contains information reported by program suppliers and captured by the data management function; information extracted from other supplier documents and review forums via data mining, functional data products, forecasts, independent assessments, and the results of integrated analysis.

Key Personnel

In PP&C Second Generation, each of the three PP&C elements is now led by one person responsible for that element's work and data requirements, and accountable for its performance. The responsibilities of the leads include leadership and work duties, and active collaboration with peers in the other elements within the program and within the enterprise and its other programs.

Marshall described the role this way: "To be effective in this Next Gen PP&C, in my view, one has to have skills in integrating and synthesizing information in ways that a program manager does. Not because they are program managers, but because they're providing that information to the program managers for decision making." He emphasized that the most important ability for a

PP&C staff member was "the ability to synthesize data for the purposes of [facilitating] program management decisions, followed very closely by the ability to communicate that."[198] Kirasich said, "Some of the people who are most successful in PP&C are the ones that understand [that] it's about how these pieces fit together."[199]

In response to staff's initial hesitancy to embrace these new roles, Kranz wrote duties into position descriptions and performance expectations into annual employee performance plans in order to make the new roles and structure "crystal clear."[200] Position descriptions for civil servants in the Orion Program serving as PP&C leads were provided to human resources. This helped alleviate the concern of PP&C staff that the new roles would inhibit their future career growth. Kranz explained how from her perspective, employees "would individually benefit with those new skills and that new emphasis on integration."[201] Position descriptions for the PP&C Office manager and for each of the three lead positions are provided as Appendix D.

With the first component of definition of PP&C (program controls) in progress, Orion then turned to the next component of definition, PPM (program control).

CHAPTER 6

Program Performance Management

The work performed to research, analyze, and determine cause, and to identify and take action to eliminate cause led to the definition of Program Planning & Control and Program Performance Management as systems, each performing a subset of a program manager's roles and responsibilities. Chapter 5 explored how PP&C Second Generation is defined and implemented as an organization along with requirements for work, data, and key personnel. This chapter discusses how PPM operates in conjunction with PP&C to enable a better-informed decision-making process.

Implementation

Program Performance Management is the union of program controls with program control to assess status relative to plan, to review predictions of future performance, and to make decisions necessary to achieve commitments. This intersection of controls and control is highlighted as the dashed box in Figure 6.1.

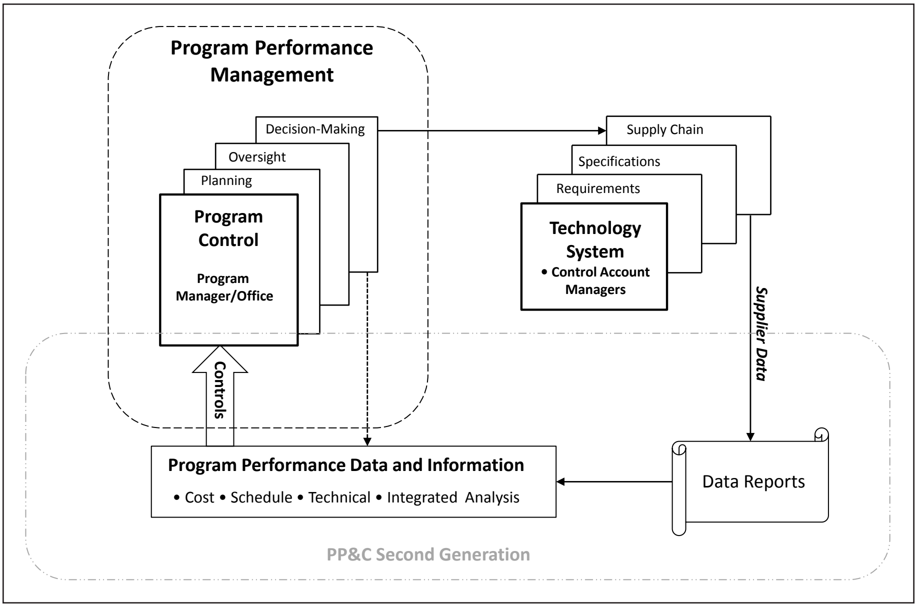

Figure 6.1 Program Performance Management is the intersection of program controls and program control.

The PPM system is shown as a schematic diagram in Figure 6.2 below to identify that both feed-forward and feed-back regulate system performance. Feed-forward prescriptive controls comprise the information imposed onto the system at inception, including the policy, rules and regulations, procedures, and standards of an organization, as well as the training and experience of its professional staff. Feed-back includes direction, recommendations, requests for additional information, and comments on the content and format of the program controls provided by PP&C to management.

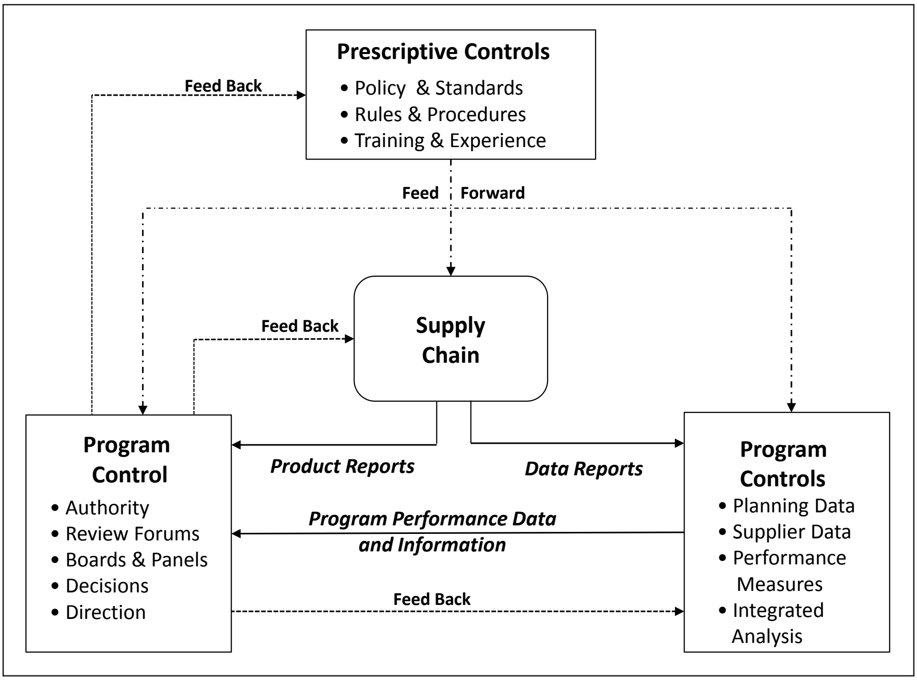

Figure 6.2 The Program Performance Management system.

As depicted in the diagram, the three main elements of the PPM system are Prescriptive Controls, Program Control, and Program Controls. Combined, they operate around the supply chain developing the technology system and reporting performance data. Prescriptive controls document the expected behaviors for all participants and reinforce them through corporate policy and procedure, as well as personnel qualifications and training.[202]

Prescriptive Controls are common at an industry level (i.e., aerospace for major acquisition programs). Program Controls were the subject of Chapter 5. Program Control is decision-making informed by Program Controls.

Program Control is exercised by: 1) determining current position based on reported performance data, 2) forecasting future position accounting for implementation strategy and tactics, 3) comparing positions with plans and commitments, and 4) issuing direction to maintain (or return to) the plan and to fulfill commitments. Program Control occurs daily, weekly, and monthly. Daily tag-ups highlight work activities and identify topics for real-time follow-up. Weekly review meetings with suppliers monitor program schedule management and focus on schedule threats. More extensive monthly meetings with PP&C and supply chain organizations are held to review supplier performance and overall program performance, including the identification of performance drivers and performance issues for consideration with individual suppliers.

Program Control is also exercised in regularly scheduled control boards by: 1) documenting change requested, 2) evaluating impacts of proposed change to planned and forecast cost and schedule performance, 3) determining the effect of change on achieving outcome commitments, and 4) making decisions that could either preserve the existing plan or initiate re-planning to better achieve commitments. Program-level boards and panels control change by serving as a system of checks and balances. Agency boards provide an independent assessment of program performance. Orion Program operates a hierarchy of internal boards and panels, each sanctioned by a charter specifying authority, composition, and rules of engagement. Higher-level boards establish the program baseline and disposition changes that affect the baseline, while lower-level boards and panels manage the design, development, test, verification, and integration of product content. Boards create working groups and product teams to evaluate change proposals within their delegated scope authority.

Overall, this structure allows for involvement in decision-making at the lowest level and provides a mechanism for accommodating dissent. However, the program manager is the ultimate authority and, when necessary, makes the final decision on elevated issues.

Trade Space

Multiple models have been developed to visually depict various approaches to managing program performance. In his *Program Planning, and Control,* David G. Carmichael advocates a linear model that uses re-planning of cost, schedule, or technical values to adjust for variance between any two state variables (as depicted in Figure 6.3).[203] In the example shown, the report of actual performance for variable 1 is below the planned value, while the actual value for variable 2 is significantly beyond the planned value. In this condition, if variable 1 is technical accomplishment and variable 2 is cost, then more money than planned was spent to achieve less than planned performance: re-planning is required.

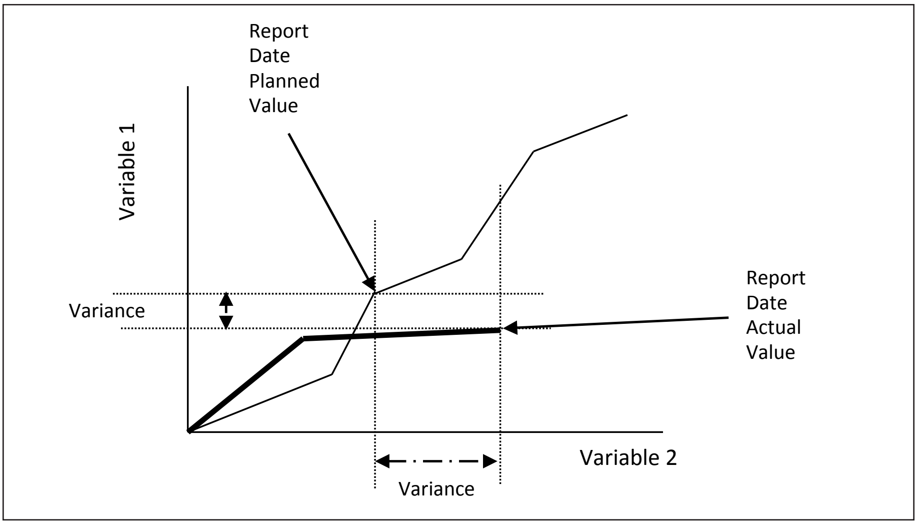

Figure 6.3 Linear Model of Performance Management.
Adapted from: Carmichael (2006), *Project Planning, and Control*, Figures 1.6 and 6.18, pages 18, 213, with permission from Taylor & Francis.

Alternatively, James P. Lewis in his *Project Planning, Scheduling and Control* utilizes a two-dimensional model that assumes a trade-off between technical performance and scope in order to accommodate cost or time variance.[204] In this model, values can only be assigned to three of the four constraints; the fourth is determined by the relationship (i.e., plan) of the other three. In a performance-driven version of this model shown as Figure 6.4, performance is constant and cost, time, or both are adjusted to accommodate a change in scope.

This model illustrates why cutting budgets while maintaining performance and scope extends the time required to accomplish the work—the tendency to "kick the can down the road" that employees noted during the process of causal analysis.

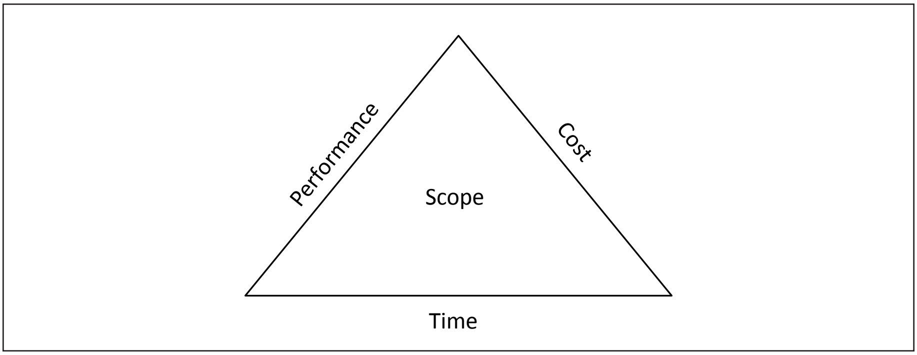

Figure 6.4 Area Model of Performance Management.
Adapted from: Lewis (2005), *Project Planning, Scheduling & Control*, Figure 1.2, psge 16, with permission from McGraw -Hill Education.

Both of the models described above do not provide a complete picture of program performance. Because three independent variables—cost, schedule, and technical—define a program, PPM requires a three-dimensional or a volume model (as opposed to linear or area models) to more completely portray content, status and prediction.

The notion of a three-dimensional "Trade Space" provides a more comprehensive visualization of the extent of data and information required to support decision-making. The scope of program controls informing Orion PPM includes not only current and forecast values of cost, schedule, technical variables, but also program performance, strategy and operating tactics, as well as factors to account for technical, manufacturing, and production complexity.[205]

The relationship between each of the three independent variables—cost, schedule, and technical—is defined by the program plan, and varies over time. These variables can be portrayed as axes on a Cartesian coordinate system (three-dimensional line graph). Because there is no mathematical relationship between the three variables, the axes do not intersect at (0,0,0). Values along the three axes do, however, intersect at an end-point. Figure 6.5 shows the relationship.

During a Formulation phase, the starting point is the intersection of values for each of the three variables at the end of the preceding fiscal year. A line connecting the starting point to the planned end point—the intersection of year-end values for budgeted cost, the schedule of milestones for planned work to be completed, and the technical content to be developed for the money and time consumed during the year—represents the annual Execution Plan.

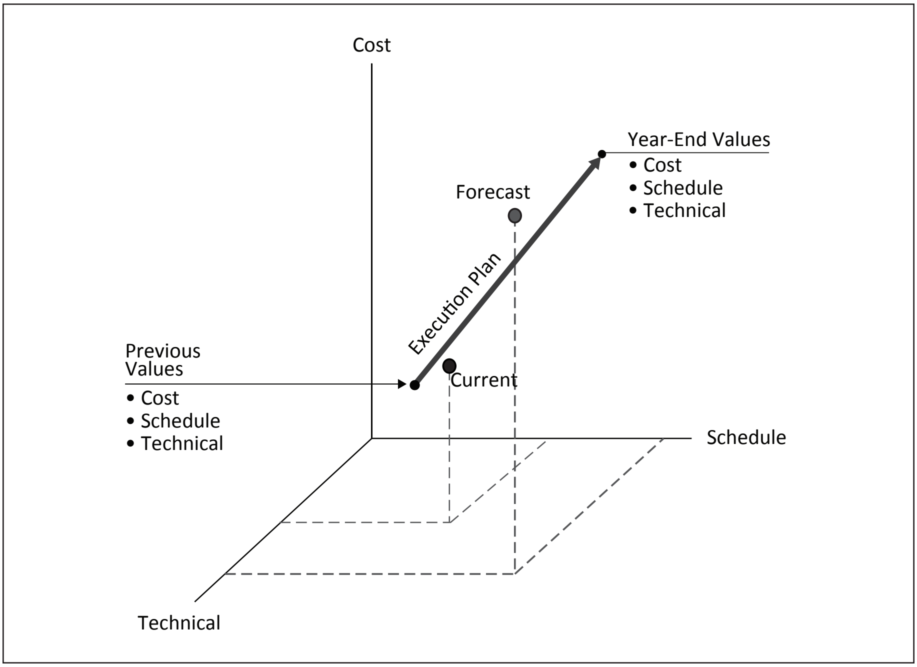

Figure 6.5 Trade Space for Program Performance Management during Formulation.

During the Implementation phase depicted as Figure 6.6, the start point is defined by the values for each of the three variables reported at the program review and decision that granted the necessary approval to enter into the Implementation phase (i.e., the Agency Baseline Commitment). The end point is the intersection of values for Life Cycle Cost (LCC), Launch Readiness Date (LRD), and Initial Operating Capability (IOC). A line connecting the start and end points represents the Program Plan. Each annual Execution Plan becomes one segment of the Program Plan.

While an individual segment can be linear, the line connecting all of the segments, and therefore representing the Program Plan, is not. Funding and accomplishment change from year to year because of the differences between resources needed vs. resources provided on an annual basis. Strategy and tactics employed to deal with the realities of an annual budget, the complexity of both technology and manufacturing, and the organizational complexity of the program office, its governance and its supply chain are also factors. When plotted together, these effects result in a jagged line from the start of implementation through the end of production of the flight vehicle: development is nonlinear.

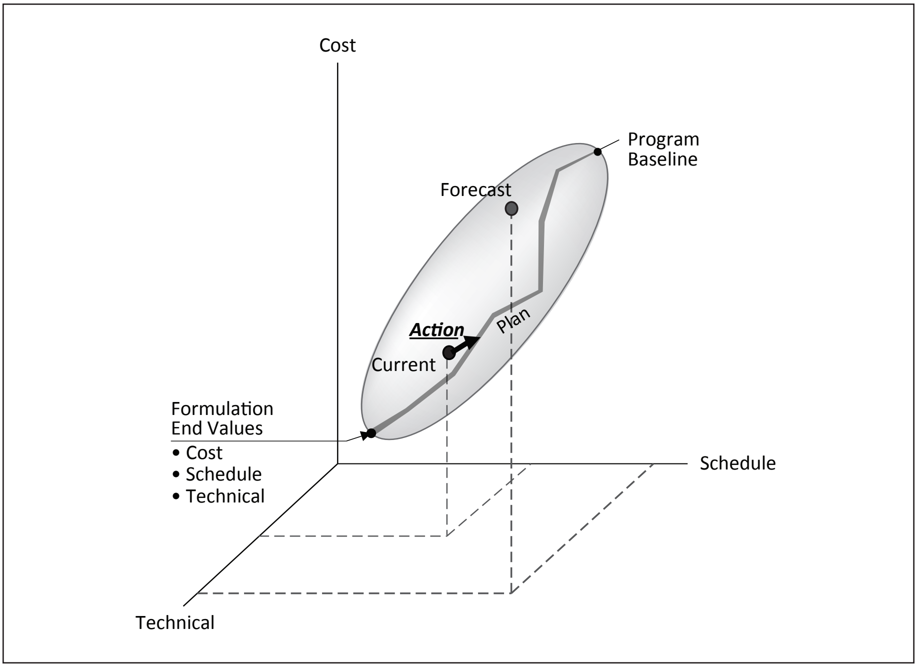

Figure 6.6 Trade Space for Program Performance Management during Implementation.

At any time, a point along the jagged line represents planned program performance based on planned values for cost, schedule, and technical variables. Both current and forecast program performance are needed in order to understand the status of the program relative to commitments made.

Both are also needed to identify and formulate action necessary to mitigate risk or to correct an identified problem in order to return to planned performance at some future point in time.

Sound Business Case

Major acquisition development programs are complex and difficult, and many previous attempts to build new technology systems have failed in part because they were focused on advancing technologies and designs without the amounts of time and money required to adequately support those efforts. GAO work on best practices shows that success in major acquisition programs requires an executable business case before committing resources to a new product development effort.[206] A sound business case requires a balance between the concept selected for a technology system (that must satisfy customer needs), and the resources of technology, design knowledge, funding, time, and manufacturing capacity that are required to transform the concept into a functional flight vehicle.

In order for a business-case approach to work, a program manager must demonstrate increasingly higher levels of knowledge about the production of the flight vehicle (technology system) as the program proceeds from the early stages of technology development through actual technology system content development and, finally, into vehicle production. In such an approach, key component technologies are demonstrated before system content development begins, design is stabilized before production begins, and testing is used to validate product maturity at each level of development. At any decision point to transition between phases of development following a milestone review, the balance among time, money, and capacity has to be confirmed: knowledge builds and supplants risk over time.[207]

A 2010 report by the National Research Council recommended that NASA, Congress, and the Office of Management and Budget should consistently use the same method to quantify and report costs: they should use as the baseline a life cycle cost estimate produced at Preliminary Design Review (PDR).[208] Within a life cycle, PDR defines the transition of a program from Formulation phase to Implementation phase. It is at this critical juncture that a sound business is needed to inform agency and program decision making. The business case, is captured as the program baseline in the Decision Memorandum signed by agency management and technical authorities, host center management, and the program manager following PDR. In 2009, GAO similarly recommended the development of a sound business case for NASA major acquisition programs at PDR. In written comments on GAO's recommendation, NASA concurred.[209]

Table 6.1 illustrates how program controls—Planning, Professional Services, and Performance Element data products—provide the information needed to build a sound business case.

Note that items in bold italics correspond to content contributing to a Sound Business Case.

Sound Business Case	Planning Data Products	Professional Services	Performance Data Products
• Firm Requirements • Mature Technologies • Acquisition Strategy • Realistic Cost Estimates • Sufficient Money and Time	• ***Program Baseline*** • Baseline Attributes • ***Cost Estimating*** • Strategic Assessments • Assumptions • ***Reserves and Margins***	• Data Management • Records Management • Configuration Management • ***Supply Management*** – Contract Changes – Undefinitized Contract Actions	• Variance • ***Technology Readiness*** • ***Design Stability*** • ***Risk Management*** • Earned Value Mgt. • EVM and Quality Audits • Integrated Analysis

Table 6.1 Program Controls Map to Sound Business Case.[210]

The PP&C Planning and Performance Elements' data products help NASA comply with the requirement for a sound business case by capturing *data* from multiple sources, integrating them and performing analysis to produce program *information*, which becomes program *knowledge* over time. This knowledge creation throughout the Formulation and Implementation phases of a life cycle is illustrated in Figure 6.7.

Program knowledge is developed through a recurring business management cycle, or business rhythm. New planning data are provided annually as content for the PPB&E process. Program controls are refreshed at regular intervals corresponding to management review cycles. The business rhythm established by contract and agreements calls for supplier data reports to be submitted monthly. Monthly performance reports are the basis for updating measurements and forecasts of program performance. Quarterly performance reports provide additional data that the Performance Element of PP&C uses to perform integrated analysis. Month-over-month, and year-over-year, these data, information, and analyses, together with actions taken by program management, build a time stream of consistent program knowledge to inform program and agency decision-making.

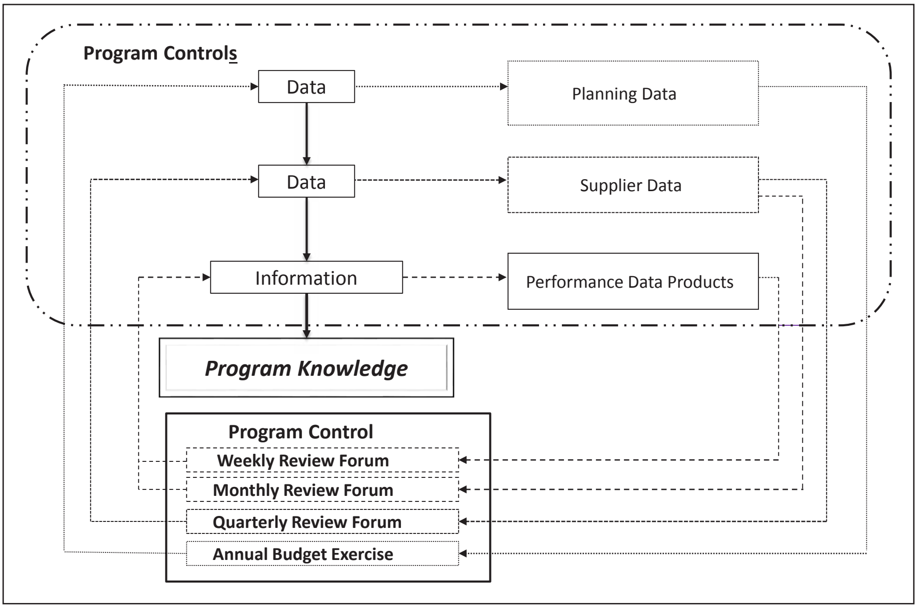

Figure 6.7 Program Performance Management generates program knowledge.

Already, this new approach has demonstrated measurable results, as discussed in the next chapter.

CHAPTER 7

Effectiveness

A quality management approach to corrective action requires that the effectiveness of corrective action taken to eliminate root cause be demonstrated. Corrective action taken in the Orion Program was to establish definition, ownership and benchmark. Definition included re-organization of the Orion PP&C Office for the development of program controls and establishment of the MPCV Orion Program Performance Review (MOPPR) as a component of PPM for program control. Ownership of both PP&C and PPM is the Orion program manager. Benchmark standards set for Orion PP&C are internal consistency, feedback and best practices.

Objective evidence of the effectiveness of action taken is budget and costs performance for PP&C and program operations, manager feedback, and the findings of quality audits conducted on both PP&C and Orion Program operations.

