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ACCURACY . PRECISION . COST UNCERTAINTY

in the Context of Budget Estimation

Estimating cost at the beginning of a project is like throwing darts at a moving dartboard from a mile away.

We may end up "close" to the bullseye, but seldom actually land there.

This is because we are using statistically derived models with uncertain technical variables to estimate the cost of a static design.

Impossible to perfectly identify everything that will happen during the development process that will impact cost, such as technical changes, test failures, accidents, and other foreseeable risks (known unknowns), but we should expect some of them to occur.

ACCURACY

Describes how close or distant an observation lies from its target value. An accurate observation is one that lies relatively close to its target. For example, an accurate cost estimate is one that predicts the true cost with a small degree of error.

PRECISION

Refers to the degree of granularity of an observation. For example, a precise cost estimate is one that can be expressed down to the nearest dollar, whether it accurately predicts the true cost or not.

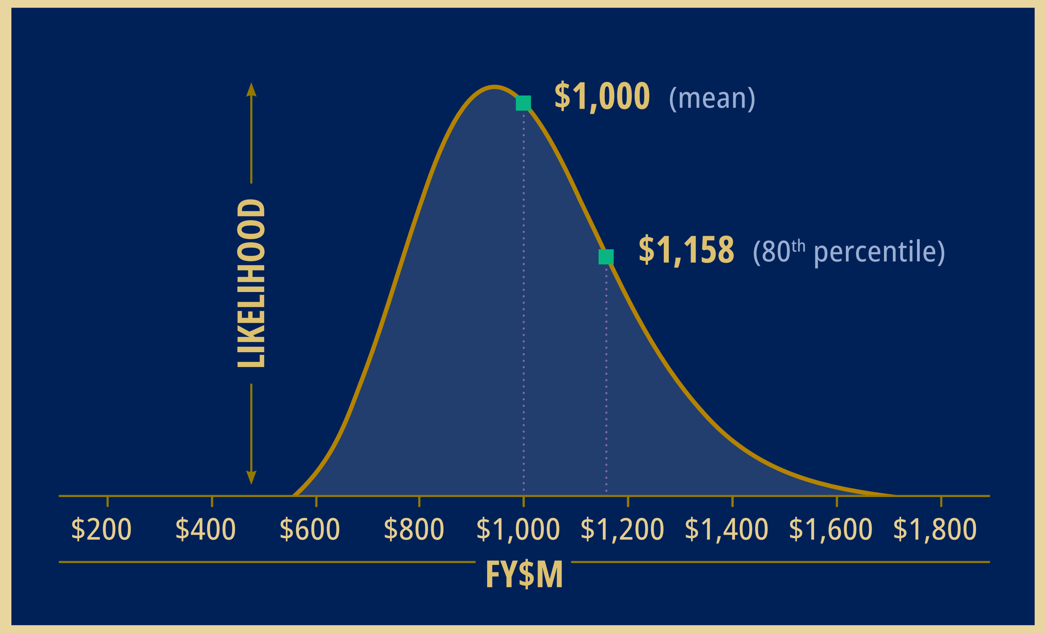
GENERAL CONCEPT DEPICTIONS OF ACCURACY AND PRECISION

HIGH ACCURACY HIGH PRECISION | LOW ACCURACY HIGH PRECISION | HIGH ACCURACY LOW PRECISION | LOW ACCURACY LOW PRECISION

UNCERTAINTY

Refers to the general indefiniteness about the outcome of a situation. For example, in cost estimating, will the predicted cost be higher or lower than the actual cost? Uncertainty can be found in the technical characteristics of the cost element as well as the cost estimating methods, which can include *engineering buildup*, *parametric analysis*, *analogy adjustment*, or *expert opinion*.