Budget and Cost Performance

Budget data for PP&C by Fiscal Year (FY) are shown as Table 7.1.[211] Budget numbers are presented as ratios relative to the FY 2009 budget when the study of PP&C was undertaken. The FY 2010 budget was based on the traditional PP&C model and higher costs are due to the growth of included disciplines. FY2011 was the transition from a traditional services-based approach to the integrated product-based systems approach of PP&C Second Generation. Annual/FY2009 budget values for FY 2012, FY 2013 and FY 2014 show consistent performance at the reduced level of approximately 50 percent. A further reduction in annual operating cost is targeted as a result of continuous improvement of work processes used to produce planning and performance data products, including integrated analysis and predictions.[212] Funds saved, however, are expected to be reinvested into continuing research, as described in Part II.

Annual/FY2009	**FY 2009**	**FY 2010**	**FY 2011**	**FY 2012**	**FY 2013**	**FY 2014**
PP&C Budget	1.00	1.18	0.46	0.51	0.50	0.49

Actual/Plan	**FY 2009**	**FY 2010**	**FY 2011**	**FY 2012**	**FY 2013**	**FY 2014**
PP&C Cost (%)	0.86	0.94	0.84	0.81	0.90	0.96
Orion Cost (%)	0.97	0.92	0.97	0.98	1.02	0.98

Table 7.1 PP&C annual budget and cost performance prior to and after Second Generation.

The ratio of actual PP&C cost performance compared to planned cost performance (Actual/Plan) is also presented in Table 7.1.[213] Lower than planned PP&C cost in both FY 2011 and FY 2012 are associated with transition to PP&C Second Generation. Underspending was due to a realignment of civil servant staff and the phasing in of the new MPIC contractor. Actual/Plan values for FY 2013 and FY 2014 show that performance appears to be stabilizing to within budgeted amounts. Actual/Plan cost data for the Orion Program are also presented in the Table. The data show consistent performance throughout the period of major change in PP&C operations.

In the first year of PP&C Second Generation implementation, PP&C staff was reduced by 30 percent, and the number of products and services delivered to the program manager was reduced by more than 50 percent.[214] Although some PP&C staff reported concerns that the reduction in staff meant some important information was not being recorded or that more personnel would be needed to complete the planning work required for future missions, others saw the streamlined offices as a positive feature of the new approach.[215]

“We are data hoarders at NASA,” said the Data Management and IT lead, comparing the traditional method of storing all possible data in incoherent sets to a person searching for an umbrella in an overcrowded front closet. In other words, “the problem is when you’re data-rich, you can’t find anything. You don’t know what is important.” Therefore, PP&C [Second Generation] actually serves its function more effectively by pursuing only “vital data,” using the agency’s five-plus decades of spaceflight experience to find the data needed to answer the most commonly-asked questions.[216]

Another colleague agreed and said, “You found a lot of things that you could really live without and not see much of an impact, things that had always been done that could be done differently. That's probably one of the biggest successes."[217]

Manager Feedback

Feedback from program management similarly validates the benefits of the new approach, confirming that a product-based paradigm is indeed more helpful for decision making. For example, in March 2014, it was announced that the Orion Exploration Flight Test-1 (EFT-1) would be delayed from autumn of that year to December because of a higher-priority Air Force launch. Kranz reflected that, prior to the systems approach reorganization, PP&C would have reacted with almost a knee-jerk response: "I worry—I think we would have said, 'Well, this is a surprise. I didn't see this as an outcome,' and we would generate a bunch of new products that are around a single point in time."[218]

But, as a result of the new perspective of Orion PP&C—one focused on meeting the long-term baseline for the Exploration Mission (EM)-1 and EM-2 flights—the program was able to take the change in stride, and readjust schedules accordingly. Kranz said, "We know how the schedules and the budgets will align, and we hope it'll be a small impact while we wait. But I wasn't nervous about that at all."[219]

Marshall made a similar statement when he noted that instead of adjusting the baseline to meet the new launch date, PP&C Second Generation remained focused on "shaping a trajectory" for future targets. He continued, "We don't change a thing. We're trying not to change anything based on a new launch date." In other words, "it just gives us a more sophisticated way to measure our progress, in terms that are easy to grasp, access, and remember, as we assess where our ultimate targets are going to be downstream."[220]

Overall Kranz reported that since the implementation of PP&C Second Generation:

> We get better feedback. The [control account managers] CAMs are very clear which of our products are timely and how they're working for them. The program manager, I think, is much clearer about what he needs. He understands very well this planning part of our job, the performance measurement part of our job, and how all of those inputs come together to get those done.

"Actually, now it has become his expectation … that we provide him with the performance measures so that he can act upon them and make good decisions,"[221] Kranz continued. Geyer said, "That's why Lucy's work has been so important, to say, 'The tools are interesting, but how really are we going to tie all these pieces together to get a better sense for where we really are and how we make good decisions going forward?' The tools by themselves are useless and sometimes get in the way."

Marshall said, "It's already striking a different vision for how to look at the set of tools. Not so much as ends in themselves, but as part of describing a situation in a current state and a projected state to a program manager, to be useful as a decision support system." He added, "That integrated assessment, essentially refining the data into more directly usable management-level information, can give situational awareness and forecasting assessment of what we know today."[222]

Kirasich said, "We put an emphasis on function and the product we were trying to deliver, and how do these disciplines support the goal … The goal was to build a spacecraft, and we use these things to help us … the products we get today are much more meaningful, much more useful and helpful in helping me understand and steer the program … We're getting a much more functional, informed product for a lower cost." Geyer said, "I have a lot more confidence in the process that the team has now."[223]

Audits

JSC is the host center for the Orion Program. Work performed by the Orion Program Office is within the scope of JSC's certifications for quality management. Following reinstatement in October 2010, the Orion Program was audited for conformity with the requirements of international standards ISO 9001 2008 and AS9100C.[224] In August 2011, the Orion Program was audited for Section 7.1, Planning of Product Realization and Section 7.2, Customer Related Processes. In February 2012, Orion PP&C was audited for Section 5.6, Management Review. In February 2012 it was audited for Section 7.1.2, Risk Management. In April and September 2014, Orion control account managers responsible for the flight products parachute assembly system, crew module, service module, avionics, power and software, along with the S&MA technical authority were audited for Section 7.5, Production and Service provision. Audit reports showed no observations or findings of nonconformity in the Orion Program, and the Process Effectiveness Assessment Report from the 2014 audits certified the Orion Program Life-Cycle Process to a level 3 effectiveness (with 4 being the highest possible): the program was meeting its defined performance objectives and appropriate actions are being taken to better achieve planned results.[225]

Audit results demonstrate the effectiveness of the corrective action taken to eliminate the cause of cost overruns and schedule delays. Preliminary results indicate that PP&C Second Generation has the potential to impact not just work within the Orion Program, but also within NASA as a whole, and even other federal agencies. Geyer noted the importance of the work: “If you don’t do this well and can’t communicate how we’re doing it, it’s probably the biggest risk to these programs, not the technical … That’s why it’s such a big deal.” He further described how Orion was able to brief NASA Headquarters on the PP&C paradigm shift: “I think it’s helping the agency, so I think it’s absolutely headed in the right direction.”[226]

Part I Remarks

Concepts

The Introduction began with the critical observation that "Words are important." The words "program" and "project" are good examples. Each word describes a temporary, focused effort to produce a unique product or result. While *project* is more commonly seen in general usage, within U.S. government agencies *program* refers to a larger effort that encompasses multiple smaller projects; programs are more expensive and time consuming than projects. As set by Congress, a major government acquisition program meets the minimum criterion of a life cycle cost of $250 million; however, many of those programs have budgets that are measured in billions or even tens of billions of dollars.

Because program work is performed in a public forum—marked by interest in the excitement of space exploration, the discovery of new knowledge and, perhaps, new worlds—it is also subject to higher levels of public scrutiny. The nation's space program must respond to the ever-changing political environment of competing interests, positions, and priorities. The complex and oftentimes polemical environment of major NASA acquisition programs means that "unique interpretations" of the aptitude of program managers and the value of their work to and for the public are not uncommon.

Language and terminology must therefore be precise; cost overruns and schedule delays are not possible during the Formulation phase of a program. Only in the Implementation phase can values for cost and schedule be subject to overruns and delays in relation to the established Agency Baseline Commitment or Congressional Baseline Report. However, as a vision or concept is developed into a practicable design during Formulation, real resource requirements begin to manifest. Real resource requirements will exceed early values, often significantly; however, they are neither *uncontrolled nor are they overruns*. Rather they represent the work of highly skilled professionals using best practices and state-of-the-art methodologies and tools to perform work requested by the U. S. Congress.

As noted in the Introduction and reviewed in Chapter 2, the *appearance* of cost or schedule growth during Formulation phase is possible, especially when program management fails to maintain alignment of the cost and schedule consequences of changing technical requirements, and to keep a hierarchy of governance and the public informed of the resources now needed to develop a new space system. The importance of alignment and awareness cannot be overemphasized.

Improvement

For more than five decades, NASA managers have faced the challenging task of executing projects and programs within a volatile political environment—and have made great strides in implementing program management tools such as earned value management, confidence levels, and performance dashboards that improve budget and cost outcomes. Chapter 2 reviewed some of the most commonly-applied standards for how program management work should be accomplished, including the widely adopted guides of the Project Management Institute (PMI) and Software Engineering Institute (SEI).

In addition to these institutions, NASA also defines the roles, responsibilities, and requirements for its program managers in agency-controlled documents, such as the NASA Space Flight Program and Project Management Requirements document and its accompanying handbooks for Program Management, Systems Engineering, Schedule Management, Earned Value Management, Risk Management and others. Numerous training programs, qualifications, and certifications further aim to enforce agency and industry standards.[227]

Building on the importance of words, Part I is based on the observation that:

> *Scope is important*.

Both project and program managers are responsible for managing the conversion of resources (i.e., time and money) into the desired product. Managing the conversion of resources within a program or a project requires the same work, but the scope of that work varies. While scope does not affect the work that needs to be accomplished, scope does affect how that work is performed. Major acquisition programs require teams of dedicated professionals in specialized disciplines, all working together to accomplish tasks that are performed by individuals in smaller-scale projects. The need for greater coordination between individuals and teams introduces a complexity into large-scale programs that ultimately cannot be accommodated by simply improving discipline tools or increasing the size of a discipline, or by adding more disciplines; a new paradigm is required.

Problems of scale in major acquisition programs became apparent when, around the year 2000, public awareness of cost and schedule requirements to accommodate technical requirements growth for the ISS culminated in a crisis that threatened to terminate the program. From this crisis arose, for the first time, the concept of PP&C. The ISS Business Office responsible for managing the program's budget and other services evolved as an independent body of PP&C work. Management became increasingly aware of how information from other disciplines such as cost estimating, schedule management, strategic assessment, and risk management also affected calculations of program performance, especially prediction.

This manuscript aims to fulfill an unmet need in program management articulated in lessons learned from the Constellation Program:

> While the agency is renowned for its technical prowess, senior managers in programs can be faced with a multitude of nontechnical challenges for which they have far less training or preparation.[228]

The nontechnical challenge is not with the work or tasks of program management but rather with how those tasks are performed in major acquisition programs. Standards and training built around PMI, CMMI, and agency policy and requirements to educate, train, and certify program and project managers are applicable regardless of program size. However, size matters; and an objective of this monograph is to provide knowledge and training materials in how management tasks can be performed in large-scale programs to augment available training and personnel certification curricula.

Challenges

In 2010, the Orion Project implemented a new paradigm for performing PP&C. By replacing traditional, discipline-specific data reports with integrated, program-level data products, PP&C Second Generation succeeded in providing better program controls that enabled a more effective decision-making process at lower operating costs. However, challenges remain.

Acceptance of PP&C integrated data products is a challenge. Governance includes independent reviews of technology system and program performance prerequisite to granting authorization to transition between life-cycle phases. Life cycle phases are separated by Key Decision Points where technology readiness is scrutinized and program estimates of resource requirements are dissected and analyzed for viability. Following a successful review, a decision memorandum records approval and documents the cost, schedule and technical baseline for work to be performed in the next life cycle phase. From past experience, agency independent reviewers as well as management and technical authorities are familiar with program office versions of supplier data products; reproduction by a program office provides direct evidence of government oversight and due diligence as, for example, a program-level IMS or an EVM report cannot be produced without review and incorporation of supplier-reported IMS and EVM.

A supply chain provides about 90% of a major acquisition program content, split 85/15 between industry and government.[229] Supplier data products reflect this distribution. Accordingly, PP&C Second Generation approach avoids recreating supplier-reported data products because the value added is minimal. Rather, PP&C develops value added integrated products. First, supplier-reported and Planning Element data products are used to develop cost, workforce, and schedule variance reports. Then assumptions about development, manufacturing, fabrication and production are assessed for realism, sensitivity to change and impact on cost and schedule performance using cost estimating methodologies, schedule analysis algorithms and independent assessments. DDT&E task times are assessed by comparing the planned schedule duration with historic norms for performing that work in relevant programs. Flight element, system and subsystem DDT&E work is triaged by criticality to determine priority for, and level of detail of, independent assessment. Risk management is tracked and assessed.[230] Supply chain nonconforming product and the results of quality audits are monitored. An integrated analysis is then performed using all of the above to determine program status and predicted performance relative to commitments. Analysis results along with supporting data and information are posted to a PP&C Data Dashboard and are subsequently communicated to program management as a narrative of threats to future performance and drivers for discussion, feedback and follow-up with the supply chain.[231]

Career is a challenge. Discipline experts have little incentive to pursue PP&C work when it may not be a viable career path. PP&C's emphasis on integrated products places discipline experts in a support role rather than a primary position of responsibility; and they spend less direct time with program management. Like program management, career progression for integrated PP&C work requires extensive study, apprenticeship, and experience. This monograph advocates that PP&C should be recognized as a profession at least equivalent to a discipline, with defined career paths for PP&C professionals. The extent of responsibility and accountability for persons performing PP&C work is a measure of the professionalism required for successful performance.

Communication is a challenge. The disciplines performing traditional PP&C are familiar with each other's language, including jargon. PP&C Second Generation now adds systems engineering expertise to the mix of disciplines needed to produce integrated products to characterize current and future program performance. Time will be needed to expand the common context for communication and collaboration to include this new discipline. Management feedback on the value of products provided by the collective is crucial to achieving the integration of disciplines needed for effective PP&C Second Generation operations.

Funding is a continuing challenge. The cost of PP&C relative to an overall program is less than five percent.[232] As a non-technical endeavor, funding PP&C is a different type of challenge for program managers, one they may be less enthusiastic to take on. One headquarters official said, "PP&C is obviously neglected." She added, "We're all engineers it seems like, so everybody likes the technical."[233] In other words, program managers must be convinced of the need to dedicate resources to non-technical effort. By demonstrating an ability to operate effectively at lower that traditional costs, PP&C Second Generation is vulnerable to further reductions.

Next Steps

The journey from a service-based paradigm to a product-based paradigm is predicated on a systems approach for performing PP&C work. We now know that both PP&C and PPM are systems that operate together to manage program performance within cost, schedule, and technical constraints.

The PPM system is a complex system. Complexity exists when multiple, large, complicated organizations (from governments, industry, and academia) each with its own disciplines with tools (budget, schedule, cost estimating, procurement, configuration management, risk management, etc.) are brought together to achieve a major acquisition, such as a new vehicle for space exploration. Interdependencies, interrelationships and interactions, i.e., relationships become very important to outcomes realized.

Uncertainty accompanies complexity; because of uncertainty, calculated values of program performance, especially predictions of future program performance, are subject to more than one interpretation. The components of uncertainty—organizational influences, institutional conditions, and human behaviors—combine to affect the outcome of decisions made that were informed by program controls. Decisions made based on similar values for program performance may have drastically different outcomes because of dynamic external factors. The effect of external factors and how to deal with them is the subject of Part II.

PART II
Discovery Continues

Part I established a three-part root cause of recurring cost and schedule problems in major acquisition programs: no Definition, no Ownership, and no Benchmark. It was shown that cost overruns and schedule delays are abetted by the traditional services-based approach to PP&C of independent disciplines with silos of performance. The ability of traditional PP&C to predict cost overrun and schedule delay is a function of program size; the traditional approach has limits and better performance in major acquisition programs requires a new approach for performing PP&C.

Corrective action established a product-based systems approach. The Definition of PP&C was expanded to include both PP&C and PPM; each a system of interdependent, interrelated and interacting elements. Implementation of Ownership at the agency level is forward work. Benchmark using internal consistency as the standard is being implemented in the Orion Program. Implementation of PP&C in the Orion Program is showing significant improvement as measured by the value of its products to management and its lower operating costs.

Part I addressed the internal forces driving root cause: the limitations of traditional PP&C. Part II addresses the external forces driving root cause: complexity and uncertainty. The focus of Part II is the PPM system and its behavior as a factor in predicting program performance. Because the notion of PP&C and PPM as systems is new, Part II contributes new ideas and knowledge for further development within the field of performance management.

Chapter 8: Uncertainty, shows that the PPM system meets established criteria for complexity and introduces uncertainty as its corollary. Confirmation of uncertainty in the Orion Program is documented as recently completed research that analyzed cost, schedule, and technical data produced by Orion Project using nonlinear dynamical systems methods. A model for conceptualizing the effects of uncertainty on program performance is derived.

Next, Chapter 9: Human Factors, documents the application of a Failure Modes and Effects Analysis methodology to the PPM system. The hypothesis that cost overruns and schedule delays are management failures resulting from a breakdown in program control is developed. By analogy with failure analyses published in the open literature, a new methodology for determining cause of management failure is postulated and tested with past failures to demonstrate plausibility. A fourth variable to compliment cost, schedule, and technical—Human Factors—is defined as a mechanism for incorporating the effects of uncertainty into program controls.

The last chapter of Part II, Chapter 10, Third Generation, serves as an epilogue by providing an overview of continuing research to develop both data instruments and analysis methods to formally incorporate the effects of uncertainty into program controls. It also describes current thinking about how program controls with human factors would constitute a PP&C Third Generation—one that would further improve a program's ability to control cost and schedule growth. The fate of the Second Generation is to become the Third Generation:

PP&C 3rd Gen = PP&C 2nd Gen + Human Factors.

CHAPTER 8
Uncertainty

This chapter explores the complexity of the Program Performance Management System. Information presented shows how the uncertainty that accompanies complexity can influence outcomes.[234] A model of uncertainty is derived.

Complexity

The causal analysis presented in Chapter 3 identified external forces that are beyond the control of program managers. NASA managers have no direct influence over decision makers on Capitol Hill, administrators, and headquarters' personnel. However, the opinions expressed and decisions made by them can directly affect program outcomes. Information in this chapter provides a foundation for incorporating the effects of uncertainty into predictions of program performance.

Technology System

NASA is a highly complex organization with a hazardous mission. The space agency is charged to develop new technology systems (satellites, large rockets, and spacecraft) through major acquisitions for space science and for human exploration, as is the case with the Orion Program. These technology systems are complex because they are made up of a large number of interacting component parts that can break down in unanticipated ways: when component parts are integrated into a larger system, unanticipated interactions can occur. Adding redundancy for safety exacerbates the problem by increasing the complexity of the system. During operation, failed parts cannot be isolated from other parts, sometimes resulting in a catastrophic loss of vehicle and mission—as was the case with the Space Shuttle *Challenger* and *Columbia* disasters. Because NASA's core processes are tightly coupled, interactions are not wholly predictable, and failure is enormously costly in lives, resources, and national stature.[235] This interacting tendency is a characteristic of a system and has been labeled interactive complexity.[236]

Organization System

The organization system NASA uses to manage the development of its technology systems is similarly interactively complex.

> Interactive complexity refers to component interactions that are non-linear, unfamiliar, unexpected or unplanned, and either not visible or not immediately comprehensible for people running the system. The idea behind system accidents is that our ability to intellectually manage interactively complex systems has now been overtaken by our ability to build them and let them grow (like a NASA-contractor bureaucratic organizational complex).[237]

Like the technology systems it builds, the organization system is made up of a large number of interdependent, interrelated, and interacting suppliers all collected into a single larger management system. Its components are tightly coupled, problems may ripple through suppliers, and the larger system can break down in unanticipated ways.[238]

The scope of the organization system for NASA's major acquisition programs is shown in Figure 8.1.

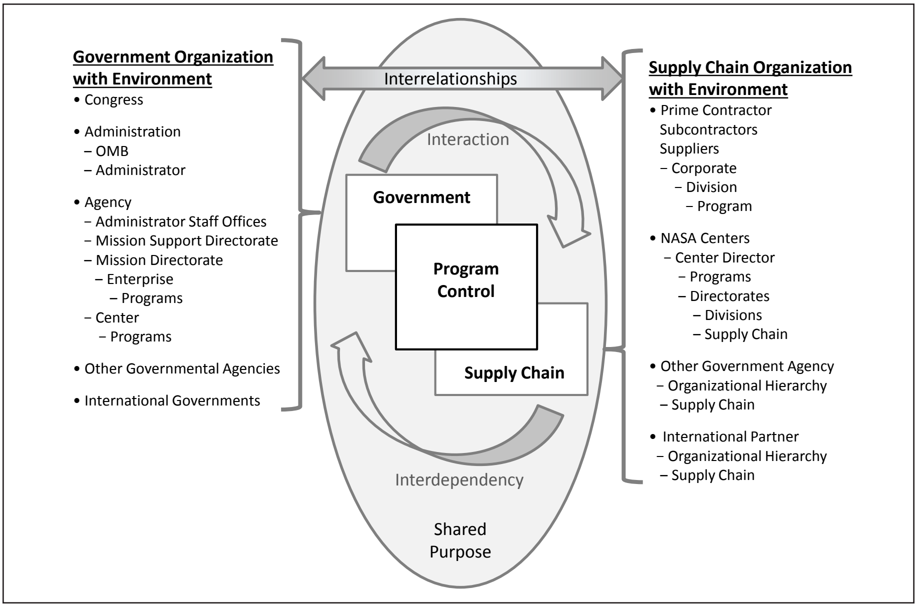

Figure 8.1 Uncertainty is driven by the number of government and supply chain participants and their environments, the degree of interdependency, and the extent of interactions.

As seen on the left side of Figure 8.1, the U.S. Congress authorizes major acquisition programs and the appropriation of funds, in accordance with national policy. The current NASA administration sets space policy and operates the agency, while the Office of Management and Budget interfaces with Congress for annual funds to operate the government—funds that are scrutinized each fiscal year.

Within NASA, agency participants include administrator staff offices and mission support directorates for common functions such as budget, finance, procurement, engineering, and safety; mission directorates and enterprise offices for program requirements and governance; centers for infrastructure; the Inspector General for oversight; program offices for managing major acquisition development; project offices managing content development; and participating organizations at multiple centers managing the development of government furnished equipment.

Outside government participants include individuals from other U.S. government agencies, namely the Government Accountability Office (GAO) that performs oversight and the Defense Contract Management Agency that performs contractor audits and inspections. Additionally, representatives from international governments and their agencies participate in NASA major acquisition programs. In the case of the Orion Program, the European Space Agency works as a partner in a "critical-path" position to provide the service module for the vehicle. Each of these agencies works with its own supply chain, complete with individual constituents and stakeholders.

Next, on the right side of Figure 8.1, program supply chain participants are persons and facilities from government and from commercial, industrial, and academic entities. Government suppliers are NASA centers providing spaceflight product content and professional services. Commercial suppliers include a hierarchy of aerospace companies, together with their subcontractors and industrial vendors. Academic entities provide research, specialized expertise and in some cases, custom instrumentation. Dependencies exist both within and between participant organizations, as each participant works with its own people, environments, and supply chain and with each other's. Therefore a program participant is not an individual, but rather an organization comprised of its own personnel, environments and supply chain.

The above description highlights how the NASA organization system meets published criteria for complexity:

- The system is comprised of groups of components, each with additional subcomponents that contribute to or define overall behavior.
- The system changes behavior to improve chances of success through learning or evolutionary processes.
- Subcomponents of the system engage with each other over time in ways that have the potential to influence subcomponent behavior.
- Structural and behavioral components are influenced by rules of interaction that are dominated by highly contextual, perhaps vaguely specified and changing "laws" that influence overall behavior in direct and indirect ways.
- Aspects of participants can differ, through initial endowments, consequences of actions, or both, and such individuality can impact overall system behavior.
- Both systems and components are driven by goals to attain within the context of a shared purpose.[239]

The extent of interdependencies, interrelationships, and interactions of program participants defines the complexity of the system. The extent of complexity can be gauged by examining the organizational environments where development occurs.[240] As outlined in Table 8.1, the external forces (political environment) where major acquisition programs are created, funded, managed, and adjudicated ensures complexity and guarantees that uncertainty will be a factor in program outcomes. The table lists the inherent contradictions in the operating environment of major acquisition programs.