COST PROBABILITY DISTRIBUTION EXAMPLE



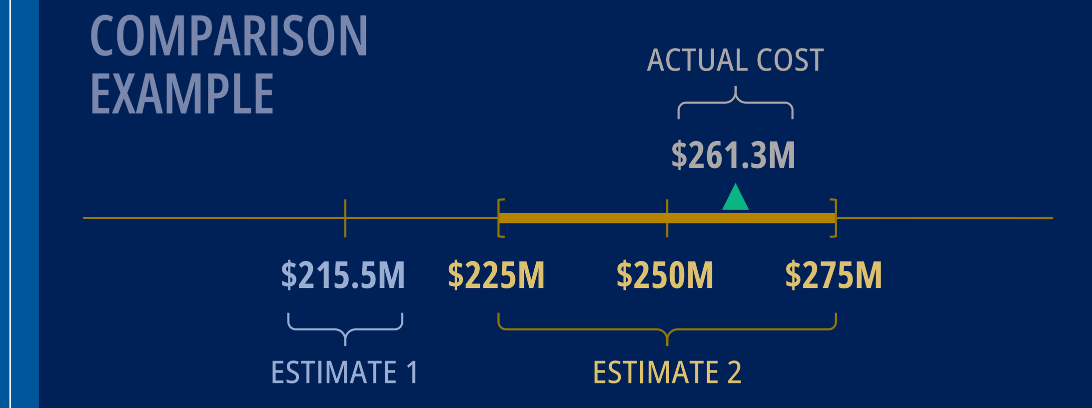
The Cost Distribution describes the uncertainty of the estimate when variation in underlying cost elements is considered. In this example, the cost estimate has a mean of $1,000M, standard deviation of $200M, and 80th percentile of $1,158M.

What it means: The cost estimate is uncertain, depending on variability in technical assumptions such as size, weight, power, rates, etc. In this case, the cost is most likely to be somewhere near $1,000M ± $200M, but depending on variability in assumptions could be as low as $600M or as high as $1,700M (or anywhere in between).

ACCURACY VS. PRECISION — IT IS ALWAYS BETTER TO BE ACCURATE THAN PRECISE

When estimating the cost of a major acquisition, it is impossible to accurately factor in every event, mishap, test failure, labor rate, airfare, inflation rate, etc. Moreover, the basis of estimate (BOE) has inherent uncertainty.

COMPARISON EXAMPLE



This image illustrates accuracy vs. precision for a cost estimate. Estimate #1 is fairly precise (nearest $100K) and is represented as a point estimate with no uncertainty, while estimate #2 is less precise (nearest $M) and is represented with uncertainty bounds. If the actual cost is $261.3M, then estimate #2 was the more accurate estimate despite being less precise than estimate #1.

EXAMPLES OF SOURCES TO CONSIDER WHEN DEALING WITH UNCERTAINTY

COST ELEMENT TYPES

- Level of Effort
- Equipment / Hardware
- Software

TECHNICAL CHARACTERISTICS

- Labor Hours / Rates
- Weight / Dimensions
- Software Lines of Code

NSF TOOLS AVAILABLE TO ADDRESS COST UNCERTAINTY

- Allowances: Most Likely Cost for Known but As-of-Yet Undefined Requirements *(in baseline)*
- Contingencies: Budget | Schedule | Scope
- Reserves: Management Reserve *(only for Major Facility Construction)* — MREFC; Funding Held by the NSF Program *(for all other projects/programs)* — R&RA

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MID-SCALE RESEARCH INFRASTRUCTURE
at the National Science Foundation

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Mid-scale RI is an "enabling" Big Idea that implements agile mechanisms for funding experimental research capabilities costing between $6.0 million and $100.0 million. The Mid-scale Research Infrastructure program is an NSF-wide effort to meet the research community's needs for modern research infrastructure to support priority science and engineering research.

Scan this code for the
NSF'S 10 BIG IDEAS FOR MID-SCALE RESEARCH INFRASTRUCTURE

A Few Bits of History

Scan this code for the
BRIDGING THE GAP: BUILDING A SUSTAINED APPROACH TO MID-SCALE RESEARCH INFRASTRUCTURE AND CYBERINFRASTRUCTURE AT NSF

The scientific importance of mid-scale research infrastructure is reflected in the 2017 American Innovation and Competitiveness Act (AICA), which directed NSF to "evaluate the existing and future needs, across all disciplines supported by the Foundation, for mid-scale projects.