• Programs are a product of policy, but Policy changes with administration, therefore existing programs become out of alignment with current priorities.
• Programs are a result of congressional action, and programs are defined by compromise. Program life cycles are measured in decades that span elections and administrations, but a program's budget (business) cycle is annual.
• Vision and purpose are shared, but goals and objectives are individual; individual needs are met by shared vision, and the nexus is a single plan.
• Cost and schedule estimates are required to meet "visionary" outcomes, and estimates are treated as "baseline" by stakeholders. Estimates become a "baseline" ahead of requirements, therefore subsequent cost deviations are considered to result from "poor" management.
• Participants are optimistic, but stakeholders are pessimistic. Therefore motivations are different.
• Authority is distributed, but accountability is singular.
• Contractors are hired early in the life cycle for both design and production, and contractor work defines the program baseline. When technical requirements change, life cycle costs increase and schedules are extended; the contract baseline becomes out of alignment with program baseline, therefore contracts have to be changed.
• Until change is definitized, contract work proceeds at risk: When new requirements are issued, costs and basis are proposed, new work is negotiated, contracts are changed, and definitization takes time. Therefore until changed, contract work is misaligned.

Table 8.1 Contradictions in a major acquisition programs environment.

Uncertainty

The number of participants in the NASA organization system, the extent of their interrelationships and interactions, and the high degree of interdependency make the system complex—not just simply complicated. The uncertainty in the PPM system is driven by this complexity, as a product of the coupled, context-dependent, nonlinear interactions characteristic of major acquisition programs. When programs are complex, outcomes cannot be ascertained by simply adding each of the constituent parts—the whole will also be influenced by other uncontrollable factors.[241]

Uncertainty in the PPM system means that program status or viability may be different from that indicated by performance measurements alone. The difference is not due to inaccurate calculations, but rather to incomplete calculations as emergence--a result of the nonlinear dynamics of the management system driven by external forces--has not been previously accounted. Prevailing external conditions are constantly in flux, and a level of program performance that was perfectly acceptable under one set of conditions at a given time may no longer be acceptable under similar conditions at a later time.[242] In other words, uncertainty means that for any set of measurements for program performance, the program may be better off, or worse, than indicated by the numbers alone, even for the same numbers but at different time periods.

Therefore, program performance cannot be properly managed by managing supplier performance alone. Other considerations associated with emergence in complex systems argue for new management approaches.[243] The success of program control requires knowledge of the uncertainty resulting from the complexity and how this uncertainty can affect program outcomes.

System Model

New mathematical approaches to complexity provide methods and techniques for understanding uncertainty. Figure 8.2 illustrates two models, where the X axis represents value for any cost, schedule, or technical variable, and the Y axis represents potential energy.[244] To illustrate, visualize program cost as a marble. When a cost-as-a-marble is "dropped" on the left side of the single bowl of Figure 8.2, it rolls to the bottom. This defines an attractor. Perturbations (i.e., a technology development problem that requires unplanned reserves and margin to fix) affect costs; they "move" the marble around from side to side. Depending on the model, perturbations can have different impacts. For example, a big enough perturbation (i.e., a major delay in achieving a technology readiness level) in the right-side double bowl could move it into a different portion, where it would have a different impact on system stability.

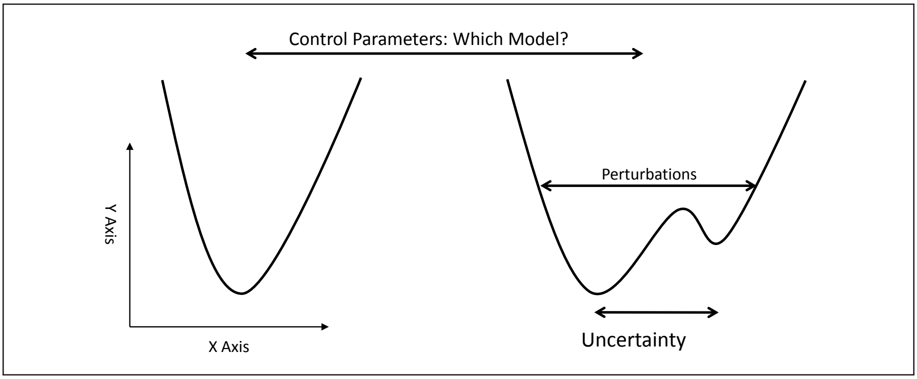

Figure 8.2 Uncertainty.

Control parameters alter system stability and therefore the number of stable states and the influences of perturbations within a state. Control parameters determine which system state will be expressed at a given point in time. When control parameters are known and measured, prediction is possible and the effects of uncertainty can be assessed.

In the above figures, for example, the number and shape of bowls is a function of the scale of a control parameter: when a control parameter is low there might be only a single bowl, but when it is high, the double bowl may appear. The relationship can also be more subtle. For example, when a control parameter is high, it could be a very deep (and thus stable) bowl, and when it is low, it could be a shallow bowl (and less stable).

Perturbations within a system affect stability. Perturbations are all the various influences through time, i.e., external forces, which must be overcome to maintain stability. They are part of the system, and their main function is to test the system's stability. If the system is stable (bowl is deep), perturbations will have minor influence, if any. Conversely, if the system can have multi-stability (bowl is shallow), perturbations can lead to catastrophe.[245]

Based on the above models, two manifestations of uncertainty are possible:

1. Stability: In the presence of a *strong attractor*, perturbations have no effect. However, in the presence of a *weak attractor* those same perturbations will be wildly influential.

2. Multi-stability (a number of simultaneous stable states): In the presence of two attractors, perturbations will knock the marble around as was the case for the single bowl model. However, perturbations can lead to sudden and catastrophic change in the double bowl model.

Relevance

Examination of cost, schedule, and technical data from the Orion Project (2005-2010) shows that the PPM system meets the above-defined criteria for complexity; and therefore is affected by uncertainty. Work to date suggests that the PPM system operates under conditions of multi-stability, with two attractors and two possible simultaneous stable states, as depicted below in Figure 8.3. In this system, perturbations can lead to sudden and catastrophic change.[246]

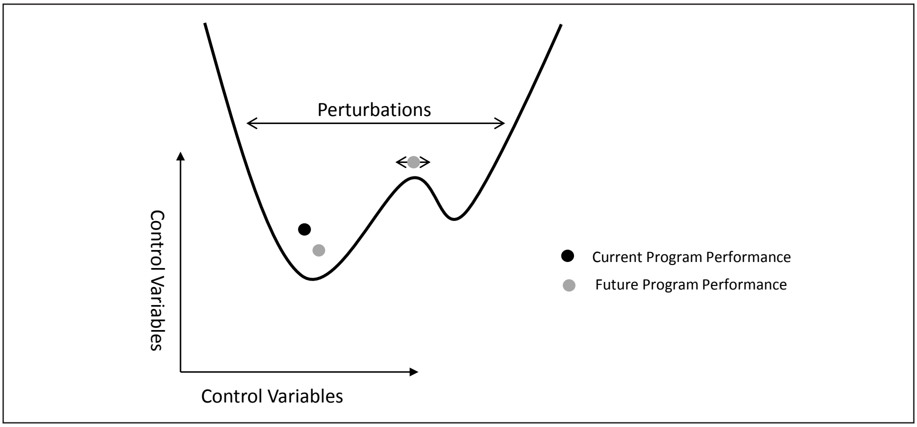

Figure 8.3 The effect of uncertainty on actual program performance.

In Figure 8.3, current program performance (i.e., the results of integrated analysis of cost, schedule and technical variables) is represented as the black dot. Predictions of future program performance are represented as the gray dots. Without explicitly accounting for the effects of uncertainty, program management could conclude that program performance is becoming even more stable as the gray dot on the left is below the black dot and therefore has lower potential energy. However, because of ever-changing external forces, the program may actually be on the verge of catastrophe.

The gray dot on the right with the arrows pointing in the horizontal direction shows this precarious condition (a.k.a. "tipping point") where the program could recover (move to the left through the use of budget reserves, schedule margin, or technical margin), or fall-to-the-right and experience overruns and delays to an extent that requires notifications to Congress, with re-baselining or cancellation as possible outcomes.

Program position relative to a catastrophe is a variable, as budgets, external political climate, and executive support change with circumstances not necessarily related to the program or its performance. Therefore an actionable PP&C (program controls) must include a capability to gauge program position within its range of uncertainty between stability and catastrophe in order to more accurately inform decision making.

Research, Phase I

In 2011, the Orion Program issued a grant to the University Of Utah Department Of Psychology to study uncertainty in the Orion Program.[247] Part I of the study analyzed six years of Orion Project cost, schedule, and technical performance data using recently developed data analysis methodologies.[248] Results were documented in a final report, and findings have been reported as a technical paper.[249]

The research applied nonlinear dynamical systems analysis methods to investigate stability of the PPM system. A portion of the results of the analysis of cost data by Orion Work Breakdown Structure is presented in Figure 8.4 and shows that a large segment of the time series hovers around a value of zero, representing stable regions. However, small subsets of budget deviate substantially from zero, demonstrating evidence of multi-states. Uncertainty in the PPM system can be characterized as a double-bowl cusp catastrophe model, as was shown in Figure 8.3. Note that the value of control parameters would further describe model geometry.

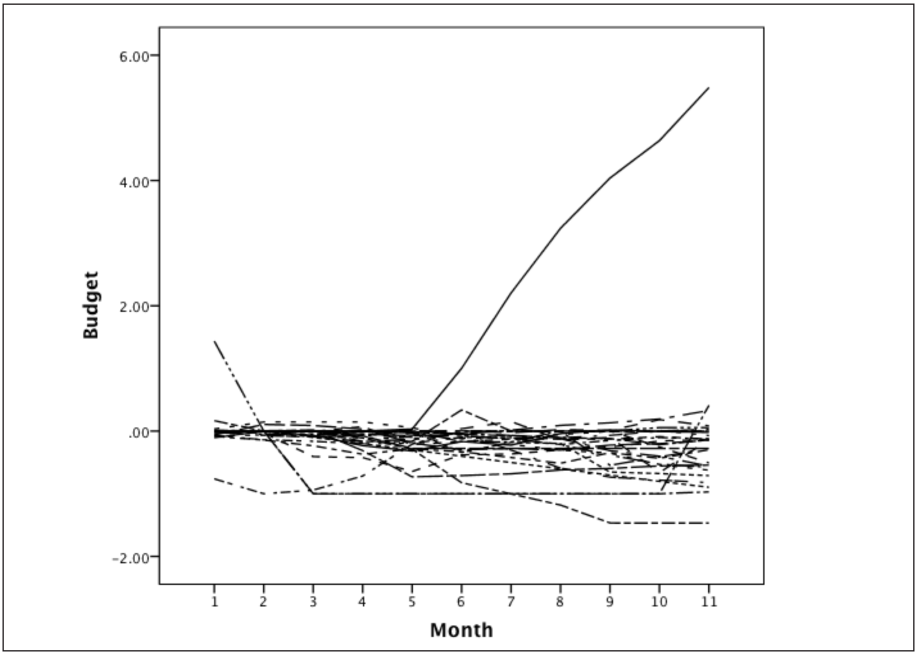

Figure 8.4 Time series for Orion budget and cost data.

From the data analyzed, a cusp catastrophe model showing both continuous and discontinuous change through time provides the most accurate representation of the PPM system. The model presented as Figure 8.5 shows one strong attractor (left) and one weak attractor (right).

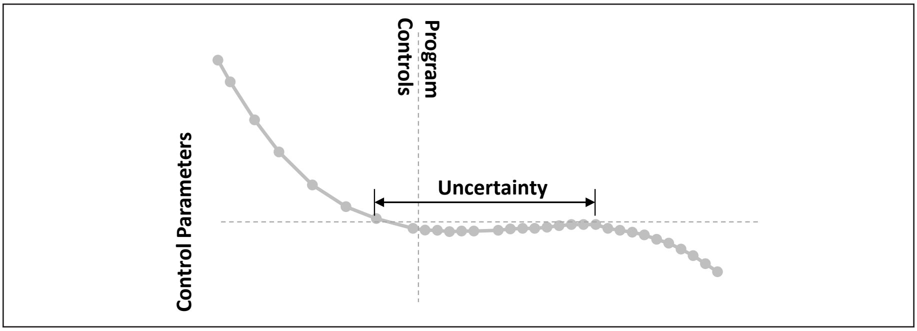

Figure 8.5 Cusp Catastrophe Model of the Program Performance Management System.

Uncertainty in the model is represented as the range between the two attractors; for the same or very similar values of program controls, actual program status with respect to external forces may be anywhere along the uncertainty range. At the end points of the uncertainty range, a small perturbation can produce either one of two possible outcomes.

For example, if the left end point of uncertainty range represents conditions under which cost and schedule growth can be accommodated within program reserves and margin, the system is stable and recovery is perfunctory. Then, the right side of the uncertainty range represents conditions under which further negative change cannot be accommodated, and catastrophe occurs. This is the "tipping point" beyond which recovery within existing reserves is not possible, and intervention by upper-level management will happen.

Program status correlates to governance, the exercise of authority by the government. Governance of a program repeatedly exhibiting "on-target" performance is very different than for a program that consistently hovers "dramatically on the edge" or "over target" of planned performance. Unchecked, repeated poor performance—or what appears to be surprise revelations of poor or unexpected performance (i.e., reporting a large increases in cost and schedule to maintain alignment with changes in technical requirements)—can lead to loss of customer and stakeholder confidence as happened with ISS in 2001.

Calculations of program performance must account for the effects of external forces in addition to cost, schedule and technical. Identification of position along the uncertainty range is an approach. Figure 8.6 shows the concept where for one value of program performance (black dot) the program can be at a stable point, a tipping point, or anywhere in between. Proximity also plays an important role, as a position closer to a tipping point means it will be more difficult for the program to slow down, stop, or reverse direction toward planned cost and schedule commitments.

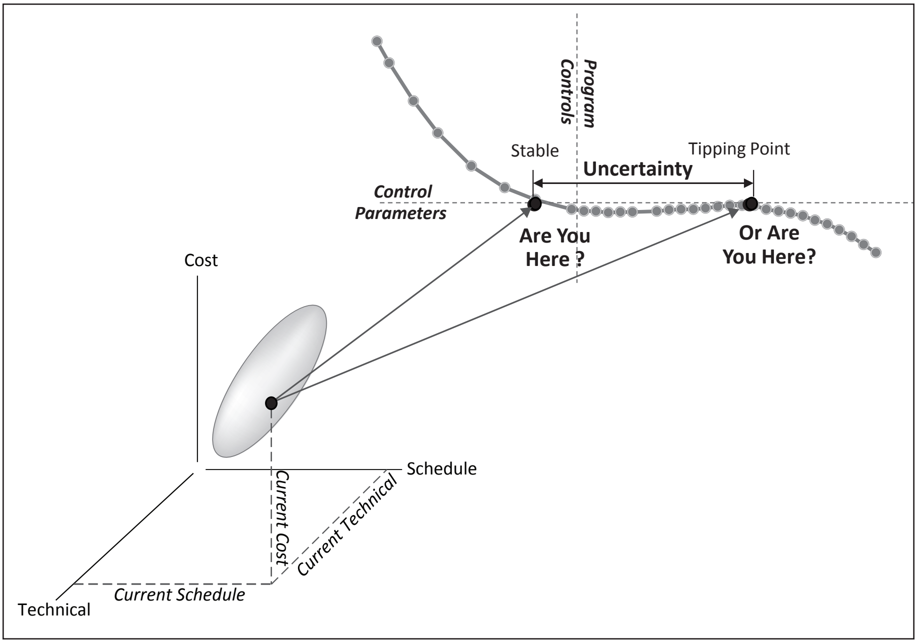

Figure 8.6 The effect of uncertainty on the Program Performance Management System.

Risk and Uncertainty

Program control is maintained by making decisions to constrain the program to operate within a baseline of set values of cost, schedule, and technical performance, including margins and reserves. The cost, schedule, and technical parameters represent known items that are planned for, monitored, measured, and analyzed throughout technology system development. Risk, on the other hand, represents known unknowns associated with the development process.

In a sense, risk accounts for those cost, schedule, and technical unknowns that are tacitly understood to exist but cannot be precisely quantified and therefore are scored or ranked numerically on a consistent scale for comparison and management.

Currently, NASA major acquisition programs represent known unknowns as 1) assumptions that are tracked for continuing validity, 2) statements of risk that are scored and managed, and 3) confidence level of estimates of cost and schedule expressed numerically as probabilities that accompany published values. The continuing validity of assumptions is assessed as agenda items in management reviews. Scored risk is managed with technical margins and mitigation plans. Cost and schedule confidence levels are managed with cost reserves and schedule margins.[250] Uncertainty, however, is not accounted.

The Department of Defense addresses uncertainty by applying a Probability of Program Success process to account for external and environmental factors that affect program viability. The process assesses the current state of a program's health in a disciplined and consistent fashion. It forecasts the probability of program success by accounting for its "fit" with the vision and priority of the current administration and for the program's advocacy within the agency, Congress, and industry. The result is a percentage that can be applied to program performance metrics to account for unknown unknowns. The percentage is regularly reviewed and revised as necessary.[251]

The existing suite of tools and methodologies used to calculate program performance based on values for cost, schedule, and technical variables include risk and confidence levels to account for known unknowns. Numerous improvements—including earned value and joint confidence, improving cost estimating methodologies—have not eliminated cost overruns and schedule delays in major acquisition programs. Something else is needed. Some method for gauging the effects of uncertainty on major acquisition program performance, i.e., position relative to tipping point shown in Figure 8.6 is required. A new methodology based on an analysis of precursors to cost overruns and schedule delays that have occurred in the past could provide insight. Hypothesis and approach are discussed in Chapter 9.

CHAPTER 9

Human Factors

Organization systems are complex because of the number and diversity of participants and the extent of interdependencies, interrelationships, and interactions between them. The NASA Program Performance Management System is a complex system. Because of its complexity, management outcomes are subject to emergence. Evidence of complexity and emergence were confirmed by research that analyzed Orion budget and cost performance data. A phase portrait of the PPM system was developed and used to suggest a model for explaining and predicting outcomes, so that the effects of uncertainty could be identified. A cusp catastrophe model was developed.[252]

The PPM system model shown in Figure 8.6 is reproduced as Figure 9.1, where the uncertainty range is emphasized. The uncertainty range characterizes the impact of external forces on program outcomes, as for very similar values of program controls, actual program status can be anywhere between stable (on-plan performance left) to catastrophic (on-plan performance right). Values for control parameters will prescribe the shape of the model and therefore sensitivity to change. A method for determining position along the shape (proximity to a tipping point) is needed.

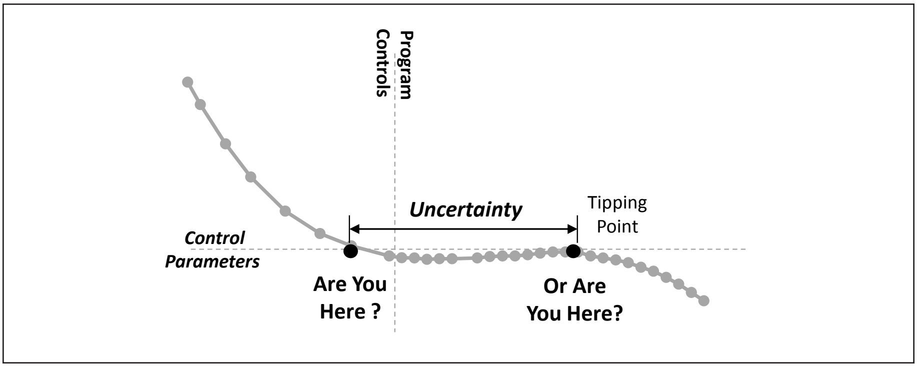

Figure 9.1 Model and tipping point for cost overruns and schedule delays.

Hypothesis

The effect of external forces can be characterized by Human Factors. Human Factors is the combination of organizational influences, institutional factors, and human reactions to deal with them. Human Factors is the 4^{th} variable of program controls:

Program Controls = f (Cost, Schedule, Technical, Human Factors).

Human Factors is a technique to account for uncertainty.[253] Uncertainty by definition means imprecise, and defies being either measured or scored. Therefore, Human Factors cannot be expressed numerically as a measurement, a score or a probability. But the effects of uncertainty can be assessed relative to conditions known to result in failure. Such a "gauge" for uncertainty (position along the uncertainty range) when used in conjunction with values for cost, schedule, and technical performance would provide more accurate predictions of actual program status. The gauge can be developed by applying a Failure Modes and Effects Analysis (FMEA) methodology to a management system.

Failure Modes and Effects Analysis

FMEA is one commonly-applied, systematic technique for assessing failure in technology systems. As a design tool it is used to identify critical components of, for example, a flight vehicle. The FMEA process involves reviewing as many component parts, assemblies, and subsystems as possible to identify any possible failures. Failure Mode describes the way a failure occurs, while Effects Analysis determines the outcomes of a failure. Analysis results provide a basis for defining interventions that would lower the probability of failure, lessen the severity of the effects of failure, or ameliorate the consequences of a failure. Actions include, for example, more stringent requirements for designing, operating, maintaining, and sustaining the subject technology system.[254]

FMEA has also been applied as an analysis tool to identify failure modes in an organization system that operates a technology system. Both James Reason's 1997 *Managing the Risks of Organizational Accidents* and Wiegmann and Shappell's 2003 *A Human Error Approach to Aviation Accident Analysis* apply a failure approach to organizational and aviation accidents. Reason's model was originally developed for the nuclear power industry and is based on the assumption that some fundamental elements of all organizations must work together harmoniously in order for efficient and safe operations to occur. Accidents take place when interactions between the various elements in a production process break down.[255] Subsequently, Wiegmann and Schappell adapted Reason's methodology and applied it to the analysis of cause of aircraft accidents in the military.[256]

Organizational Accidents

Reason developed his model of Organizational Accidents by studying the work performed by organizations and the environments in which the work was performed. In Reason's model, organizations produce product. During product development, organizations protect people and assets from harm by providing defenses placed between both natural and man-made hazards and their possible victims. These defenses are layered to provide redundancy should any one fail.

Therefore, both production and protection are common to all organizations that develop or operate product. The two operate together, with an ideal level of protection matched to the hazards of production operations. Typical of an outcome when technical needs compete with nontechnical challenges for resources, production receives priority over protection, and the amount of protection realized fluctuates based on then-current circumstances. Accidents occur when the level of protective defenses provided are penetrated.

Reason divides the cause of accidents into two main categories: active failures and latent conditions. *Active failures* occur when individuals within an organization system make errors or violate procedure. Active failures usually have immediate and relatively short-lived effects.

The term *latent conditions* captures the environmental and situational conditions that arise from a history of top-level decisions made by governments, regulators, manufacturers, designers, and managers. Latent conditions are always present in any complex system; they shape a distinctive corporate culture and create error-producing factors within any organization. They cannot be prevented, and therefore they must be made known to those who are responsible for the management of the organization.

According to Reason, organizational accidents occur when active failures—either as deliberate acts or as unwitting errors in response to off-nominal conditions—create gaps in a system's defenses. Latent conditions then cause defenses to fail or exacerbate the effects of a failure. Reason developed the "Swiss Cheese" Model of Organizational Accidents (Figure 9.2) to describe how these organizational accidents transpire.

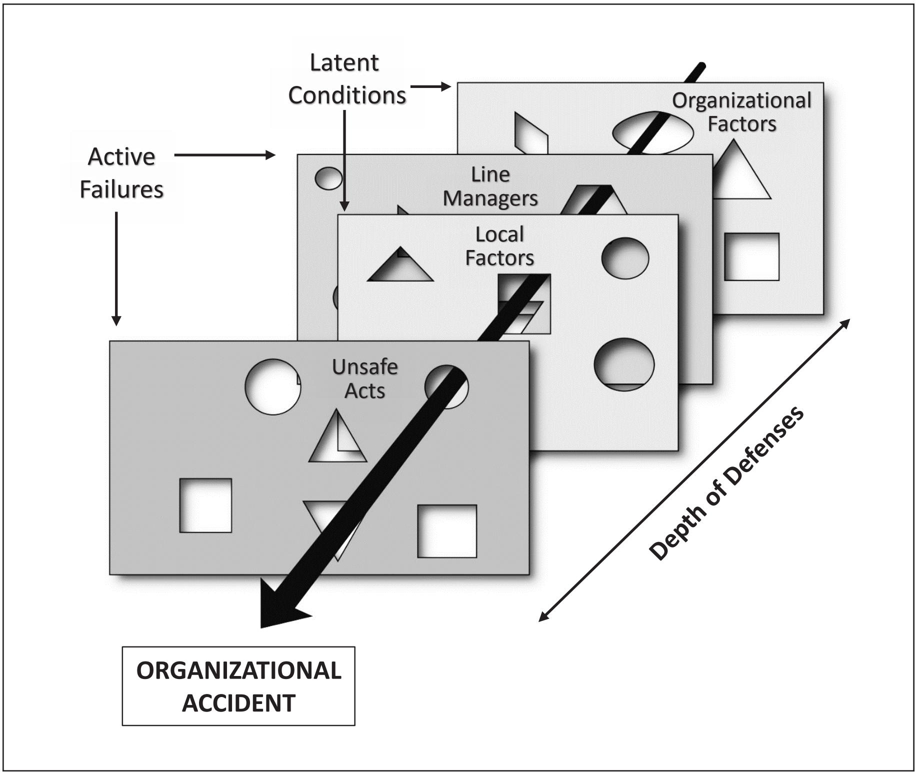

Figure 9.2 Reason's Swiss Cheese Model of Organizational Accidents.
Adapted from Reason (1997), Organizational Accidents, Figure 1.5, page 12, with permission from Ashgate Publishing.

Organizational accidents occur when the gaps produced by active failures align with those created by latent conditions, opening a "window of opportunity" that brings hazards into contact with people and assets.[257] Organizational accidents can have many causes, each attributable to a confluence of people from different organizations and environments interacting over some period of time. The greatest danger is the rare, but often disastrous, failure resulting from contributions from many different people distributed widely both throughout the organization and over time (a.k.a. catastrophe).

Aviation Accidents

About six years after Reason published his findings, Douglas A. Wiegmann and Scott A. Shappell applied Reason's model to aircraft accidents. Wiegmann and Shappell developed the Human Factors Analysis and Classification System (HFACS) to define the active failures and latent conditions in the context of aircraft accidents. Under this system, an aircraft is a technology system; operation of the aircraft (air and ground, flight, and support) is an organization system; and an aviation accident is an organizational accident. The resulting "Swiss Cheese Model" of Aircraft Accidents is shown as Figure 9.3.

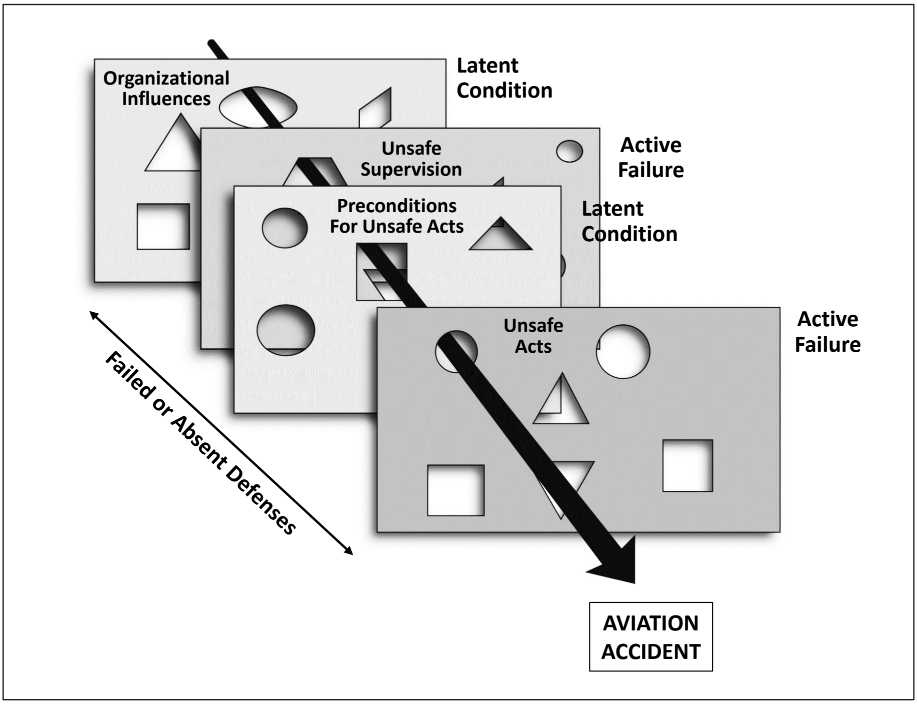

Figure 9.3 The Swiss Cheese Model of Aircraft Accident Analysis.
Adapted from Wiegmann and Shappell (2003), A Human Error Approach to Aviation Accident Analysis, Figure 3.2, page 47, with permission from Ashgate Publishing.

Wiegmann and Shappell analyzed hundreds of military and civil aviation accident reports that contained thousands of human causal factors and categorized them into four components of failure: Unsafe Acts, Preconditions for Unsafe Acts, Unsafe Supervision, and Organizational Influences. Within the aircraft accident investigation and classification system (Table 9.1), accidents occur when breakdowns take place in the interactions within and among the four components.[258]

Unsafe Acts	Preconditions for Unsafe Acts	Unsafe Supervision	Organizational Influences
• Errors – Skill-Based Error – Judgment Error – Decision Making Error • Violations	• Environmental Factors – Physical – Technological • Condition of Individuals – Cognitive – Psycho-Behavioral – Adverse Physiological – Limitations • Personnel Factors – Coordination/ Communication/Planning – Self-imposed	• Inadequate Supervision • Planned Inappropriate Operations • Failure to Correct Known Problem • Supervisory Violations	• Resource/ Acquisition Management • Organizational Climate • Organizational Process

Table 9.1 DOD Human Factors Analysis and Classification System.

Breakdown in Program Control

Cost overruns and schedule delays are failures by management to operate within agreed-upon constraints. They are the result of a breakdown in program control that for one reason or another failed to take the right action at the right time to avoid or forestall a catastrophe. Generally, a breakdown in program control is not as ruinous to property and human lives as is a nuclear power plant accident or an aviation aircraft accident, but it does present a real cost, an opportunity cost, and a human cost. Real cost is the additional resources required to complete development; opportunity cost is the value of other technology systems that are either cancelled or delayed because resources had to be reprogrammed; and human cost is the effect of failure on careers when jobs are lost as programs are re-baselined or cancelled.

Orion PP&C wants a methodology to directly account for the effects of uncertainty in major acquisition programs in order to inform program control of proximity to catastrophe. No such methodology was found in the literature reviewed.

Accordingly, a methodology was postulated and assessed for plausibility based on the following four assumptions:

1. The performance of Orion is representative of a major acquisition program.
2. A Failure Modes and Effects Analysis approach can be used to develop a mechanism to predict future breakdowns by analyzing the cause of past failures.
3. Program conditions and events that have resulted in cancellation and re-baselining in past programs are not only present in current programs, but will also be present in future programs.
4. Breakdown in program control is analogous to an organizational accident or an aircraft accident.[259]

By analogy, human errors and violations of policy and procedures, coupled with corporate-level influence and the latent conditions associated with local and shared environments, can result in a breakdown in program control (Figure 9.4). Errors and violations correspond to unsafe acts, which can be performed by any program participant at any point in time. Latent conditions correspond to organizational influences and institutional factors. Organizational influences describe "corporate" behavior, and include the decisions made by corporate management that affect the performance of line organizations operating under their authority. Lastly, institutional factors refer to local policy, rules, regulations, requirements, procedure, and culture.

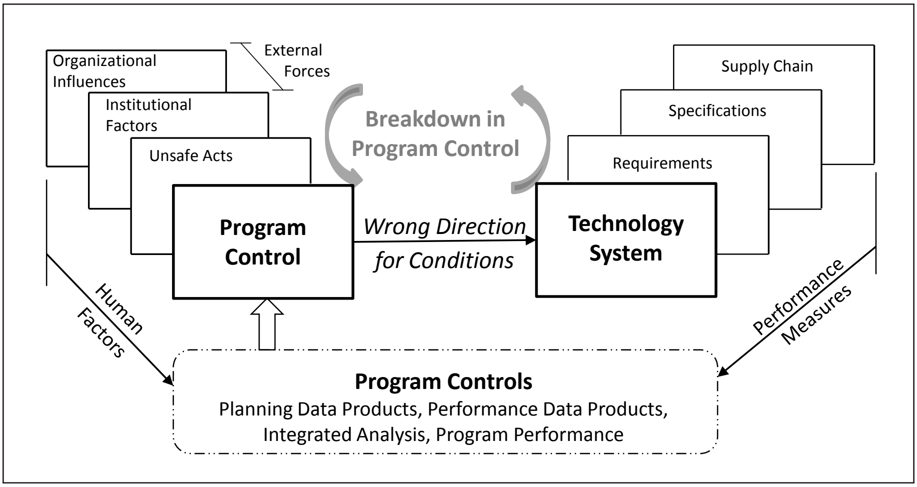

Figure 9.4 Representation of a breakdown in program control.

Wiegmann and Shappell's four-component classification system was applied to major acquisition programs. However in those programs, errors and violations can be made by any participant, at any level, and at any time. Therefore, a model of failure mode must account for the conditions and actions of all program participants, including the program manager (local), each participant in the supply chain (corporate and line, local and distant), and supervisors and staff for each organization.

Table 9.2 summarizes the relationship of the elements of a breakdown in program control compared to organizational and aircraft accidents. For NASA, the technology system is a major acquisition, and the failure is a breakdown in program control that results in cost or schedule growth of such a magnitude that a report to Congress is required. The four modes of failure are grouped into active failures (which manifest as errors and violations committed by people, management, and supervisors), and latent conditions (which manifest as organizational influences and institutional factors).

	Reason, 1997	HFACS, 2003	NASA, 2014
Technology System	Production System	Aircraft	Major Acquisition
Organization System	Power Plant Operation	Aircraft Operation	Program Performance Management
Failure	Organizational Accident	Aircraft Accident	Breakdown in Program Control
Mode			
Active Failures	Unsafe Acts	Unsafe Acts	Breakdowns by Management
Latent Conditions	Local Factors	Preconditions	Institutional Factors
Active Failures	Line Management	Unsafe Supervision	Breakdowns by Supervisors
Latent Conditions	Organizational Factors	Organizational Influences	Organizational Influences

Table 9.2 Application of organizational accident and aviation accident FMEA methodology to a breakdown in program control.

Because of the extent of interdependencies in the management system, the four components of failure operate over all participating organizations, namely: 1) organizational influence in Congress, the administration, and at executive levels of government and industry suppliers, 2) latent conditions in line-level cost centers in industry and NASA centers, 3) active failures of agency supervisory persons and program management in the program office, and 4) active failure of supervisory persons and line management in supply chain offices.

Figure 9.5 presents the resulting model for analyzing management failure as a breakdown in program control in major acquisition programs as a sequence of conditions and events culminating in failure.

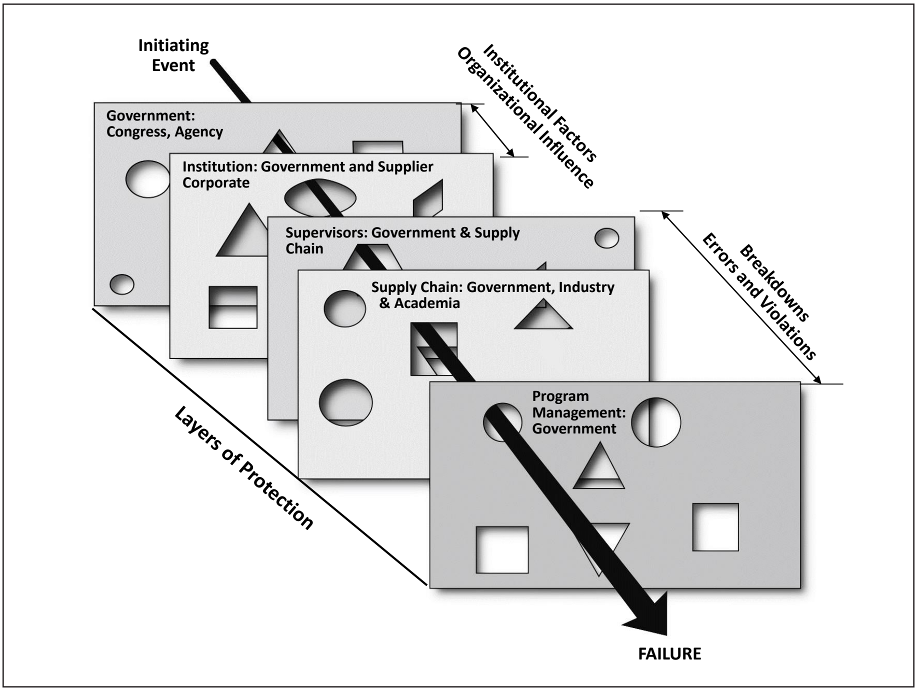

Figure 9.5 Failure Mode Model of breakdown in program control in major acquisition programs.

Definition of the events within each failure category allows for identification of the signs of impending catastrophe. A list of prevailing conditions and recorded events present in past breakdowns was developed by culling information from published reports of failure in major development acquisition programs in NASA and the DOD.[260] Information was extracted and organized by each of the four failure modes. The resulting *preliminary* classification system is shown as Table 9.3a for latent condition modes and as Table 9.3b for active failure modes.

Participant	Organizational Influence (decisions)	Institutional Factors (policy, culture)
Government Congress & Agency	• Misalignment with congressional priority • Misalignment with administration policy or priority • Underfund Program	• Use of agency-unique definitions for common metrics and measurements • Underfund Program
Institution – Agency – Other Gov't – Int. Partner – Industry – Academia	• Perform technical design at agency level • Substantial change in requirements • Inadequate or unstable funding • Insufficient numbers of qualified persons • Facilities not available when needed • Financial reporting does not support EVM • Design-production procurement strategy drives change • Amount of supplier work at risk that is due to undefinitized contract actions	• Contractors charge a premium to perform work for the government (NASA) • Culture of optimism at all levels • No clear lines of authority but singular accountability • View success in technical rather than business terms • Institutional wants more important than program needs • No program control over matrix personnel • Poor communication between organizations • Difficulty in tailoring requirements and specifications

Table 9.3a Preliminary classification system for analyzing cause of breakdown in program control because of latent conditions.

Participant	Error	Violation
Program Management – Agency	• Accept inadequate budget to perform work • Accept inadequate budget reserves • Accept inadequate schedule margin • Accept inadequate technical margins • Defer work to stay within annual budgets • Inadequate/ineffective supplier oversight • Inadequate monitoring of assumptions • Manage technical challenges not business • Underestimated growth • Underestimated risk • Underestimated complexity • Unrealistic cost and schedule estimates	• Failure to correct a known problem • Failure to disclose cost growth or schedule delay • Failure to demonstrate required milestone knowledge and maturity • Failure to manage to baseline LCC and LRD values • Failure to use independent cost estimates
Supply Chain – Agency – Other Gov't – Int. Partner – Industry – Academia	• Lack of capability with technology • Underestimated effort to perform work • *Underestimated risk* • *Underestimated complexity* • *Unrealistic cost and schedule estimates* • Concurrency required to meet schedules • Amount of rework; product quality	• Buy-in with expectation for recovery in later phases • Failure to perform in accordance with governing Documents • *Failure to correct a known problem* • *Failure to disclose cost growth and/or schedule delays*
Supervisors – Agency – Other Gov't – Int. Partner – Industry – Academia	• Flawed funding strategy • Flawed acquisition strategy • Misaligned incentives • Inadequate/ineffective oversight of program performance • Lack of leadership in resolving program issues	• Allowed program to move into next phase prematurely • *Failure to correct a known problem* • *Failure to disclose cost growth and/or schedule delay* • Allowed repeated work deferral to stay within annual funding

Table 9.3b Preliminary classification system for analyzing cause of breakdown in program control because of active failures.

****Note: Items in italics show that the same active failure event may be committed by more than one participant in any organization.***

Plausibility

The PPM is a complex system and uncertainty affects the outcomes of decisions made by program control on the program controls provided by PP&C. Envisioning human factors as a variable to account for the effects of uncertainty is a hypothesis, as is the use of a Failure Modes and Effects Analysis approach to gauge position relative to a breakdown. The application of a "Swiss Cheese" model of accidents to identify a sequence of events that precipitates a breakdown in program control is thought to be a viable approach. The assumption is that while uncertainty cannot be measured or scored, it can be gauged relative to conditions (events and sequence) that have led to breakdowns in past programs. Events can be captured from literature. Sequence can be structured by analogy with organizational accidents. Cause can be ascertained by investigating the chain of events culminating in failure.

In theory, a checklist of events inclusive of organizational influences, institutional factors, and breakdowns can be used to capture program management's perception of conditions extant at any point in time, preferably concomitant with a program review of cost, schedule and technical performance. Ongoing research to develop this approach is discussed in the next chapter.

The plausibility of the hypothesis and approach was tested by combining event information available in open literature for major acquisition programs with the failure modes model shown in Figure 9.5 to diagram the chain of events leading to a breakdown in program control. Sources of generic information about breakdowns in program control of NASA programs is provided in Table 9.4.

Generic Information
• National Research Council, Controlling Cost Growth of NASA Earth and Space Science Missions (Washington, DC: National Academies Press, 2010). • NASA Office of Inspector General, NASA's Challenges to Meeting Cost, Schedule, and Performance Goals, multiple reports. • Paul K. Martin (NASA Inspector General) to Charles F. Bolden, Jr. (NASA Administrator), Report on NASA's Top Management and Performance Challenges, multiple reports. • Government Accountability Office, NASA: Assessments of Selected Large-Scale Projects, multiple reports.

Table 9.4 Source data for breakdown in program control for NASA programs.

Source data for Constellation, James Webb Scape Telescope, and Navy A-12 Avenger Programs is provided below followed by an analysis of cause. For each program, occurrences in time were extracted from the cited documents and then sequenced by the chain model. The results demonstrate that events and sequence can be combined to show cause. Its purpose is to show plausibility of proposed method for further research and development and _not_ to ascribe definitive cause of outcomes experienced by each program.

Cancellation of the Constellation Program
• Constellation Program Lessons Learned, vol. 1: Executive Summary (Washington, DC: NASA SP-2011-6127-VOL-1, 2011). • J. Steven Newman and David Lengyel, "Cancellation: Program Cancellation Failure Modes & Lessons Learned" (PowerPoint presentation, NASA PM Challenge 2012, Orlando, FL, February 22-23, 2012).

Table 9.5 Source data for breakdown in program control for NASA Constellation Program.

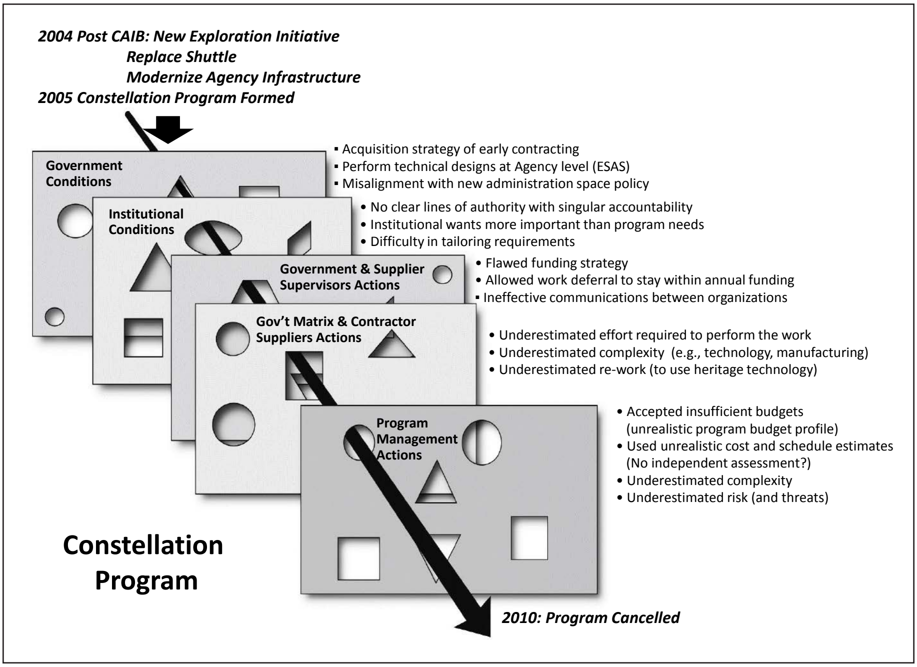

Figure 9.6 Possible cause of breakdown in program control in the Constellation Program.

Re-baseline of James Webb Space Telescope
• James Webb Space Telescope (JWST) Independent Comprehensive Review Panel (ICRP): Final Report, October 29, 2010. • "The James Webb Space Telescope," NASA accessed May 13, 2014, http://jwst.nasa.gov/about.html

Table 9.6 Source data for breakdown in program control for NASA James Webb Space Telescope Program.

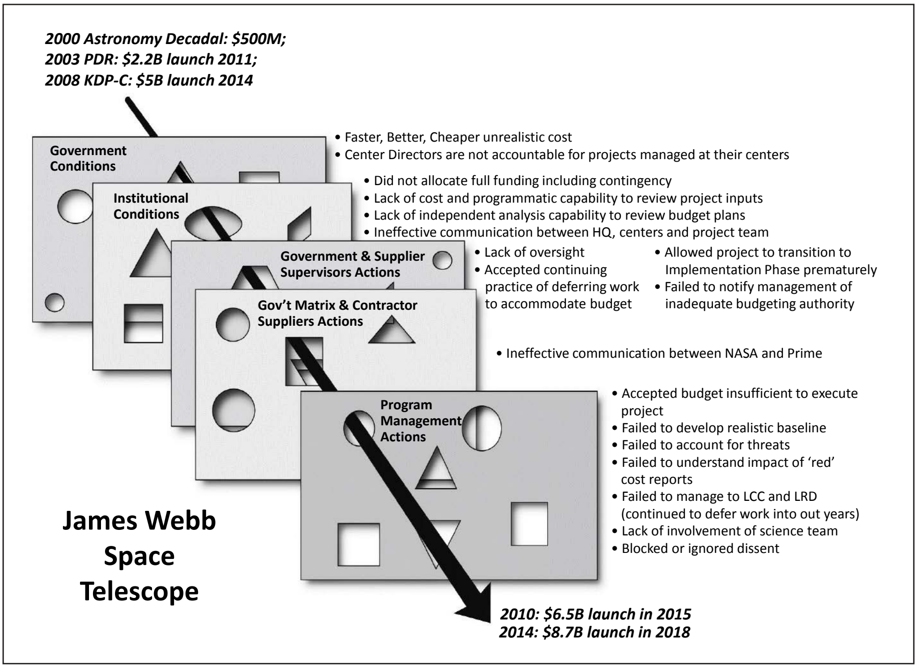

Figure 9.7 Possible cause of breakdown in program control in the James Webb Space Telescope Program.

Cancellation of the NAVA A-12 Avenger Program
• David Christensen, Memorandum for the Secretary of the Navy, "A-12 Administrative Inquiry," November 28, 1990. • Louise A. Eckhardt, Bureaucratic Politics: Explaining Cancellation of the Navy A-12 Aircraft (Washington, DC: National War College, 1996).

Table 9.7 Source data for breakdown in program control for Navy A-12 Program.

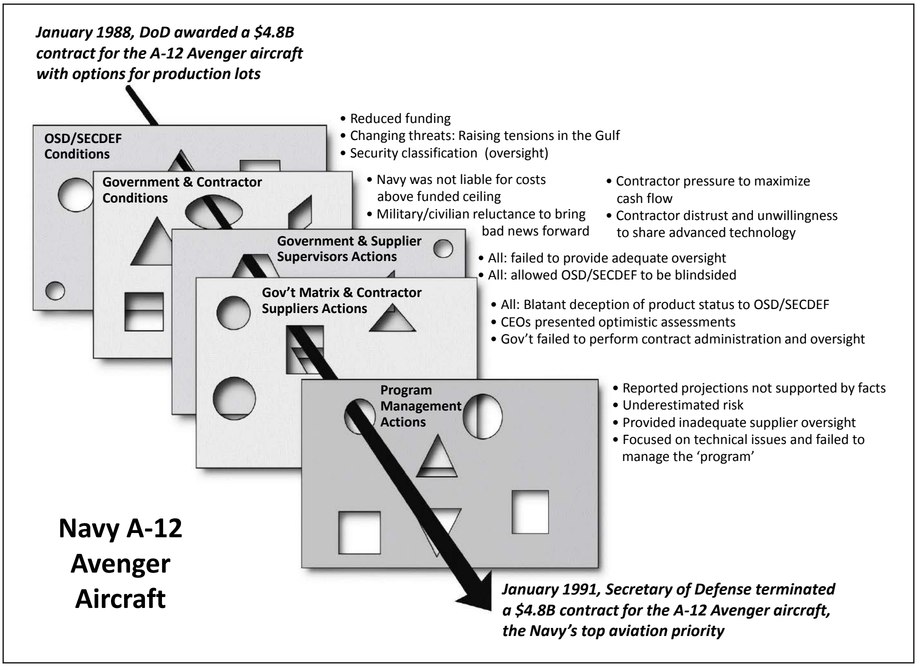

Figure 9.8 Possible cause of breakdown in program control in the Navy A-12 Program.

The Fourth Variable

The preliminary study of Human Factors appears to validate the hypothesis that four variables—and not three—are required to accurately predict program performance. Cost, schedule, and technical are all influenced by the fourth variable, Human Factors. Information about Human Factors can be used to account for the situations and conditions associated with external forces and the behaviors of humans in reacting to them.

Human Factors ≡ 4^{th} Variable

To apply Human Factors to major acquisition programs, a checklist of organizational influence, latent conditions, and errors and violations from past management failures can be used to capture program management's perception of program status relative to the onset of a breakdown in program control. Under assumption 3 on page 121 above, it can be used to capture perceptions of current conditions. Regular use of the checklist on a time-scale compatible with cost, schedule, and technical measurements of program performance would provide a series of linked data with trends.

Analysis over time would provide a means to gauge program position relative to catastrophe. Position and supporting data would be an input, along with cost, schedule, and technical data and information, to the integrated analysis PP&C uses to develop the program controls used to inform program control of program status.

The fact that the cancellation of the A-12 Avenger in 1991 and the Constellation Program in 2010 occurred nearly 20 years apart supports the key assumption 3:

> ***Program conditions and events that have combined in the past to result in cancellation and re-baselining are present in not only current programs, but will also be present in future programs.***

The next chapter discusses potential approaches to further verify the methodology and to test it in the Orion Program.

CHAPTER 10
Third Generation (Epilogue)

This chapter expands on research into the effects of complexity in major acquisition programs by further exploring the concept of Human Factors. Continuing research aims to develop the methodology and tools necessary to gauge the effects of uncertainty, and to integrate it with cost, schedule, and technical controls into predictions of program performance. The results of continuing research will enable a Third Generation of PP&C.

Research, Phase II

Ongoing work with the University of Utah is studying emergence within the Orion PPM system using nonlinear dynamical systems (NDS) theory—the analytical study of change. Work to date has identified temporal patterning inclusive of a tipping point for where overruns and delays would most likely occur.

The initial phase of the grant, described in Chapter 8, found that the PPM system exhibits multi-stability, which means that both stable and unstable states separated by a region of uncertainty can be present. Findings were documented as a final report and a technical paper that was published in 2014.[261] Further research is confirming patterning, identifying control parameters, and researching Human Factors.

Phase II research is expanding the scope of study to investigate the hypothesis that Human Factors provides a means to gauge uncertainty. Both NDS and Human Factors are disciplines of psychology, the science of behavior. Phase I work focused on NDS. Phase II work will combine the disciplines of NDS and human factors to study emergence in the PPM system. The mathematical analysis methods of NDS are being used to verify the applicability of the cusp catastrophe model and to determine sensitivity to external forces (control parameters). The Human factors' method of situation awareness is being used to develop a methodology for consistently gauging the effects of uncertainty.

Situation Awareness

Interviews conducted as part of the causal analysis determined that 1) managers are inherently sensitive to congressional, agency, and public perceptions of performance, and 2) data or information about situational awareness are not currently being collected.[262] A manager's ability to discover anomalies in a complex system—in other words, to be aware of potential breakdowns before negative consequences ripple through the system—depends on his/her mental representation of the dynamically changing task environment. In 1943, British psychologist Kenneth Craik termed this the manager's "mental model."[263] Situation awareness is a method for studying mental models.

Situation awareness proceeds along three levels. At the first level, a manager perceives relevant information and detects a change in the environment; the manager discovers that an event has happened. Then, at the second level, these various pieces of data are integrated into an understanding of the event. Finally, at the third level, a manager predicts future system states based on system knowledge. This system knowledge is used to form a mental plan, as the individual weighs the potential effects of implementation—including considerations of efficacy, resource availability, time to implement, time for effects, and costs. This mental plan governs how and when a manager chooses a particular course of action, and the more adequate the situation awareness, the more likely it is that the outcome of decisions will be successful.[264]

Plan of Study

NDS discipline work will collect and analyze cost, schedule, and technical data to verify and refine the applicability of the cusp catastrophe model introduced in Chapter 8, while new human factors discipline work will use methods of observation and critical decisions to identify the cognitive factors that play an important role in identifying anomalies and their causes. Initially observations will occur in conjunction with management reviews of program performance. Subsequently, a questionnaire to assess the critical aspects of anomaly identification will be developed and made available for managers to complete online directly following a management review. Lastly, structured interviews based on the critical decision method will study how program managers detect anomalies and their attributes and the decision-making process used to attempt to resolve the anomaly.[265]

A Principle Investigator for each discipline will work independently to acquire data and produce results and collectively to develop a more comprehensive understanding of the underlying theory and prescribe analysis methods. Following an initial period of data collection, NDS discipline methods will be applied to identify control parameters that determine shape and sensitivity to change. Human factors discipline analysis methods will be used to refine data collection instruments and organize results into failure modes and effects classification system (i.e., similar to Table 9.3). Collaborative data analysis will integrate the results of both disciplines into a new methodology for gauging program position relative to catastrophe. Findings and results will be documented for validation by peer review.

The application of expected results into program controls is shown conceptually in Figure 10.1.

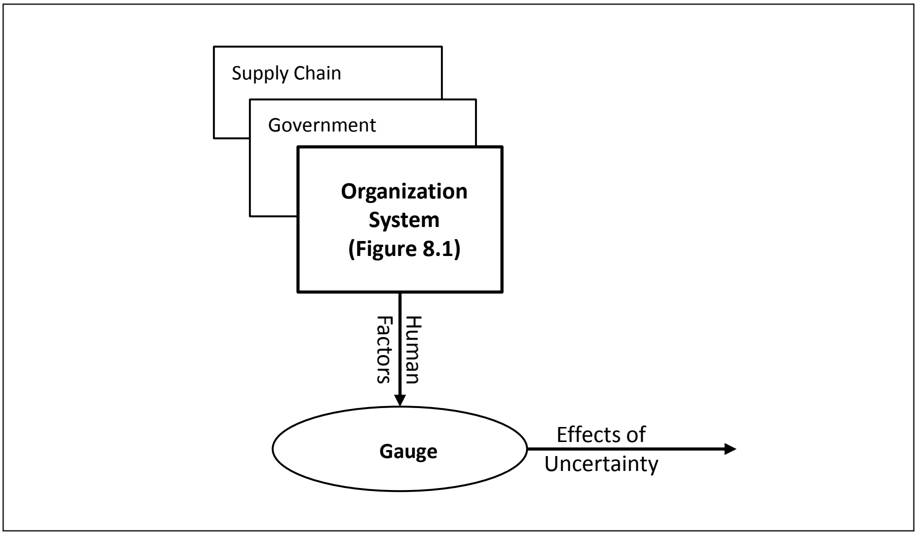

Figure 10.1 Human Factors provides a means to gauge uncertainty.

Third Generation

Third Generation PP&C will expand the content of program controls by adding information about uncertainty—as gauged by Human Factors—in order to produce more complete assessments of, and predictions for, program performance. The method for accounting for uncertainty driven by the complexity of the organization system (represented as Figure 10.1) are additive to Figure 5.2 PP&C Second Generation. This vision of PP&C Third Generation is shown as Figure 10.2.

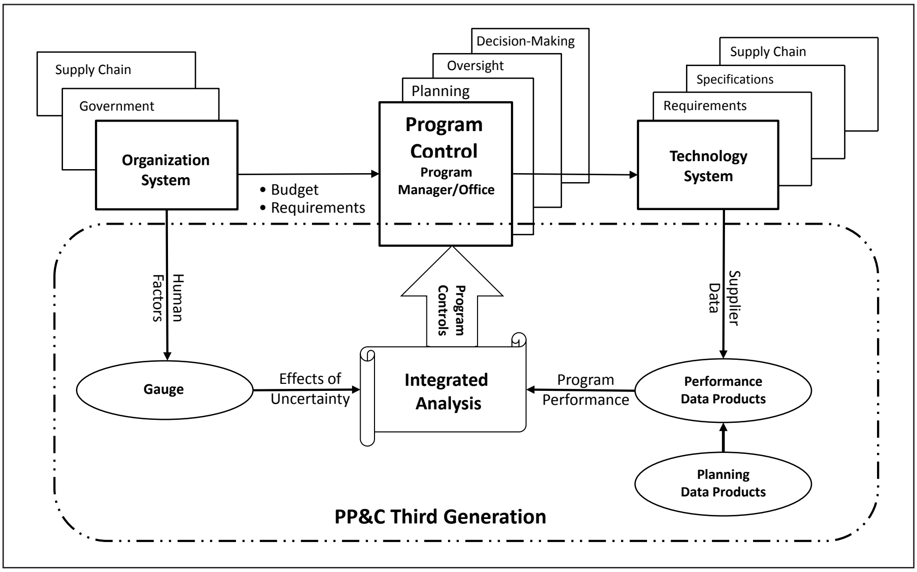

Figure 10.2 Model of the Third Generation PP&C.

Concluding Remarks

The monograph began with the observation that "words are important" and described common misrepresentations about performance management in major acquisition programs. It reviewed the perpetual struggles within federal agencies to complete major acquisition programs within baseline values for cost and schedule to develop a new technical capability.

Part I

Part I developed the observation that "scope is important" to identify limitations in performing common program management tasks using a traditional services-based approach. A history of continuing efforts to control cost and schedule growth was reviewed. A causal analysis was performed. Corrective action was defined, and a new approach for performing PP&C work was implemented. The effectiveness of corrective action to eliminate root cause is demonstrated by budget and cost data, management feedback and the results of audits.

PP&C: Program Controls

Corrective action addressed the structural component of root cause by providing Definition, Ownership, and Benchmark for PP&C work. PP&C Second Generation was established as a product-based systems approach for developing program controls. It was implemented. The experience of implementation is described in detailed to help others who might want to make the change. Similarly, work, data, and key personnel requirements are provided to facilitate use by others.

PPM: Program Control

Corrective action also addressed the management component of root cause by defining PPM as the union of program controls with program control. The new approach to program control added a review forum to perform integrated analysis, which is based on the notion of a three-dimensional "trade space" to manage performance and of a sound business case to create the knowledge that demonstrates cause for progressing throughout a life cycle with a high probability of success.[266]

Effectiveness

The job of PP&C is to position program management to be able to make sound decisions by providing the best available information on program performance and status. PP&C's value lies in its ability to provide data and information to program management that are correct, accurate, and consistent so that values and trends can be acted upon with confidence. Corrective action taken as measured by budget and cost data, manager feedback, and audit is effective in managing cause; proof of elimination of cause requires more observations over time. PP&C Second Generation is delivering value. According to Orion program management:

"That integrated assessment, essentially refining the data into more directly usable management-level information, can give situational awareness and forecasting assessment of what we know today,"[267] Marshall said.

Kirasich said, "The products we get today are much more meaningful, much more useful and helpful in helping me understand and steer the program. Also, I think we're doing it for a smaller percentage and certainly a much smaller absolute dollar value. So we're getting a much more functional, informed product for a lower cost." [268]

Geyer said, "I have a lot more confidence in the process that the team has now." He further described how Orion was able to brief NASA Headquarters on the PP&C paradigm shift: "I think it's helping the agency, so I think it's absolutely headed in the right direction." [269]

Part II

Part II developed the observation that "position is important" to explain how and why programs fail. It defined Human Factors as the fourth variable of program controls and is developing a methodology to gauge program status and to integrate it along with cost, schedule, and technical measurements into a more accurate portrayal of current and predicted program performance.

Complexity and Emergence

The complexity of major acquisition programs results from the extent of interdependencies, interrelationships, and interactions within and among the many organizations and operating environments comprising the supply chain needed to develop today's spaceflight systems. Analysis of data demonstrated that the PPM system is nonlinear and dynamic with multi-stability, meaning that small perturbations can lead to sudden change. An analytical model of emergence produced by research showed the effect quite clearly as program position relative to catastrophe: for similar values of performance, a program could be secure at one extreme, or in jeopardy—adjacent to a tipping point for catastrophic change—at the other. Program position along this range of uncertainty is a variable that needs to be included in calculations of program performance.

Human Factors

Program position can be gauged relative to past conditions that have resulted in failure. Using a Failure Modes and Effects Analysis approach, a methodology for analyzing cause of breakdown in program control leading to cost overruns and schedule delays, was postulated and assessed. Testing with data from documented breakdowns in major acquisition programs appears to validate the plausibility of the proposed approach. The methodology is termed Human Factors, and it is the fourth variable of program performance. The PP&C Third Generation will incorporate human factors as an input to program controls along with cost, schedule, and technical variables to improve predictions of future program performance.

Next Steps

This monograph has explored how a paradigm shift for performing common program management tasks provides better program controls at substantially reduced costs that also improved program control. Continuous improvement in the form of academic research is providing new knowledge and insights that offer the promise of even better program controls and more effective program control in the near future.

Chapter Endnotes

PREFACE

1 Office of Management and Budget, "Historical Tables," Table 4.2—Percentage Distribution of Outlays by Agency: 1962–2019, accessed May 13, 2014, *http://www.whitehouse.gov/omb/budget/Historicals/*.

2 Howard E. McCurdy, *Faster, Better, Cheaper: Low-Cost Innovation in the U.S. Space Program* (Baltimore: John Hopkins University Press, 2001), 83-84.

3 Howard E. McCurdy, *Faster, Better, Cheaper: Low-Cost Innovation in the U.S. Space Program* (Baltimore: John Hopkins University Press, 2001), 85-89.

4 "The James Webb Space Telescope," NASA, accessed May 13, 2014, *http://jwst.nasa.gov/about.html*.

5 Pertinent legislation is reviewed in Chapter 2

6 *Root Cause Analysis: Contract and Project Management* (Washington, DC: Department of Energy, 2008), 1-1, accessed May 13, 2014, *http://energy.gov/sites/prod/files/maprod/documents/RCA_Report_FINAL_April_2008%281%29.pdf*.

7 *Root Cause Analysis: Contract and Project Management* (Washington, DC: Department of Energy, 2008), 1-3, accessed May 13, 2014, *http://energy.gov/sites/prod/files/maprod/documents/RCA_Report_FINAL_April_2008%281%29.pdf*. Similarly, approximately 85 percent of the NASA budget is assigned to contractors.

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138 Elizabeth R. Mustain, interview by Rebecca Hackler, March 12, 2014, transcript, Orion PP&C History Project. In 2011 the Exploration Systems Mission Directorate merged with the Space Operations Mission Directorate to form the Human Exploration and Operations (HEO) Mission Directorate.
139 Elizabeth R. Mustain, interview by Rebecca Hackler, March 12, 2014, transcript, Orion PP&C History Project.
140 Cristina Guidi, interview by Rebecca Hackler, March 4, 2014, transcript, Orion PP&C History Project.
141 "Causal Analysis" (PowerPoint presentation, Orion Project Planning & Control Office, n.d.), 5, Multi-Purpose Crew Vehicle Program Office, Houston, TX.
142 Cristina Guidi, interview by Rebecca Hackler, March 4, 2014, transcript, Orion PP&C History Project. Guidi also noted that applying PP&C budget judiciously also allows more money to go towards the mission as opposed to overhead. See also Elizabeth R. Mustain, interview by Rebecca Hackler, March 12, 2014, transcript, Orion PP&C History Project.
143 One staff member opined that responsibility for PP&C would best be located even higher, at the agency level. Elizabeth R. Mustain, interview by Rebecca Hackler, March 12, 2014, transcript, Orion PP&C History Project.
144 Today's NASA has four mission directorates: Aeronautics Research, Science, Human Exploration and Operations, and Space Technology. Hence, that while there could be four 'different' PP&C instantiations each would be an implementation of common agency-level policy, requirements and procedure, and each would be consistent throughout its supply chain.
145 Based on today's NASA administration, the Administrator Staff Office of the Chief Engineer would be the "book manager" responsible for capturing, documenting, issuing and configuration controlling PP&C requirements and procedure.
146 Cristina Guidi, interview by Rebecca Hackler, March 4, 2014, transcript, Orion PP&C History Project. One employee expressed the concern that, "You can't really write that as a recipe," although it is useful to have the basic structure identified as a "point of departure." Daniel W. Mulligan, interview by Rebecca Hackler, March 12, 2014, transcript, Orion PP&C History Project.
147 "Orion PP&C: Learning Curve" (PowerPoint presentation, September 26, 2011), Part II, 8, Multi-Purpose Crew Vehicle Program Office, Houston, TX.
148 See the discussion on benchmarking found in James Smith, *Benchmarking Guidance: Templates, Documents and Examples of Benchmarking in the Public Domain* (Tebbo, 2006), 17-23.
149 Project Management Institute, *A Guide to the Project Management Body of Knowledge: PMBOK® Guide,* 4th ed. (Newton Square, PA: Project Management Institute, 2008), 197.
150 Cristina Guidi, interview by Rebecca Hackler, March 4, 2014, transcript, Orion PP&C History Project.
151 See for example National Research Council, *Progress in Improving Project Management at the Department of Energy: 2002 Assessment* (Washington, DC: National Academies Press, 2003), accessed May 16, 2014, *http://www.nap.edu/catalog/10679.html*.
152 "MSCI World Index," MSCI, accessed May 16, 2014, *http://www.msci.com/resources/factsheets/index_fact_sheet/msci-world-index.pdf*.

153 "S&P 500® - S&P Dow Jones Indices," McGraw Hill Financial, accessed May 16, 2014, *http://us.spindices.com/indices/equity/sp-500*.

154 Office of Management and Budget, "Memorandum to the Chief Financial Officers, Chief Operation Officers, Chief Information Officers, and Program Managers," OMB Circular A-123, December 21, 2004, accessed July 7, 2014, *http://www.whitehouse.gov/omb/circulars_a123_rev*.

155 Federal Managers Financial Integrity Act of 1982, Public Law 97-255, 97th Cong., 2d sess. (September 8, 1982), accessed July 7, 2014, *http://www.whitehouse.gov/omb/financial_fmfia1982*.

156 Government Accountability Office, *Standards for Internal Control in the Federal Government,* GAO/AIMD-00-21-3-1, November 1999, accessed May 16, 2014, *http://www.gao.gov/special.pubs/ai00021p.pdf*.

157 National Aeronautics and Space Administration Authorization Act of 2005, Public Law 109-155, 109th Cong., 1st sess. (December 30, 2005), accessed May 14, 2014, *http://www.gpo.gov/fdsys/pkg/PLAW-109publ155/pdf/PLAW-109publ155.pdf*; and "NASA Space Flight Program and Project Management Requirements," NASA Procedural Requirement 7120.5Em August 14, 2012, accessed May 14, 2014, *http://nodis3.gsfc.nasa.gov/displayDir.cfm?t=NPR&c=7120&s=5E*.

158 National Aeronautics and Space Administration Authorization Act of 2005, Public Law 109-155, 109th Cong., 1st sess. (December 30, 2005), §1122, accessed May 14, 2014, *http://www.gpo.gov/fdsys/pkg/PLAW-109publ155/pdf/PLAW-109publ155.pdf*

159 Drivers for the growth reported were prevalent and consistent making the results applicable to any major acquisition: 1) complexity of technology development, 2) reuse of heritage technology, 3) managing contractors, 4) managing Partners, 5) understanding risks and challenges, 6) stabilizing design, 7) funding issues, 8) launch issues, and 9) parts availability. Agency Enterprises and Mission Directorates should set expectations for them during the Formulation phase and monitor the status of each during the Implementation phase.

160 *Unless* it is assumed that PP&C is responsible for program performance; it is not.

161 Elizabeth R. Mustain, interview by Rebecca Hackler, March 12, 2014, transcript, Orion PP&C History Project.

162 These reflections of PP&C staff correspond almost exactly to observations Gary Cokins made in his 2009 book, *Performance Management*. Cokins claimed that one of the most important purposes of project management was "predictive analytics" that could help "anticipate problems earlier in the time cycle." Gary Cokins, *Performance Management: Integrating Strategy Execution, Methodologies, Risk, and Analytics* (Hobokon, NJ: John Wiley & Sons, 2009), 10. He observed that "organizations are shifting their management style from after-the-fact control … to an anticipatory management style," continuing, "Information is used for knowledge. At this stage, employees can know not only what happened and why it happened, but also what can happen next." Gary Cokins, *Performance Management: Integrating Strategy Execution, Methodologies, Risk, and Analytics* (Hobokon, NJ: John Wiley & Sons, 2009), 20-21.

163 Daniel W. Mulligan, interview by Rebecca Hackler, March 12, 2014, transcript, Orion PP&C History Project.

164 *A Review of NASA's Space Launch System: Hearing before the Committee on Science, Space and Technology, United States House of Representatives,* 112th Cong., 1st sess., July 12, 2011, accessed May 14, 2014, *http://www.nasa.gov/pdf/569239main_Bolden_2011_0712_HSSTfinalx.pdf*.

Chapter 5: PROGRAM PLANNING AND CONTROL

165 In addition to GAO and NASA IG audits, 1st, 2nd and 3rd party audits are used in and on the Orion Program. 1st party audits are the self-inspections used as part of continuous improvement to identify opportunity. 2nd party audits are performed by JSC for conformity with the JSC QMS and by Headquarters for conformity with management, engineering and safety requirements. 3rd party audits are performed by independent authorities as a condition of certification to industry consensus standards, such as ISO 9000 and AS9100.

166 Lucy V. Kranz, interview by Rebecca Hackler, March 21, 2014, transcript, Orion PP&C History Project. Note that Next Gen and Second Generation are synonyms with Second Generation being the more formal reference for the systems model of PP&C. Next Gen was used during transition for emphasis.

167 For more on the retreats see Lucy V. Kranz, interview by Rebecca Hackler, March 21, 2014, transcript, Orion PP&C History Project.

168 Rodney D. Young, interview by Rebecca Hackler, March 12, 2014, transcript, Orion PP&C History Project.

169 Lucy V. Kranz, interview by Rebecca Hackler, March 21, 2014, transcript, Orion PP&C History Project.

170 Mark S. Geyer and Mark A. Kirasich, interview by Rebecca Hackler, June 23, 2014, transcript, Orion PP&C History Project.

171 Paul F. Marshall, interview by Rebecca Hackler, April 15, 2014, transcript, Orion PP&C History Project.

172 Lucy V. Kranz, interview by Rebecca Hackler, March 21, 2014, transcript, Orion PP&C History Project. Until the Position Descriptions provided as Appendix D were provided to HR and implemented in Orion PP&C.

173 Lucy V. Kranz, interview by Rebecca Hackler, March 21, 2014, transcript, Orion PP&C History Project.

174 Rodney D. Young, interview by Rebecca Hackler, March 12, 2014, transcript, Orion PP&C History Project.

175 Rodney D. Young, interview by Rebecca Hackler, March 12, 2014, transcript, Orion PP&C History Project.

176 Rodney D. Young, interview by Rebecca Hackler, March 12, 2014, transcript, Orion PP&C History Project.

177 Lucy V. Kranz, interview by Rebecca Hackler, March 21, 2014, transcript, Orion PP&C History Project.

178 Mark S. Geyer and Mark A. Kirasich, interview by Rebecca Hackler, June 23, 2014, transcript, Orion PP&C History Project.

179 Lucy V. Kranz, interview by Rebecca Hackler, March 21, 2014, transcript, Orion PP&C History Project.

180 Paul F. Marshall, interview by Rebecca Hackler, April 15, 2014, transcript, Orion PP&C History Project.

181 Daniel W. Mulligan, interview by Rebecca Hackler, March 12, 2014, transcript, Orion PP&C History Project.

182 Daniel W. Mulligan, interview by Rebecca Hackler, March 12, 2014, transcript, Orion PP&C History Project.

183 Daniel W. Mulligan, interview by Rebecca Hackler, March 12, 2014, transcript, Orion PP&C History Project. Disciplines are identified in Figure 3.1.

184 Staff members who were familiar with and/or trained in the Project Management Body of Knowledge (PMBOK) noted that the reorganization into Next Gen PP&C followed the PMI principle of integration. Said one, "That's what project planning and control is—it's an integration function of all of these silos of data, to be able to answer questions at the project, program, and Agency level." Elizabeth R. Mustain, interview by Rebecca Hackler, March 12, 2014, transcript, Orion PP&C History Project.

185 Daniel W. Mulligan, interview by Rebecca Hackler, March 12, 2014, transcript, Orion PP&C History Project. Initially, the Performance Element was termed, "Monitor and Control before the import of the word Control was understood.

186 Elizabeth R. Mustain, interview by Rebecca Hackler, March 12, 2014, transcript, Orion PP&C History Project.

187 Daniel W. Mulligan, interview by Rebecca Hackler, March 12, 2014, transcript, Orion PP&C History Project.

188 Rodney D. Young, interview by Rebecca Hackler, March 12, 2014, transcript, Orion PP&C History Project.

189 Elizabeth R. Mustain, interview by Rebecca Hackler, March 12, 2014, transcript, Orion PP&C History Project.

190 Lucy V. Kranz, interview by Rebecca Hackler, March 21, 2014, transcript, Orion PP&C History Project.

191 Lucy V. Kranz, interview by Rebecca Hackler, March 21, 2014, transcript, Orion PP&C History Project.

192 Paul F. Marshall, interview by Rebecca Hackler, April 15, 2014, transcript, Orion PP&C History Project. Both Kranz and Marshall observed the parallels with the Space Station—another NASA program that had been cancelled or under threat of cancellation multiple times since its inception in 1984.

193 NASA JSC Solicitation: Multi-Purpose Crew Vehicle Integration Contract, Solicitation Number: NNJ12414367R, posted June 26, 2012, accessed May 19, 2014, *https://www.fbo.gov/spg/NASA/JSC/OPDC20220/NNJ12414367R/listing.html*. .

194 Lucy V. Kranz, interview by Rebecca Hackler, March 21, 2014, transcript, Orion PP&C History Project.

195 Lucy V. Kranz, interview by Rebecca Hackler, March 21, 2014, transcript, Orion PP&C History Project.

196 Elizabeth R. Mustain, interview by Rebecca Hackler, March 12, 2014, transcript, Orion PP&C History Project.

197 During the Formulation phase near-term is a month and long-term is end of fiscal year. During The Implementation phase near-term a milestone and long-term is the cost, schedule and technical values comprising the Program Baseline a.k.a. Agency Baseline Commitment.

198 Paul F. Marshall, interview by Rebecca Hackler, April 15, 2014, transcript, Orion PP&C History Project.

199 Mark S. Geyer and Mark A. Kirasich, interview by Rebecca Hackler, June 23, 2014, transcript, Orion PP&C History Project.

200 Lucy V. Kranz, interview by Rebecca Hackler, March 21, 2014, transcript, Orion PP&C History Project.

201 Lucy V. Kranz, interview by Rebecca Hackler, March 21, 2014, transcript, Orion PP&C History Project.

Chapter 6: PROGRAM PERFORMANCE MANAGEMENT

202 James Reason, *Managing the Risks of Organizational Accidents* (Burlington, VT: Ashgate, 1997): 63-64

203 David G. Carmichael*, Project Planning, and Control* (London: Taylor & Francis, 2006), 18, 213.

204 James P. *Lewis, Project Planning, Scheduling & Control: The Ultimate Hands-On Guide to Bringing Projects in On Time and On Budget,* 5th ed. (New York: McGraw-Hill, 2011), 16.

205 For example, implementing some form of goal setting theory including stretch goals: Edwin A. Locke et al., "Goal Setting and Task Performance: 1969 – 1980," *Psychological Bulletin* 90, no. 1 (1981): 125-152, accessed May 19, 2014, *http://datause.cse.ucla.edu/DOCS/eal_goa_1981.pdf*; Steven Kerr and Steffen Landauer, "Using Stretch Goals to Promote Organizational Effectiveness and Personal Growth: General Electric and Goldman Sachs," *Academy of Management Perspectives* 18, no. 4 (2004): 134-138.

206 Government Accountability Office, *DEFENSE ACQUISITION, Realistic Business Cases Needed to Execute Navy Shipbuilding Programs, Elements of a Business Case*, GAO-07-943T, July, 2007, p. 8, accessed September 10, 2014, *http://www.gao.gov/assets/300/294326.pdf*.

207 Government Accountability Office, *NASA: Constellation Program Cost and Schedule Will Remain Uncertain Until a Sound Business Case Is Established,* GAO-09-844, August 2009, p. 8, accessed May 14, 2014, *http://www.gao.gov/assets/300/294326.pdf*.

208 National Research Council, *Controlling Cost Growth of NASA Earth and Space Science Missions* (Washington, DC: National Academies Press, 2010), 5, accessed May 15, 2014, *http://www.nap.edu/catalog/12946.html*.

209 Government Accountability Office, *NASA: Constellation Program Cost and Schedule Will Remain Uncertain Until a Sound Business Case Is Established,* GAO-09-844, August 2009, 23-25, accessed May 14, 2014, *http://www.gao.gov/assets/300/294326.pdf*.

210 Bold and italics in the Table identify items GAO associates with the cause of cost and schedule growth in large-scale projects. For more see the "Benchmark" section in Chapter 3.

Chapter 7: EFFECTIVENESS

211 E-mail from Rodney D. Young, PP&C Planning Element Lead, September 8, 2014

212 The PP&C integrating contractor was incentivized to meet or exceed target value by attaching a fee to individual work orders. Orion PP&C operation includes a Process Improvement and Affordability Panel (PIAP) operated by the integrating contractor. The PIAP is a forum for making decisions to implement change in products and processes to reduce operating costs by continuously improving the performance of Orion PP&C.

213 E-Mail from Mary Kirby, resources management Office, September 8, 2014

214 "Orion PP&C: Learning Curve" (PowerPoint presentation, September 26, 2011), introductory material, Multi-Purpose Crew Vehicle Program Office, Houston, TX.

215 See Rodney D. Young, interview by Rebecca Hackler, March 12, 2014, transcript, Orion PP&C History Project and Daniel W. Mulligan, interview by Rebecca Hackler, March 12, 2014, transcript, Orion PP&C History Project.

216 Elizabeth R. Mustain, interview by Rebecca Hackler, March 12, 2014, transcript, Orion PP&C History Project.

217 Rodney D. Young, interview by Rebecca Hackler, March 12, 2014, transcript, Orion PP&C History Project.

218 Lucy V. Kranz, interview by Rebecca Hackler, March 21, 2014, transcript, Orion PP&C History Project.

219 Lucy V. Kranz, interview by Rebecca Hackler, March 21, 2014, transcript, Orion PP&C History Project.

220 Paul F. Marshall, interview by Rebecca Hackler, April 15, 2014, transcript, Orion PP&C History Project.

221 Lucy V. Kranz, interview by Rebecca Hackler, March 21, 2014, transcript, Orion PP&C History Project.

222 Paul F. Marshall, interview by Rebecca Hackler, April 15, 2014, transcript, Orion PP&C History Project.

223 Mark S. Geyer and Mark A. Kirasich, interview by Rebecca Hackler, June 23, 2014, transcript, Orion PP&C History Project.

224 International Standard ISO 9001, Fourth Edition 2008-11-15, Quality management systems – Requirements, Reference Number ISO 9001:2008(E)E; Aerospace Standard AS9100C, Quality management Systems – Requirements for Aviation, Space and Defense Organizations, SAE Aerospace, Revised 2009-01

225 The results of internal and external audits are maintained by JSC. Audit information is available from "External Audits," NASA Quality Management System (QMS), last modified June 13, 2014, accessed June 30, 2014, *http://qms.jsc.nasa.gov/index.cfm?event=auditexternalmeetingsandminutes*.

226 Mark S. Geyer and Mark A. Kirasich, interview by Rebecca Hackler, June 23, 2014, transcript, Orion PP&C History Project.

Part I: REMARKS

227 NASA requirements and handbooks are available on-line through the NASA On-line Directives Information System (NODIS) *http://nodis3.gsfc.nasa.gov/* NASA training programs are available through the Academy of Program/Project and Engineering Leadership (APPEL) *https://nen.nasa.gov/web/appel*, both accessed September 3, 2014

228 *Constellation Program Lessons Learned*, vol. 1: Executive Summary (Washington, DC: NASA SP-2011-6127-VOL-1, 2011), accessed May 27, 2014, *http://history.nasa.gov/SP-6127.pdf*.

229 From discussions on cost performance with MOCV Program Resource Management Office, September 25, 2014

230 The program level risk matrix combines prime with nonprime and with program risks; combination is possible without compromising data integrity or authority because each instantiation of risk management uses common rules for scoring and reporting results, including the status of mitigation.

231 *https://nasa-ice.nasa.gov/confluence/display/OrionPPC/Data+Dashboard*, accesses September 25, 2014

232 The cost number can be about half the amount cited depending on the scope of work included in PP&C beyond that needed to develop program controls and operate program control within a program's WBS.

233 Cristina Guidi, interview by Rebecca Hackler, March 4, 2014, transcript, Orion PP&C History Project.

Chapter 8: UNCERTAINTY

234 Henrik Jeldtoft Jensen writes that systems consisting of many interacting constituent parts may organize themselves into a state with a complex structure—complex in the sense that there is not just one time scale or one length scale that controls temporal evolution. Rather, these 'self-organizing' systems have the same kind of properties exhibited by equilibrium systems at the critical point. The dynamical response of such a system is complex and statistical properties are described by power laws (i.e. phase transitions). The cusp catastrophe model is a power law change; a sudden transition from one stable state to another stable state separated by a range of metastable states. Henrik Jeldtoft Jensen, "Introduction," in *Self-Organized Criticality: Emergent Complex Behavior in Physical and Biological Systems,* Cambridge Lecture Notes in Physics (Cambridge: Cambridge University Press, 1998), 1-6.

235 Julianne G. Mahler, with Maureen Hogan Casamayou, *Organizational Learning at NASA: The Challenger and Columbia Accidents,* Public Management and Change Series, ed. Beryl A. Radin (Washington, DC: Georgetown University Press, 2009).

236 Charles Perrow, *Normal Accidents, Living with High-Risk Technologies* (Princeton, NJ: Princeton University Press, 1999), p4 *http://www.hq.nasa.gov/office/codeq/doctree/87201.htm*;.

237 Sidney Dekker*, Drift into Failure, From Hunting Broken Components to Understanding Complex Systems* (Surrey, England: Ashgate Publishing Limited, 2011), p128

238 *Columbia Accident Investigation Board Report,* vol. 1 (Washington, DC: NASA, 2003), 6, accessed May 21, 2014, *http://history.nasa.gov/columbia/CAIB_reportindex.html*.

239 Melanie Mitchell, *Complexity: A Guided Tour* (New York: Oxford University Press, 2009); Michael J. Prietula, "Thoughts on Complexity and Computational Models," in *The SAGE Handbook of Complexity and Management,* ed. Peter Allen, Steve Maguire, and Bill McKelvey (Thousand Oaks, CA: Sage Publications, 2011), 93-110.

240 Organizations are inescapably bound up with the conditions of their environment; to understand the behavior of an organization you must understand the context of that behavior. Jeffrey Pfeffer and Gerald R. Salancik, *The External Control of Organizations: A Resource Dependence Perspective* (Stanford: Stanford University Press, 2002).

241 John H. Holland, *Emergence: From Chaos to Order* (Reading, MA: Addison-Wesley, 1998),121-122

242 Interviews conducted with aerospace contractors in 2011 revealed that work performed for the Government cost 30 to 40% more in non-recurring and 15% more in recurring costs than for similar work performed for commercial industry because of the NASA environment. H. Lawrence Dyer, "Affordability in the Orion-MPCV Program," January 3, 2012. Multi-Purpose Crew Vehicle Program Office, Houston, TX.

243 Christopher Goldspink and Robert Kay, "Emergence In Organizations: The Reflexive Turn," *Emergence: Complexity and Organization* 12, no. 3 (2010): 47-63; Barry W. Stevenson, "Developing an Awareness and Understanding of Self-Organization as It Relates to Organizational Development and Leadership Issues," *Emergence: Complexity and Organization* 14, no. 4 (2012): 69-85.

244 Jonathan Butner and Tom Malloy, discussions with author, April 24-25, 2014.

245 The word catastrophe is used as both an event and an outcome. As an event it is a sudden shift or a discontinuous change. As an outcome, it is a management failure due to a breakdown in program control that requires a program re-baseline as minimum or a program cancellation as maximum

246 Jonathan Butner et al., "Uncertainty in Cost Performance as a Function of the Cusp Catastrophe in the NASA Program Management System," *Journal of the Society for Chaos Theory in Psychology & Life Sciences* Volume 18, Number 4.

247 NASA JSC: Assessing Performance in Nonlinear Management Systems, Grant Number: NNX11AR71A, September 22, 2011. NASA Shared Services Center, Stennis Space Center, Mississippi.

248 Stephen J. Guastello, "Discontinuities and Catastrophes with Polynomial Regression," in *Nonlinear Dynamical Analysis for the Behavioral Sciences Using Real Data,* ed. Stephen J. Guastello and Robert A.M. Gregson (Boca Raton, FL: CRC Press, 2011), 251-280.

249 Jonathan Butner et al., *Assessing Performance in Nonlinear Management Systems: Final Report,* 2013, Multi-Purpose Crew Vehicle Program Office, Houston, TX; Jonathan Butner et al., "Uncertainty in Cost Performance as a Function of the Cusp Catastrophe in the NASA Program Management System," *Journal of the Society for Chaos Theory in Psychology & Life Sciences* Volume 18, Number 4.

250 For consistency, all risks in a program are scored using a common grid (i.e., 5 x 5 matrix) and common definitions for likelihood of risk occurrence and for consequence should that risk occur. Confidence levels are also based on common definitions and computational methodologies, and results expressed as a probability.

251 Al Moseley, "Program Success Metrics" (PowerPoint presentation, Defense Systems Management College – School of Program Managers, Defense Acquisition University, December 8, 2009), accessed May 23, 2014, *https://acc.dau.mil/CommunityBrowser.aspx?id=249513*.

Chapter 9: HUMAN FACTORS

252 Jonathan Butner et al., "Uncertainty in Cost Performance as a Function of the Cusp Catastrophe in the NASA Program Management System," *Journal of the Society for Chaos Theory in Psychology & Life Sciences* Volume 18, Number 4, October 2014.

253 As used, human factors has two meanings: 1) human factors is the name given to a variable, like cost, schedule and technical used to characterize program performance; 2) human factors is a discipline of psychology, the science of human behaviors. In Chapter 9, human factors is a variable. In Chapter 10, both meanings are used with distinction as human factors the discipline is unique to Phase II research now in progress.

254 "Failure Mode Effects Analysis (FMEA)," American Society for Quality (ASQ), accessed May 22, 2014, *http://asq.org/learn-about-quality/process-analysis-tools/overview/fmea.html*. Reliability and Maintainability assessments and Failure Mode and Effects Analysis are developed using engineering and safety methodologies and tools to identify events and sequence for operational failures of complex systems. They are used as input to both system design and development, and procedures for operations, including maintenance and sustaining engineering. NASA Reliability and Maintainability (R&M) Program Policy, NASA Policy Directive 8720.1C, April 18, 2008, accessed May 22, 2014,

255 James Reason, *Managing the Risks of Organizational Accidents* (Burlington, VT: Ashgate, 1997).

256 Douglas A. Wiegmann and Scott A. Shappell, *A Human Error Approach to Aviation Accident Analysis: The Human Factors Analysis and Classification System* (Burlington, VT: Ashgate, 2003).

257 James Reason, *Managing the Risks of Organizational Accidents* (Burlington, VT: Ashgate, 1997): 19.

258 Reproduced from DOD HFACS, "Department of Defense Human Factors Analysis and Classification System: A Mishap Investigation and Data Analysis Tool," January 11, 2005, accessed May 27, 2014, *http://www.public.navy.mil/comnavsafecen/Documents/aviation/aeromedical/HFAC/DOD_HF_Anlys_Clas_Sys.pdf*

259 The DRAFT nature of this product cannot be overemphasized as the work is preliminary and it will be reviewed and verified by continuing academic research performed by nonlinear dynamics and human factors experts whose work will then be peer reviewed and published. Prior to this level of validation, the assertion of a methodology for gauging the effects of uncertainty in Program Performance Management is hypothetical and its derivation and its application to major acquisition programs is preliminary and subject to correction.

260 Source Data for Plausibility

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Chapter 10: THIRD GENERATION

261 Jonathan Butner et al., *Assessing Performance in Nonlinear Management Systems: Final Report,* 2013, Multi-Purpose Crew Vehicle Program Office, Houston, TX; Jonathan Butner et al., "Uncertainty in Cost Performance as a Function of the Cusp Catastrophe in the NASA Program Management System," *Journal of the Society for Chaos Theory in Psychology & Life Sciences* Volume 18, Number 4, October 2014.

262 Multiple interviews with the Orion MPCV program manager indicated an awareness of relative position with regard to go/no go, or the extent of scrutiny and supervision to be expected based on perceptions of performance. Mark S. Geyer, interviews with author, March 2014.

263 Kenneth Craik, *The Nature of Explanation* (Cambridge: Cambridge University Press, 1943).

264 Mica R. Endsley, "Toward a Theory of Situation Awareness in Dynamic Systems," *Human Factors* 37, no. 1 (March 1995): 32-64, accessed May 28, 2014, *http://uwf.edu/skass/documents/HF.37.1995-Endsley-Theory.pdf*. See also Richard D. Gilson, "Special Issue Preface," *Human Factors* 37, no. 1 (March 1995): 3-4.

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CONCLUDING REMARKS

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Appendices

Appendix A: ACRONYMS

ABC	Agency Baseline Commitment
AS	SAE Aerospace Quality Standards
C/SCSC	Cost/Schedule Control Systems Criteria
CAM	Control Account Manager
CARD	Cost Analysis Requirements Description
CDR	Critical Design Review
CEV	Crew Exploration Vehicle
CMMI	Capability Maturity Model Integrated
COTR	Contracting Officer's Technical Representative
CRM	Continuous Risk Management
DCMA	Defense Contract Management Agency
DDT&E	Design, Development, Test and Evaluation
DOD	Department of Defense
DOE	Department of Energy
DRD	Data Requirements Description
EAC	Estimate At Completion
EFT	Exploration Flight Test
EM	Exploration Mission
ESD	Exploration Systems Development Division
ESMD	Exploration Systems Mission Directorate (Reorganized into HEOMD)
EVM	Earned Value Management
FMEA	Failure Modes and Effects Analysis
FY	Fiscal Year
GAO	Government Accountability Office
GFE	Government Furnished Equipment
GSDO	Ground Systems Development and Operations Program
GSFC	Goddard Space Flight Center

HEOMD	Human Exploration and Operations Mission Directorate
HF	Human Factors
HFACS	Human Factors Analysis and Classification System
IBR	Integrated Baseline Review
IFMP	Integrated Financial Management Program
IMCE	ISS Management and Cost Evaluation Task Force
IOC	Initial Operational Capability
IPC	Integrated Planning and Control
IPCE	Independent Program and Cost Evaluation Office
ISO	International Organization for Standardization
ISS	International Space Station
JPL	Jet Propulsion Laboratory
JCL	Joint Confidence Level
JSC	Johnson Space Center
JWST	James Webb Space Telescope
KDP	Key Decision Point
KSC	Kennedy Space Center
LCC	Life Cycle Cost
LRD	Launch Readiness date
MOPPR	MPCV Orion Program Performance Review
MPCV	Multi-Purpose Crew Vehicle
MPIC	MPCV Program Integrating Contractor
MSCI	Morgan Stanley Capital International
MSFC	Marshall Space Flight Center
NDS	Non-linear Dynamical Systems
NID	NASA Interim Directive
NPD	NASA Policy Document
NPR	NASA Procedural Requirements Document
NRC	National Research Council of the National Academies
OCE	Office of the Chief Engineer
OMB	Office of Management and Budget
OSF	Office of Space Flight (Reorganized into ESMD)
PD	Position Description
PDR	Preliminary Design Review

PL	Public Law
PMB	Performance Management Baseline
PMBOK	Project Management Book of Knowledge
PMI	Project Management Institute
POC	Point of Contact
PP&C	Program Planning and Controls
PP&C	Program Planning and Control
PPB&E	Program Planning, Budget and Execution
PPM	Program Performance Management
PRA	Probabilistic Risk Assessment
QMS	Quality Management System
QRA	Quantitative Risk Management
RFP	Request for Proposal
RIDM	Risk Informed Decision Making
S&MA	Safety and Mission Assurance
S&P	Standard & Poor
SAE	Society of Automotive Engineers
SE	Systems Engineering
SEI	Software Engineering Institute
SLS	Space Launch System
SRB	Standing Review Board
t	Time, when used as a subscript
TBD	To Be Determined
TMR	Technical Management Representative
ToR	Terms of Reference
TRL	Technology Readiness Level
UCA	Undefinitized Contract Action
WBS	Work Breakdown Structure

Appendix B: GLOSSARY

Glossary of words and terms used in writings about Program Planning and Control in major acquisition programs.

Descriptions

Descriptions reproduced from authoritative sources are bordered with quotation marks, and sources are identified in the endnotes.

Acquisition

The process used to gain possession of a new product or capability involving design, development, test and evaluation carried out over a defined life cycle.

Affordability

"Conducting a program at a cost constrained by the maximum resources the [organization] can allocate for the capability."[1]

Agency Baseline Commitment

"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."[2]

Assumption

A belief or condition forming a basis for end-state values that must be formally captured and documented at a program level. Assumptions, especially those made in the early phases of a program, affect the likelihood of achieving the technical outcome and staying within cost and schedule constraints.

Attractor

A piece of space with the special property that if an object gets too close, the object is pulled into it and does not leave it, except under special conditions.[3]

Baseline

"An agreed-to set of requirements, cost, schedule, designs, documents, etc. that will have changes controlled through a formal approval and monitoring process."[4] See also Program Baseline.

Baseline Attributes

Information about technical, schedule, and cost end-point values (Baseline) that is used by an enterprise or a program/project manager to manage performance. Attributes are controlled by management discretion (not by formal process), and they must be regularly reviewed for continuing applicability because, for example, an assumption about technology development—which is an attribute of a technical baseline element—that is no longer valid becomes a risk to future performance.

Baseline Performance Review (BPR)

"A monthly agency-level independent assessment to inform senior leadership of performance and progress toward the agency's mission and program/project performance. The monthly meeting encompasses a review of crosscutting mission support issues and all NASA mission areas."[5]

Behavior

Outcomes emerging from the interaction of a system and its environment and from local interaction between system participants and their environments. Each follows rules and exists without any central coordination.

Benchmark

A standard or point of reference used in measuring value or judging quality.[6]

Best Practices

Activities identified as best for the program: tailored from agency requirements and industry standards to ensure product integrity while minimizing overhead; directly associated with PP&C products and services; controlled by conformity with requirements of a quality management system, and continuously improved.

Breakdown in Program Control

Management failure that results in cost growth and overruns or schedule growth or delays sufficient to require congressional notification with concomitant action to re-baseline or cancel.

Business Rhythm

The time required for suppliers to capture and submit performance reports to a PP&C office, plus the time required for a PP&C office to process those data and report results to the program. Business rhythm can also refer to the frequency of reviews (i.e., weekly, monthly or quarterly) held with the program manager. Additionally, business rhythm can also refer to the elapsed time required to process a change to a contract or to an agreement.

Catastrophe

A term of reference in nonlinear dynamic systems analyses meaning "Sudden [shifts] and discontinuous changes in events."[7]

Cause

Sequence of events and interactions (pathways) that lead to outcomes that can be intended, unintended, or unexpected.

Complexity

An expression used to characterize something with many parts in a complicated arrangement of structured interactions. Many different actions and states interact so the effect of actions is difficult to assess. Characterized by the extent of interrelationships and interdependencies.[8]

Complicated

Consisting of parts that are intricately combined and therefore difficult to analyze, understand, or explain.

Contract Baseline

End-state values of cost and schedule constraints for the technical requirements written into a governing contract. Contract Baseline equals Program Baseline at the time a contract is issued but then lags the Program Baseline as work is performed in the Formulation phase of the life cycle. The contractor can perform only work that is both within the scope of work in the contract and authorized by the government.

Cost and Workforce Performance Reports

The results of an evaluation of actual resource expenditures (program's cost and workforce) compared to planned amounts for a consistent time period.

Cost Estimating
The process of approximating the cost of a program, programs, or operation. The cost estimate is the product of a cost estimating process.

Cost Overrun
A value in excess of a baseline value sufficient to require notification to a governing authority (e.g., PL 109-155 notification to Congress when cost equal or exceed baseline by 15% or more).

Critical Path
A path in a development schedule that has no float or slack and is the longest path through the project.[9]

Cusp Catastrophe
"A three-dimensional surface [that] features a two-dimensional manifold that describes two stable states of behavior. Change between the two is a function of control parameters, which can be smooth for one set of values and potentially discontinuous for other values."[10]

Decision Memorandum
"The document that summarizes the decisions made at KDPs or as necessary in between KDPs. The decision memorandum includes the Agency Baseline Commitment (if applicable), management agreement cost and schedule, UFE, and schedule margin managed above the project, as well as life-cycle cost and schedule estimates, as required."[11]

Design Readiness aka Design Stability
Design stability is a characterization of preparedness for production based on the extent of drawings, technical data, hardware and software documentation, production process, test and quality specifications, tools, test equipment, materials available for production. Measurements of stability could include: use of mass margin vs. planned use, use of power margin vs. planned use, number and status of change orders, and percent increase in post-CDR drawings.

Earned Value Management (EVM)
"A tool for measuring and assessing project performance through the integration of technical scope with schedule and cost objectives during the execution of the project. EVM provides quantification of technical progress, enabling management to gain insight into project status and project completion costs and schedules. Two essential characteristics of successful EVM are EVM system data integrity and carefully targeted monthly EVM data analyses."[12]

Emergence
Phenomena that can arise at the system level because of the interaction of participants working within a local environment, while also interacting at the same time with other participants working within their own environment, all operating together simultaneously in a common environment.

Environment (Organizational)
The aggregate of all of the external conditions and influences affecting the life, development and operation of an organization.

Error
Action failed to achieve its intended outcome; (organizational) the natural culmination of a series of events or circumstances (cascading) that invariably occurs in a fixed and logical order.

Failure aka management failure

Occurrence of one or more of overrun of cost, delay of schedule or compromise in capability (technical) in large-scale programs that develop new technology to the extent that stakeholder action is required to either terminate or rescue the program; any change in cost and/or schedule growth sufficient to require a report to congress and/or a re-baseline of cost, schedule and technical constraints; or any unfavorable Decision Memorandum at any one of the five Key Decision Points.

Failure Mode and Effects Analysis (FMEA)

Step-by-step approach for identifying all possible failures in a system. Mode is the way in which failure occurs. Effects analysis is studying the consequences of failures.

Feedback

Direction from program control to program controls (PP&C) based on an evaluation of the controls presented; direction from program control to a supply chain based on an evaluation of accomplishment and performance information provided; direction becomes input to a next cycle of performance review.

Feed forward

A pathway within a system that passes direction from an external authority to a subordinate organization that is expected to respond in a pre-defined way. In a feed-forward system, direction is based on implementation of government, corporate- or executive-level policies, requirements, and procedures for performing work on major acquisition programs.

Forecast (aka prediction)

Statements of alternative future performance based on extrapolations or projections of past and current values of Functional Data Products (trends).

Functional Data Products

Products that capture and report variance calculated by comparing actual, as reported by a program supplier, with planned performance for that function. Note: functional data products are historic and are applicable for the time period for which “actual” values were reported.

Governance

System of governing. Method used by government to exercise authority and control.

Heritage Content

Capitalized assets planned for re-use in implementing a major acquisition program. The costs of acquiring, constructing, improving, reconstructing, or renovating are program expenses. Assumptions regarding use such as availability, condition, function and operating environment which would impact cost, schedule, and required capability if incorrect, should be documented and managed as a risk to the program.

Human Error

Human error is a mental or physical activity of an individual that fails to achieve its intended outcome.

Human Factors

The term applied to the combination of the environmental factors organizational influences and institutional conditions along with the human behaviors for dealing with them; a way to gauge the effects of uncertainty because of the complexity of an organization system.

Independent Assessments

Characterizations of current and future performance developed by alternative methodologies such as identifying critical flight-product elements and subsystems, and tracking actual development compared to planned development developed by personnel applying their expertise impartially and without conflict of interest or inappropriate interference or influence.

Integrated Analysis

A characterization of current and future program level performance that informs management of threats and drivers for achieving the program baseline of 1) LCC and staying on annual budget, 2) LRD and maintaining schedule, and 3) IOC and preserving technical content.

Integrated Baseline Review (IBR)

"A risk-based review conducted by the program/project management to ensure a mutual understanding between the customer and supplier of the risks inherent in the supplier's PMB and to ensure the PMB is realistic for accomplishing all the authorized work within the authorized schedule and budget."[13]

Integrated Master Schedule (IMS)

"A logic network-based schedule that reflects the total project scope of work, traceable to the WBS, as discrete and measurable tasks/milestones and supporting elements that are time phased through the use of valid durations based on available or projected resources and well-defined interdependencies."[14]

Joint Cost and Schedule Confidence Level (JCL)

"(1) 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. (2) A process and product that helps inform management of the likelihood of a project's programmatic success. (3) A process that combines a project's cost, schedule, and risk into a complete picture. JCL calculations include the period from KDP C through the hand over to operations, i.e., end of the on-orbit checkout."[15]

Key Decision Point (KDP)

"The event at which a Decision Authority determines the readiness of a program/ project to progress to the next phase of the life cycle (or to the next KDP)."[16]

Latent Conditions

Underlying factors and organizational influences conducive to failure including: conditions that directly impact individual performance; conditions that directly impact team performance; and the compilation of surrounding things that impact individual and team performance. Latent conditions are the policy, rules and regulations imposed on persons performing work and exist at an institutional level.

Life Cycle

Pre-Phase A: Concept Studies; Phase A: Concept and Technology Development; Phase B: Preliminary Design and Technology Completion; Phase C: Final Design and Fabrication; Phase D: System Assembly, Integration & Test Launch & Checkout; Phase E: Operations & Sustainment; and Phase F: Closeout.[17]

Life Cycle Cost

The total of the direct, indirect, recurring, nonrecurring, and other related expenses incurred or estimated to be incurred over the design, development, verification, production, deployment, and mission operation and sustaining engineering of the life cycle.

Major Acquisition

Established by PL 109-155, a major acquisition is a program established by Congress that is of significant importance, costs (more than $250 million), or both; major acquisition programs are developed and operated in accordance with governing policy, requirements, and procedure over a lifecycle that spans years.

Manufacturing Complexity

A characterization of the degree of difficulty anticipated in producing flight product including materials, tooling, processing, etc., which could impact cost, schedule and required capability. Manufacturing is the industrial production of goods using labor and machines, tools, chemical and biological processing, in which raw materials are transformed into finished goods, which may be used for manufacturing other, more complex products. Complexity is a characterization of something with many parts in an intricate arrangement.

Margin

Reserves associated with schedule and technical resources.

Metric

The assignment of a number that communicates information about the measured status or performance of that object or event compared to planned or expected status or performance of that object or event for the time period when the measurement was taken.

Milestone

Scheduled event for the delivery of program products such as analyses, models, simulators, hardware and software deliveries, etc., that can be changed only by formal process.

Nonlinear Dynamical System (NDS)

"A general systems theory for describing, modeling, and predicting change that allows the possibility that small inputs at the right time can produce a dramatic impact and that large impacts at the wrong time can produce nothing at all, and that there are many possible patterns of change. NDS is a combination of mathematics, biology, physics, and social science."[18]

Organization System

"A hierarchical organization of organizations each comprised of multiple participants with individual, diverse agendas and environments, coordinating their actions so as to exchange information, act, and interact in a nonlinear and dynamical fashion to develop new technology."[19]

"Organizations are constructed as tools [and consume substantial resources. …] Organizational politics complicates the relation between technical needs for production and the actual distribution of resources. The resulting competition … is especially severe in times of contraction or decline. Because allocations within organizations spark intense political contests, organizational action depends on the history of prior allocations and on the nature of current political coalitions. Organizations develop lives of their own, with action at least partly disconnected from ostensible goals, from demands of relevant environments, and often from the intentions of organizational leaders."[20]

Owner/Ownership

The single authority (and person fulfilling that position of authority) accountable to upper management for the operation and performance of a function, product, or service assigned to that position by a recognized authority.

Performance Management Baseline (PMB)

"The time-phased cost plan for accomplishing all authorized work scope in a project's life cycle, which includes both NASA internal costs and supplier costs. The project'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 unallocated future expenses."[21]

Performance Measures

"The set of critical or key performance parameters that are monitored by comparing the current actual achievement of the parameters with that planned at the current time and on future dates. Used to confirm progress and identify deficiencies that might jeopardize meeting a system requirement. Assessed parameter values that fall outside an expected range around the anticipated values indicate a need for evaluation and corrective action."[22]

Probability of Program Success (PoPS)

DOD framework for assessing program health risk inclusive of program requirements, program resources, program planning and execution, and external influences comprising fit with (current) vision, program advocacy, and interdependencies.

Program

"A strategic investment by a mission directorate or mission support office that has a defined architecture and/or technical approach, requirements, funding level, and management structure that initiates and directs one or more projects. A program defines a strategic direction that the agency has identified as critical."[23]

Program Baseline

"The time-phased cost plan for accomplishing all authorized work scope in a program's life cycle, which includes both internal costs and supplier costs."[24]

Program Control

Decisions made and direction provided by a program manager to fulfill commitments made to the organization authorizing the program.

Program Controls

The planning and performance data and information used to inform program control.

Program Performance Management (PPM)

A system for 1) determining a program's actual status relative to its planned performance at any point in time, 2) assessing the probable impact of the current status on a) where the program <u>wants</u> to be in the near-term, b) where the program <u>needs</u> to be in the long-term, and 3) making decisions to fulfill commitments and achieve the required outcome.

Program Planning Budget & Execution (PPB&E)

The process NASA uses for "developing Agency Strategic Goals and performance plans, formulating the Annual budget, [and] developing fully executable agency Operating and Execution Plans … through the years of execution."[25]

Program Planning and Control (PP&C)

The name given to the body of multidisciplinary work performed under a single authority to fulfill a subset of a program manager's roles and responsibilities for producing the controls (data and information) that informs program control.

Project

"A specific investment identified in a program plan having defined requirements, a life-cycle cost, 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."[26]

Quality Management System (QMS)

A system of standards to direct and control an organization with regard to quality based on eight management principles: customer focus; leadership; involvement of people; process approach, systems approach to management; continual improvement; factual approach to decision making; and mutually beneficial supplier relationships.[27]

Requirement

The agreed upon need, desire, want, capability, capacity, or demand for personnel, equipment, facilities, or other resources or services by specified quantities for specific periods of time or at a specified time.[28]

Reserves

Amount set apart and kept back for future use or for a special purpose. Reserves are associated with budget.

Resource Baseline

The time-phased cost and schedule elements of a program baseline for accomplishing all authorized work scope throughout a defined life cycle including both internal costs and supplier costs.

Risk Management

"A structured, logical analysis methodology used for identifying and assessing risks in complex technological systems."[29]

"Risk management includes risk-informed decision making (RIDM) and continuous risk management (CRM) in an integrated framework. RIDM informs systems engineering decisions through better use of risk and uncertainty information in selecting alternatives and establishing baseline requirements. CRM manages risks over the course of the development and the implementation phase of the life cycle to ensure that safety, technical, cost, and schedule requirements are met."[30]

Risk Posture

A Performance Measure showing the relative ranking of risk item(s) that determines: "(1) what can go wrong, (2) how likely is it to occur, (3) what the consequences are, (4) what the uncertainties are that are associated with the likelihood and consequences, and (5) what the mitigation plans are."[31] PRA applies to S&MA, while QRA applies to budget and schedule.

Root Cause

An initiating cause of a causal chain that leads to an outcome or effect of interest. It is used to describe the depth in the causal chain where an intervention could reasonably be implemented to change performance and prevent an undesirable outcome.

Schedule Delay

A value in excess of a baseline value sufficient to require notification to a governing authority (e.g., PL 109-155 notification to Congress when schedule equals or exceeds the baseline by 6 months or more).

Sound Business Case

Term used by GAO to characterize the program data, information, and knowledge required to evaluate its capability to successfully fulfill commitments at the next level of a product development life cycle.[32]

Standing Review Board (SRB)

"The board responsible for conducting independent reviews (life cycle and special) of a program/project and providing objective, expert judgments to the convening authorities."[33]

SRB Terms of Reference (ToR) is "a document specifying the nature, scope, schedule, and ground rules for an independent review or independent assessment" performed by an SRB.[34]

Strategic Assessments

An analysis of technical, schedule, and cost "what-ifs" used to test assumptions, to determine the impact of alternatives on the programs execution, to isolate sensitivities, or to establish plans for dealing with contingencies (re-planning). The organization "learns" from strategic assessments and the knowledge gained feeds directly into tools and strategy for operations, and hence into the definition of the trade space used for performance management.

Supplier (includes Contractor)

An organization that provides product and services to a customer and may be a contractor, grantee, agency center performing organization, university, international partner, or another government agency. A contractor is a commercial entity having a mutually binding legal relationship obligating the seller to furnish the supplies or services and the buyer to pay for them.

Supplier Management

"A cross functional, proactive process for obtaining goods and services that features the active management and involvement of suppliers. Cross functional involves purchasing, engineering, supplier quality assurance and others working together as one team to further mutual goals. Instead of an adversarial relationship, supply management features longer-term, win-win relationships."[35]

Systems Thinking

A system is a group of interacting, interrelated, or interdependent elements forming a complex whole. "Systems thinking is a conceptual framework, a body of knowledge and tools….to make full patterns clearer and to help us see how to change them effectively."[36]

Technology Development/ Readiness Level

"A scale against which to measure the maturity of a technology. TRLs range from 1 (Basic Technology Research) to 9 (Systems Test, Launch and Operations)."[37] Typically, a TRL of 6 (i.e., technology demonstrated in a relevant environment) is required for a technology to be integrated into an SE process.

Technology System

A systems that is both interactive and tightly coupled composed of elements that interact in "complex [i.e., nonlinear] and hidden ways."[38] Coupling can include interaction between system components as well as between the system and system operators.

Trade Space

"The set of program and system parameters, attributes, and characteristics required to satisfy performance standards."[39] A three-dimensional environment in which the relative value and direction of cost, schedule, and technical performance are managed to achieve the required outcome.

Uncertainty

Not precisely determined. “uncertainties are not mistakes but rather are ambiguities caused by incomplete information.”[40]

Undefinitized Contract Action (UCA)

“A unilateral or bilateral contract modification or delivery/task order in which the final price or estimated cost and fee have not been negotiated and mutually agreed to by NASA and the contractor.”[41]

Violation

Willful disregard for governing rules and regulations.

Nuance

Controls Vs. Control

“Controls” is not the plural of the word “control.” “The two words in the context of social institutions have different meaning altogether. The synonyms for controls are measurement and information. The synonym for control is direction. Controls pertain to means; control to an end. Controls deal with facts; control deals with expectations. Controls are analytical, concerned with what was and is. Control is normative and concerned with what ought to be.”[42]

Complicated and Complex

The interdependencies, interrelationships, and interactions between a large number of component parts (or participants) comprising a system distinguish complicated from complex: in a complicated system the extent and nature of interrelationships (component parts) are known (linear) and outcomes can be predicted; in a complex system, the extent and nature of interdependencies, interrelationship, and interactions between components (part-operator interface, or participants) is not well known and outcomes are nonlinear and can be catastrophic.

Risk, Risk Management, and Uncertainty

A risk is means to account for known unknowns that can affect achievable performance.

Risk management is a process for identifying, evaluating and controlling those factors to avoid or mitigate negative effects.

To deal with unforeseen uncertainty or chaos, “managers need to go beyond traditional risk management; adopting roles and techniques oriented less toward planning and more toward flexibility and learning.”[43]

Supply Management, Supplier Management, and Procurement

“Supply management is a cross-functional, proactive process for obtaining goods and services that features the active management and involvement of suppliers.”[44] Supplier management features long-term, win-win relationships characterized by active management and involvement of suppliers. Procurement is the act of obtaining equipment, materials, or supplies by the government with appropriated funds following the Federal Acquisition Regulations, used by all federal executive agencies; relationships are defined by contract and monitored by active surveillance. Supplier management relationships are proactive; contract relationships are reactive.

Unforeseen uncertainty; Chaos; Aka (terms encountered)
– Unknown unknowns
– Execution Risk
– White Risk
– External Factors
– External Influences
– Wild Cards

Unforeseen uncertainty can occur in any program that pushes a technology envelope; it can arise from the unanticipated interaction of many events, each of which might, in principle, be foreseeable; and it can also be caused by spectacular out-of-the-blue events (black swan or catastrophe).

"Programs subject to chaos start out with unstable assumptions and goals; the basic structure of the plan is uncertain and often the program ends up with final results that are completely different from the original intent."[45]

Diagrams

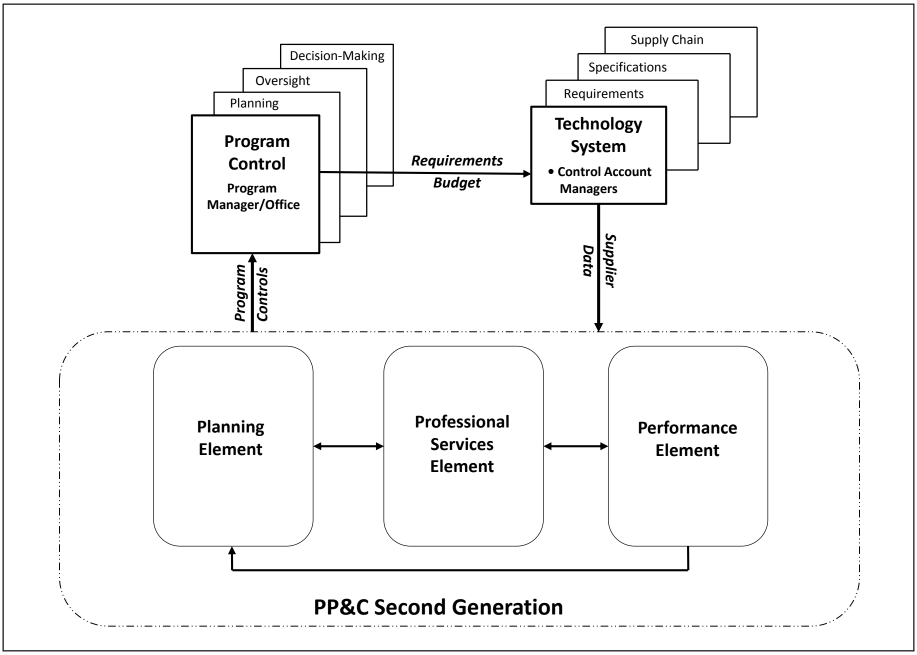

Figure B.1 Program Planning and Control.

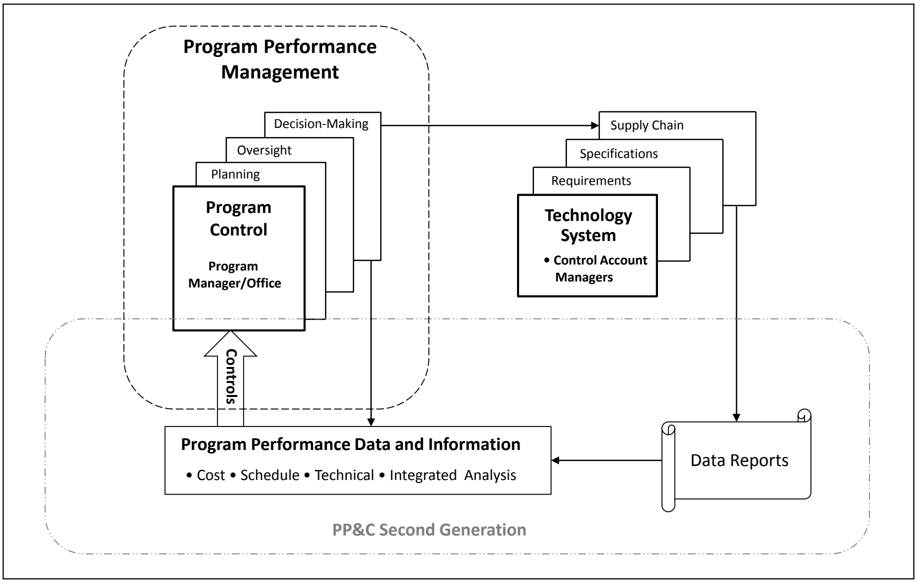

Figure B.2 Program Performance Management.

Appendix C: WORK AND DATA REQUIREMENTS

Work and Data Requirements for each of the three elements Planning, Performance and Professional Services of PP&C are documented below to facilitate implementation. As shown in Figure C.1, Planning and Performance elements share professional staff as the discipline skills and tools required to produce data products are common to both. However, the work performed by a discipline and the data products produced are unique to each element, as described below. Note that should Procurement be added to PP&C, it would be represented as a fourth element under the PP&C Office Manager. Work and data requirements for Procurement are not included.

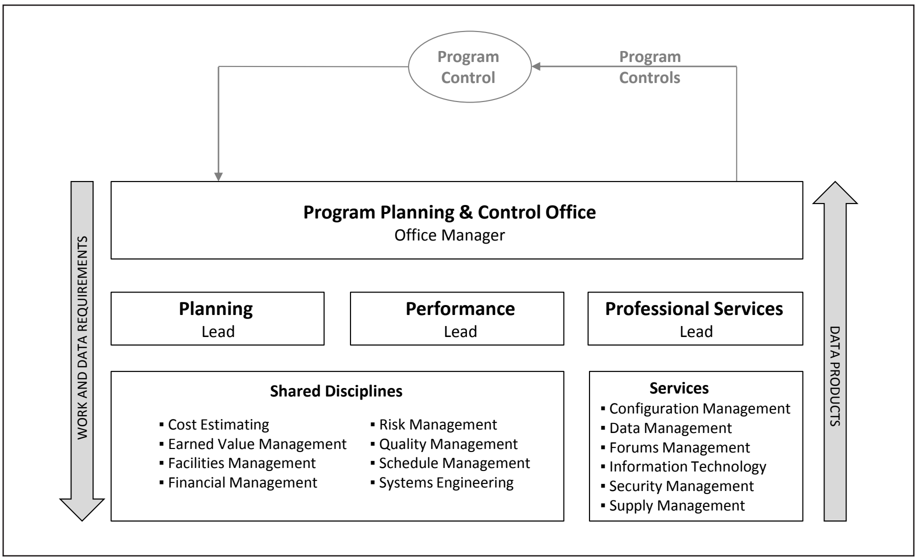

Figure C.1 PP&C work and data requirements.

Planning Element

Work Requirements

- Perform strategic assessments of program alternatives (i.e., what-ifs) and conduct trades studies.
- Monitor and manage planning element work.
  - Cost Estimating: Establish and maintain a cost estimating capability with Joint Confidence Level to assess program alternatives, change requests and risk mitigations, including but not limited to estimates at end of year, at completion and for life cycle costs; and verify cost estimates with analyses performed by parties independent of the work being validated and resolve discrepancies.
  - Earned Value Management: Establish and maintain the Performance Management Baseline used for EVM reporting and participate in Integrated Baseline Reviews (IBR) for the Prime contractor and for non-prime suppliers.
  - Facilities Management: Collect and integrate program facility requirements and technical capabilities at agency facilities. Work with technical points of contact to accurately and timely input program requirements into appropriate agency databases. Serve as the program's facilities and technical capabilities representative including responding to data inquiries and questions from external stakeholders.
  - Financial Management: Matrix function: capture budget and financial and workforce functional data products from the host center Resource Management Office.
  - Risk Management: Capture assumptions and risks associated with planning cost and schedule estimates; ensure assumptions are linked to an estimate of cost, schedule, readiness, or level of performance; and ensure risks are scored and have mitigation plans.
  - Quality Management: Serve as the program POC for the host center QMS; ensure that work instructions are developed and maintained; that management reviews are scheduled and conducted; and that controlled documents and records, including audit findings, corrective actions, and the minutes of management reviews are captured and managed.

  - Schedule Management: Establish and maintain a schedule planning capability with JCL to assess program alternatives, change requests, and risk mitigations including but not limited to key milestones and events for vehicle development, customer decision points and launch readiness; verify schedule estimates with analyses performed by parties independent of the work being validated; and resolve discrepancies.
  - Systems Engineering: Identify and capture technical attributes and planning information such as risks, assumptions, and quality of work product through participation in engineering review and change control forums and review of DCMA on-site audit reports.
- Prepare the annual PPB&E submission.
  - Obtain contractor input; direct the development, integration, and management of the plans and budgets for Government Furnished Equipment (GFE) and services; prepare submission in prescribed format for PP&C and program review; respond to comments; and prepare final package for submission.
- Develop, operate, and maintain the Planning Data Set in accordance with DRD.
- Participate in the development of technical, schedule, and cost planning products for enterprise-level activities.
- Continuously improve planning element work performance.
  - Establish objectives for work performance; incorporate industry best practice and consensus standards into work processes; measure and benchmark performance achieved; review results; and take action as required to achieve objectives and continuously improve.
  - Participate in management reviews of program and PP&C performance.
  - Conduct a management review of program and PP&C operational performance not less than twice per year; record minutes including list of participants and actions assigned; update scorecard; and provide results to host center QMS authority.

Data Requirements

The Planning Data Set is a logically singular repository of official planning information that is accessible by authorized program participants, including headquarters and the entire supply chain. The Planning Data Set operates on existing program information technology systems and operating environments. Individual items of content are linked from source into the Planning Data Set and not re-hosted. Copying of data and use of copied data is prohibited in order to preserve the integrity and authority of the source. Re-hosting can be accomplished only if initiated by its data authority and performed in accordance with a controlled procedure.

DRD P-01: Planning Data Set Content

- Strategic assessments
- Cost and schedule estimates with JCL
- Independent Assessments
- Program Baseline
    - Agency baseline
    - Contract baseline
    - Performance management baseline
- Program Baseline Attributes
    - Acquisition strategy
    - Assumptions
    - Budget
    - Execution strategy
    - Facility requirements
    - Interim milestones and events
    - Master schedule
    - Reserves
    - Risk matrix with mitigation plans
    - Schedule margin
    - Technical margin

- Controlled documents
  - Execution plan
  - Program plan
  - Vehicle requirements
  - Work breakdown structure and data dictionary
- Management Review results
  - Minutes
  - Scorecard

Performance Element

Work Requirements

- Monitor and manage Performance element work.
  - Cost estimating: Obtain and utilize cost estimates as necessary in assessments of program performance, including estimates from independent authorities.
  - Earned Value Management: Develop program-level earned value using data reported by the Prime contractor and resource reports provided by the government for suppliers of government furnished equipment; compare current with past performance; project future performance; and report results.
  - Facilities Management: Ensure the adequacy of facilities needed for performing integrated analysis through data sharing and collaboration of program and PP&C persons.
  - Financial Management: Matrix function– Capture supplier cost and workforce performance reports from the host center and supplier Resource Management Office and determine variance with plan.
  - Risk Management: Develop the program risk management process and support system required for managing top program risk; assess and report risk to program costs, schedule and technical performance including the continuing validity of assumptions; and maintain and report program top risk matrix.

  - Quality Management: Acquire and review DCMA audit reports of supplier quality and incorporate findings into functional data products, forecasts and integrated analyses.
  - Schedule Management: Determine schedule variances and discrepancies; track reported flight product development work accomplished per the integrated master schedule; analyze task durations for realism; and identify, assess and report discrepancies and impacts.
  - Systems Engineering: Obtain independent assessments of current and future program performance; perform an integrated analysis of program performance to characterize current status and threats to near-term and long-term future status; identify drivers; and report results to the program manager.
- Develop, operate, and maintain the Performance Data Set in accordance with DRD as the program repository for prime contractor, non-prime supplier and partner delivered data reports, PP&C Functional data products and the results of Integrated Analysis.
- Characterize current program performance.
  - Capture performance data reported by contractors, suppliers, and partners via the Professional Services Data Management function and store in the Performance Data Set.
  - Identify performance information in contractor, supplier, and partner briefings and presentations; extract technical, schedule and cost data; and input extracted information into the Performance Data Set.
  - Review and assess program and supplier assumptions about cost, schedule and technical performance and operating environment, and report variance.
  - Using data stored in the Planning Data Set and the Performance Data Set, develop technical, schedule and cost Functional data products in accordance with DRD.
- Forecast technical, schedule and cost performance.

- Perform an Integrated Analysis in accordance with the DRD to characterize current program performance and predict near-term and long-term future performance, identify threats and drivers, store results in the Performance Data Set, report results to the PP&C Office manager and inform the program manager of performance status and performance issues.
- Benchmark PP&C performance not less than twice per year by comparing program performance at a current time period with forecasts made previously for program performance for that same time period; identify variance; take action to improve PP&C operational performance; and present results at management reviews (see Planning element).
- Participate in the development of cost, schedule, technical and program performance measurement products for enterprise-level activities.
- Prepare data packages for agency program management reviews and for reviews by other organizations, as requested by the government.
- Continuously improve Performance element work performance.
  - Establish objectives for work performance; incorporate industry best practice and consensus standards into work processes; measure and benchmark performance achieved; review results and take action as required to continuously improve and achieve objectives.
  - Participate in management reviews of program and PP&C performance.

Data Requirements

The Performance Data Set is a logically singular repository of technical, schedule, and cost performance data and information that is accessible by all authorized program participants including headquarters and the entirety of the supply chain. The Performance Data Set operates on existing program information technology systems and operating environments. Individual items of content are linked into the Performance Data Set and not re-hosted from source. Copying of data and use of copied data is prohibited in order to preserve the integrity and authority of the source. Re-hosting can be accomplished only if initiated by its data authority and performed in accordance with a controlled procedure.

DRD PM-01: Performance Data Set Content

- Data obtained from supplier data reports
  - Earned value management reports
  - Financial and workforce reports
  - Integrated master schedule
  - Quality audit reports
  - Risk management reports
  - Technology readiness assessments
- Data obtained from mining
  - Assumptions
  - Cost issues
  - Execution plan
  - Schedule issues
  - Technical issues
- Performance Measures (See DRD PM-02)
- Integrated Analysis (See DRD PM-03)
- Data packages

DRD PM-02: Performance Measures

Performance measures are reports of current and forecast program-wide technical, schedule, and cost performance. Three separate characterizations of performance (functional data products, forecasts, and independent assessments) are developed as input to Integrated Analysis, DRD PM-03.

Functional data products capture and report variance calculated by comparing actual performance, as reported by a supplier, with planned performance for that discipline as represented by data in the Planning Data Set. Variance for an assumption is an assessment of its continuing viability along with an identification of impacts to program performance. Variance for risk is identification of any changes in technical, schedule, or cost risk, or in mitigation of those identified risks, since the last reporting period along with an assessment of impact. Functional data products are applicable only for the time period for which actual values were reported.

- Functional Data Products
  - Assumption validity assessments
  - Change management traffic
  - Cost variance assessments
  - Design maturity/stability assessments
  - Program earned value management reports
  - Quality assessment reports including nonconforming product
  - Risk management assessments
  - Schedule variance assessments
  - Technology readiness assessments
  - Workforce variance assessments
- Forecasts: Predictions of alternative future performance based on projections of past and current values of Functional data products (including trends).
- Independent assessments: Characterizations of current and future performance developed by independent authorities using alternative methodologies such as identifying critical flight-product elements and subsystems, and tracking actual development compared to planned development.

DRD PM-03 Integrated Analysis

Integrated Analysis is a near-real-time summary of current and forecast program performance in relation to planned values for technical, schedule, and cost at that time, commitment made to the agency, and planned outcomes. Results are stored in the Performance Data Set.

Integrated Analysis is performed collectively by PP&C Office persons in the Planning and Performance elements. Inputs are Planning data products, Functional Data Products, Forecasts and Independent Assessments. The output is a characterization of current and predicted future program performance that informs management of threats to 1) staying on budget, 2) maintaining schedule, 3) preserving technical content, and 4) achieving the program baseline. Results are presented to program management. Feedback to the PP&C Office provides input for continuous improvement.

Professional Services Element

Work Requirements

- Perform Configuration Management.
  - Perform configuration change control and configuration status accounting.[46]
- Perform Data Management.
  - Receive, track, monitor, report, validate, evaluate, distribute, and store program as well as contractor, supplier and international partner data, information and data-products delivered in accordance with contract and agreement requirements.
  - Identify, classify, archive, preserve, and destroy when appropriate the subset of information that comprises program records, in accordance with agency procedures.[47]
  - Serve as the program property custodian.
  - Serve as the program record's manager.
- Perform Forums Management.
  - Provide administrative services for planning, coordination, and execution of program meetings, such as control boards, panels, designated working groups, major program reviews, technical interchange meetings, ad hoc management meetings, action item tracking, and program-wide communications, including but not limited to meeting facilitation, scheduling, room and IT logistical setup, action tracking and recording, maintaining, and distributing meeting minutes.
  - Document and retain forum minutes as records.
- Perform Information Technology (IT) Management.
  - Utilize agency and center information resources, including service request forms.
  - Develop, manage and maintain the program office website(s).
  - Provide end-user IT assistance including issue resolution; work with agency and center teams to define and test program requirements; complete requests for products and services from agency and center IT contracts; install and maintain specialized software; review agency and center policy for impacts to the program; and document and communicate best practices for IT tools.

  - Administer the program risk management information system.
  - Manage the electronic equipment in program office's conference rooms and other locations.
  - Manage the property system applicable to the program.
- Perform Security Management.
  - Provide information technology security in conformity with agency policy and requirements.
  - Develop, maintain, and provide technology protection products.
  - Assess program documentation to determine sensitivity and appropriate markings for external distribution and use.
  - Implement export control for the program in accordance with agency policy, requirements, and procedure.[48]
  - Report security issues and incidents; track to resolution and improve program procedures to reduce incidents.
- Perform Supplier Management.
  - Establish supply agreements with participating organizations.
  - Participate in the establishment of supply agreements with international partners.
  - Interface with Procurement Office for contract administration.
  - Fulfill the Contracting Officer's Technical Representative (COTR) and Technical Management Representative (TMR) responsibilities for program suppliers; monitor supplier performance against plan for the delivery of procured products, evaluate the supplier's progress related to expenditures, and provide input into evaluation reports.[49]
- Participate in the development of enterprise-level professional services products for enterprise-level activities.
  - Develop and implement common information and data management processes and ensure that data integration throughout the enterprise is smooth and affordable.

- Continuously improve professional services element work performance.
  - Establish objectives for work performance; incorporate industry best practice and consensus standards into work processes; measure and benchmark performance achieved; and review results and take action as required to continuously improve and achieve objectives.
  - Participate in management reviews of program and PP&C performance.

Data Requirements

Professional Services performance metrics are reports quantifying both the level and quality of service provided and service-unique reports (e.g., security) identified by the government.

DRD PS-01, Professional Services Performance Metrics

- Level of use measurements
  - Configuration management
  - Data management
  - Change requests
  - IT services
  - Technology protection including export control
- Security reports
- Supplier Administration
  - Task Orders (for Procurement action)
  - UCA performance
  - Supplier agreements and amendments
  - Supplier performance evaluations

Appendix D: POSITION DESCRIPTIONS

Position descriptions for the PP&C Office manager and for the leads of each of the elements Planning, Performance and Professional Services are presented below. Leadership and major duties flow down from an agency's strategic plan through headquarters responsible organizations to the program manager. The program manager flows down agency requirements to program control account managers, including the PP&C Office manager. The PP&C Office manager flows down PP&C office manager requirements to the element leads. Major duties and qualifications for the four PP&C key positions are provided below. Note that should Procurement be added to PP&C, it would be represented as a fourth element under the PP&C Office Manager. A position description for the Procurement Lead is not included.

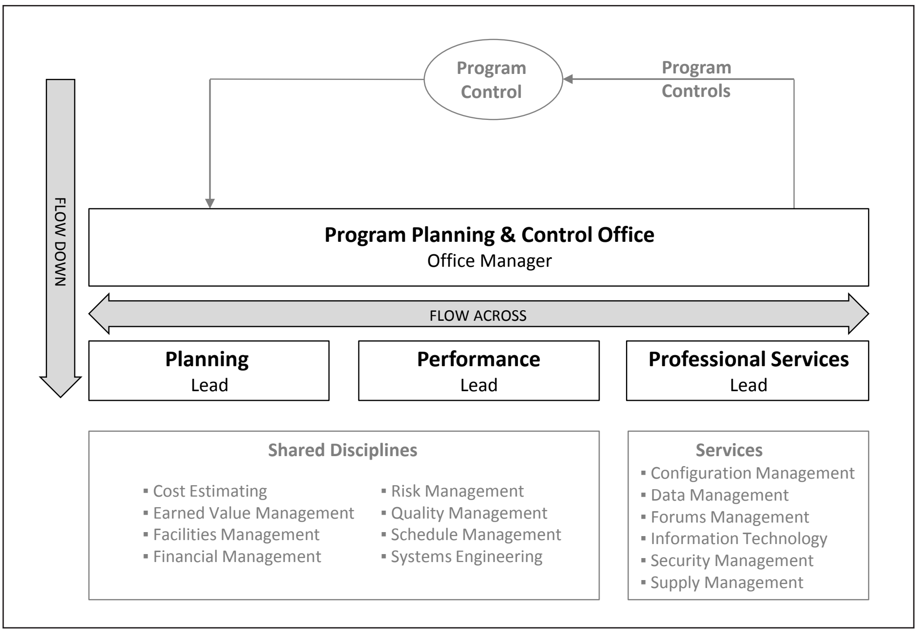

Figure D.1 PP&C key positions flow down from the program.

Office Manager

The PP&C Office manager is responsible for the development of program controls that are used to inform program control. The office manager assists program management in planning and executing the program in conformity with agency policy, requirements and procedure, and with commitments documented in decision memoranda and annual budget and execution plans.

Management Competencies

Develop and implement an organizational vision that aligns PP&C with program goals, priorities, values, and related factors. Assess and adjust to changing situations; implement innovative solutions to make organizational improvements ranging from incremental improvements to major shifts in direction or approach, as appropriate. Balance change and continuity; continually strive to improve service and program performance; create a work environment that encourages creative thinking, collaboration, and transparency; and maintain program focus, even under adversity.

- Oversee the implementation of PP&C in the program; facilitate similar change within the enterprise and its other programs, as requested.
- Establish career path for professionals performing PP&C work; provide training and mentoring.
- Develop and deliver guidance and training materials to facilitate implementation by interested parties.
- Design and implement strategies that maximize employee potential, and foster high ethical standards in meeting program's vision, goals, and major milestones. Provide an inclusive workplace that: fosters the development of others to their full potential; allows for full participation by all employees; facilitates collaboration, cooperation, and teamwork; and supports constructive resolution of conflicts. Ensure that employee performance plans are aligned with the agency and program goals and major milestones, that employees receive constructive feedback and that employees are realistically appraised against clearly defined and communicated performance standards. Hold employees accountable for performance and conduct. Seek and consider employee input. Recruit, retain, and develop the talent needed to achieve a high quality, diverse workforce that reflects the nation, with the skills needed to accomplish organizational performance

objectives while supporting workforce diversity, workplace inclusion, and equal employment policies and programs.

- Ensure position descriptions for civil servants performing in PP&C positions flow down from agency and program roles and responsibilities and are incorporated into annual employee performance evaluation plans.

Business Acumen

- Acquire, assess, analyze, and administer human, financial, material, and information resources in a manner that accomplishes program commitments. Use technology to enhance work and data product processes and facilitate decision making. Execute the operating budget; prepare budget requests with justifications; and manage resources.
- Implement affordability objectives and achieve efficiency in PP&C operations by improving work and data product processes through measurement, standardization and incorporation of best practices.

Build Coalitions

- Solicit and consider feedback from internal and external stakeholders or customers. Coordinate with appropriate parties to maximize input from the widest range of appropriate stakeholders to facilitate an open exchange of opinion from diverse groups and strengthen internal and external support. Explain, advocate, and express facts and ideas in a convincing manner and negotiate with individuals and groups internally and externally, as appropriate. Develop a professional network with peers in other organizations and identify the internal and external politics that affect the work of the organization.
- Take a lead position for the development and implementation of common PP&C work and data products throughout the organizational hierarchy.

Results Driven

- Maintain alignment of values for baseline cost and schedule with technical capability; maintain the integrity of the program baseline by controlling change; and maintain program management awareness of aligned values.
- Obtain Program annual budget and distribute funds to the program office and its supply chain.

- Ensure that strategic assessments of program and vehicle alternatives are performed and that independent estimates are used to verify the results of cost and schedule estimating.
- Direct the work performed by PP&C elements as a system of interdependent, interrelated and interactive elements and operate it for the effective production of program controls; and set PP&C performance objectives, benchmark performance and continuously improve PP&C products, services and work processes.
- Oversee the development of PP&C data products and the integration of those data products into program level assessments of current and future performance; utilize three-dimensional trade space to show alignment of cost, schedule, technical and strategy with commitments; inform program management; and work with program management to operate below thresholds of cost and schedule growth that trigger notifications to Congress.
- Ensure that program management review forums and control boards have the infrastructure and technical and administrative support necessary to perform their function.
- Conduct a management review of program and PP&C operations not less than twice per year; document results and retain as records.

Planning Element Lead

The element lead is responsible for the development and delivery of PP&C planning data products and for the utilization of those products in assessing current and future program performance.

Major Duties

- Apply critical and appropriate judgment, decision-making and strategies to organizational, and interpersonal issues; obtain relevant information and diverse opinions before making a decision; make decisions even when solutions may have unpleasant consequences; work to build trust and supportive relationships; and manage self in a manner that fosters learning and high performance.
- Implement PP&C Planning element, set goals and objectives for operational performance, measure and monitor performance, and ensure goals and objective are realized.

- Actively lead the team to achieve program and PP&C goals and objectives; recruit, retain, and develop the talent needed to produce planning data products; ensure that employee PDs are aligned with agency and program roles and responsibilities; flow down element work into employee annual performance plans; and manage work, monitor performance and provide feedback.
- Place people in positions that fully utilize their skills and abilities.
- Manage the work load of disciplines shared with PP&C performance element.
- Select and use information technology appropriate to the work that needs to be performed.

Business Acumen

- Understand and respond to policies and plans that impact the PP&C Planning element and program performance; understand and leverage the impact of the informal culture and the way that work is really accomplished; build and maintain relationships to fulfill the needs of customers and stakeholders and ensure that processes are put in place to achieve planned results and that human, financial, physical, and administrative resources are effectively utilized and managed.
- Manage work and make decisions; establish priorities; involve Planning element staff in work planning; delegate authority; use best practices; monitor work on a regular basis; manage risk; hold self and others accountable for results.
- Capture and share knowledge gained for use by others.

Discipline Competency

- Maintain a high-level of competency in program planning; sustain and grow the capability of the team to advance excellence; communicate and advocate discipline-related knowledge; and assure that the planning element's goals and objectives are achieved in a timely and effective manner.
- Manage the work performed by disciplines to develop planning data products in accordance with DRD.
- Obtain independent assessments of cost and schedule performance and use them to validate planning data products.

- Ensure Planning element data products are captured in the Planning Data Set.
- Serve as the Risk Assessment Lead for the Program overseeing both quantitative and qualitative risk analysis processes (may be performed by either the Planning element lead or the Performance element lead).
- Work with Performance element to perform an integrated analysis of program performance and report results to the PP&C Office manager.
- Prepare data packages for agency program management reviews and for use by other authorities, as requested by the government.
- Collaborate with counterparts within the enterprise to perform planning work and participate in the development of enterprise-level planning products.
- Incorporate best practices into work processes; measure performance against objectives and continuously improve efficiency and effectiveness; and participate in management reviews of program and PP&C operations.

Core Qualifications

- Professional knowledge of the principles and practices of program planning.
- Extensive knowledge of the principles, practices, methodologies, and tools of the disciplines involved with planning work:
  - Cost estimating with JCL
  - Earned value management
  - Facilities management
  - Financial management
  - Quality management
  - Risk management
  - Scheduled management
- Working knowledge of agency's policy and procedural requirements for program management, federal government operations, especially the funding and budget process.
- Demonstrated ability to work effectively and efficiently with program, center, and headquarters personnel and with international partners.
- Demonstrated ability to gather and organize data, to provide presentations for program management, and to communicate orally and in writing.

Performance Element Lead

The element lead is responsible for the development and delivery of PP&C performance data products. The lead is also responsible for the development and delivery of the program controls, comprising both planning and performance information, used to inform program management.

Major Duties

- Apply critical and appropriate judgment, decision-making, and strategies to organizational and interpersonal issues; obtain relevant information and diverse opinions before making a decision; make decisions even when solutions may have unpleasant consequences; work to build trust and supportive relationships; and manage self in a manner that fosters learning and high performance.
- Implement PP&C Performance element, set goals and objectives for operational performance, measure and monitor performance, and ensure goals and objective are realized.
- Actively lead the team to achieve program and PP&C goals and objectives; recruit, retain, and develop the talent needed to produce performance data products; ensure that employee PDs are aligned with agency and program roles and responsibilities; flow down performance element work into employee annual performance plans; and manage work, monitor performance and provide feedback.
- Place people in positions that fully utilize their skills and abilities.
- Manage the work load of disciplines shared with the PP&C Planning element.
- Select and use information technology appropriate to the work that needs to be performed.

Business Acumen

- Understand and respond to policies and plans that impact the PP&C Performance element and program performance; understand and leverage the impact of the informal culture and the way that work is really accomplished; build and maintain relationships to fulfill the needs of customers and stakeholders and ensure that processes are put in place to achieve planned results and that human, financial, physical, and administrative resources are effectively utilized and managed.

- Manage work and make decisions; establish priorities; involve Performance element staff in work planning; delegate authority; use government and industry best practices wherever possible; monitor work on a regular basis; manage risk; and hold self and others accountable for results.
- Capture and share knowledge gained for use by others.

Discipline Competency

- Maintain high-level competency in systems engineering and performance management; sustain and grow the capability of the team to advance excellence; communicate and advocate discipline-related knowledge; and assure that the Performance element's goals and objectives are achieved in a timely and effective manner.
- Manage the work performed by disciplines in developing Performance element data products.
- Ensure Performance element data products are captured in the Performance Data Set.
- Serve as the Risk Assessment Lead for the Program overseeing both quantitative and qualitative risk analysis processes (may be performed by either the Planning element lead or the Performance element lead).
- Develop predictions of program performance utilizing Performance element data products and independent assessments; report results to the PP&C Office manager; and participate in management forums that inform the program manager of performance and performance issues.
- Prepare data packages for agency program management reviews and for use by other authorities, as requested.
- Collaborate with counterparts within the enterprise to perform performance assessment work and participate in the development of enterprise-level performance products for program-to-program activities.
- Incorporate best practices into work processes; measure performance against objectives and continuously improve operational performance; and participate in management reviews of program and PP&C operations.

Core Qualifications

- Professional knowledge of the principles and practices of systems engineering & integration, and program performance management.

- Extensive knowledge of the principles, practices, methodologies and tools of the disciplines involved with performance measurement:
  - Cost estimating with JCL
  - Earned value management
  - Facilities management
  - Financial management
  - Quality management
  - Risk management
  - Scheduled management
- Working knowledge of agency policy and procedural requirements for program management, federal government operations, especially the process for reviewing and evaluating agency performance in managing major acquisition programs.
- Demonstrated ability to work effectively and efficiently with program, center, and headquarters personnel and with international partners.
- Demonstrated ability to gather and organize data, to provide presentations for program management, and to communicate orally and in writing.

Professional Services Element Lead

The element lead is responsible for providing the program's infrastructure for data and information exchange and for delivering the professional services required to operate and maintain it.

Major Duties

- Apply critical and appropriate judgment, decision-making and strategies to organizational and interpersonal issues; obtain relevant information and diverse opinions before making a decision; make decisions even when solutions may have unpleasant consequences; work to build trust and supportive relationships; and manage self in a manner that fosters learning and high performance.
- Implement PP&C Professional Services element, set goals and objectives for operational performance, measure and monitor performance, and ensure goals and objective are realized.

- Actively lead the team to achieve program and PP&C goals and objectives; recruit, retain, and develop the talent needed to operate an infrastructure and deliver professional services; ensure that employee PDs are aligned with agency and program roles and responsibilities; flow down element work into employee annual performance plans; and manage work, monitor performance and provide feedback.
- Place people in positions that fully utilize their skills and abilities.
- Provide information technology appropriate to the work that needs to be performed.

Business Acumen

- Understand and respond to policies and plans that impact the Professional Services element; understand and leverage the impact of the informal culture and the way that work is really accomplished; build and maintain relationships to fulfill the needs of customers and stakeholders and ensure that processes are put in place to achieve planned results and that human, financial, physical and administrative resources are effectively utilized and managed.
- Manage work and make decisions; establish priorities; involve element staff in work planning; delegate authority; use best practices; monitor work on a regular basis; manage risk; and hold self and others accountable for results.
- Capture and share knowledge gained for use by others.

Discipline Competency

- Maintain high-level competency in each of the professional service disciplines provided to the program; sustain and grow the capability of the team to advance excellence; communicate and advocate discipline-related knowledge; and assure that the element's goals and objectives are achieved in a timely and effective manner.
- Provide professional services to the program.
- Provide and operate a logically singular infrastructure for sharing data and information throughout program participant and supplier organizations.

- Incorporate best practices into work processes; measure performance against objectives and continuously improve efficiency and effectiveness; and participate in management reviews of program and PP&C operations.

Core Qualifications

- Professional knowledge of the principles and practices of:
  - Configuration management
  - Computer engineering
  - Data management
  - Information technology
- Extensive knowledge of the requirements, standards and practices, and tools for performing:
  - Configuration status accounting
  - Records management
  - Data engineering
  - Export control
  - Networks
  - Relational database management
  - Security
  - Supply management
  - Technology protection
  - Web design
- Demonstrated ability to establish and manage a network of heterogeneous information technology systems in large-scale, geographically distributed programs that preserves data integrity.
- Demonstrated ability to work effectively and efficiently with program, center, and headquarters personnel, and with international partners.
- Demonstrated ability to gather and organize data, to provide presentations for program management, and to communicate orally and in writing.

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13. ABSTRACT *(Maximum 200 words)*

Program Planning and Control In Major Acquisition Programs describes common misrepresentations about performance management in major acquisition programs. It reviews the perpetual struggles within federal agencies to complete major acquisition programs within baseline values for cost and schedule to develop a new technical capability. Part I develops the observation that “scope is important” to identify limitations in performing common program management tasks using a traditional services-based approach. A history of continuing efforts to control cost and schedule growth is reviewed. A causal analysis is performed. Corrective action is defined, and a new approach for performing Program Planning and Control work is implemented. Part II develops the observation that “position is important” to explain how and why programs fail. It defines Human Factors as the fourth variable of program controls and is developing a methodology to gauge program status and to integrate it along with cost, schedule, and technical measurements into a more accurate portrayal of current and predicted program performance. This monograph explores how a paradigm shift for performing common program management tasks provides better program controls at substantially reduced costs that also improved program control.

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