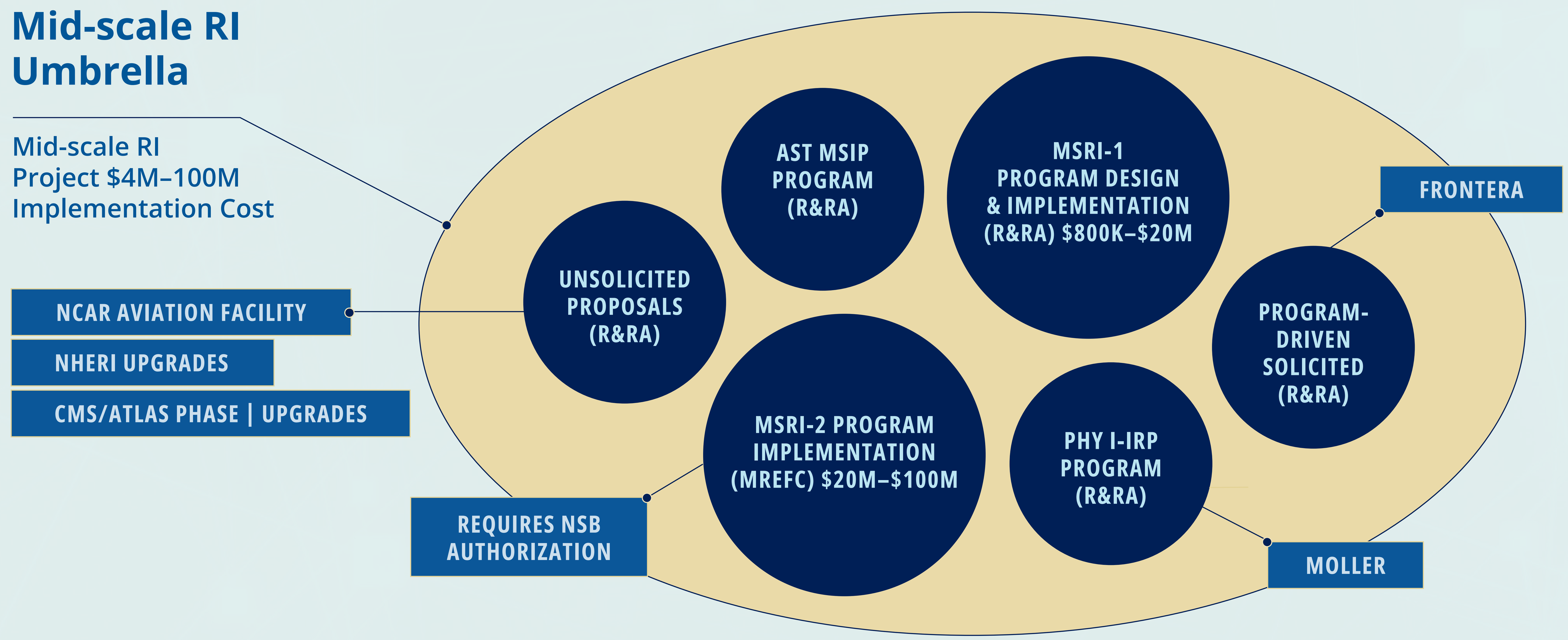
In the 2018 appropriation for NSF, report language from the House of Representatives encouraged the NSB "to consider further changes that would bridge the gap between the Major Research Instrumentation program and the MREFC account while also developing processes appropriate for mid-scale infrastructure, cyberinfrastructure, and instrument upgrades to be funded through the MREFC account." The NSB issued a report (NSB-2018-40)1 that made several recommendations, including "a long-term agency-level commitment to mid-scale research infrastructure."

Flexibility

Mid-scale project requirements are to be tailored based on each project's unique characteristics such as the technical scope, the type and mix of work performed (e.g., standard procurement by the Recipient, software development, or civil construction), and an assessment of the associated technical and programmatic risks. However, NSF is committed to the principle that this flexibility does not preclude the requirement for appropriate rigor on the part of NSF or the Recipient.

This snapshot illustrates the breadth of NSF Programs, inclusive of Division-specific examples and NSF-wide, to illustrate the breadth of NSF's mid-scale research infrastructure portfolio: →

Mid-scale RI Umbrella



MID-SCALE RESEARCH INFRASTRUCTURE

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PROJECT PLANNING AND MANAGEMENT PRACTICES FOR MID-SCALE RI PROJECTS

A Mid-scale RI project should follow project planning and management practices that suit the scale and complexity of the project while supporting sound performance measurement and management needs. Example of some key practices are highlighted below.

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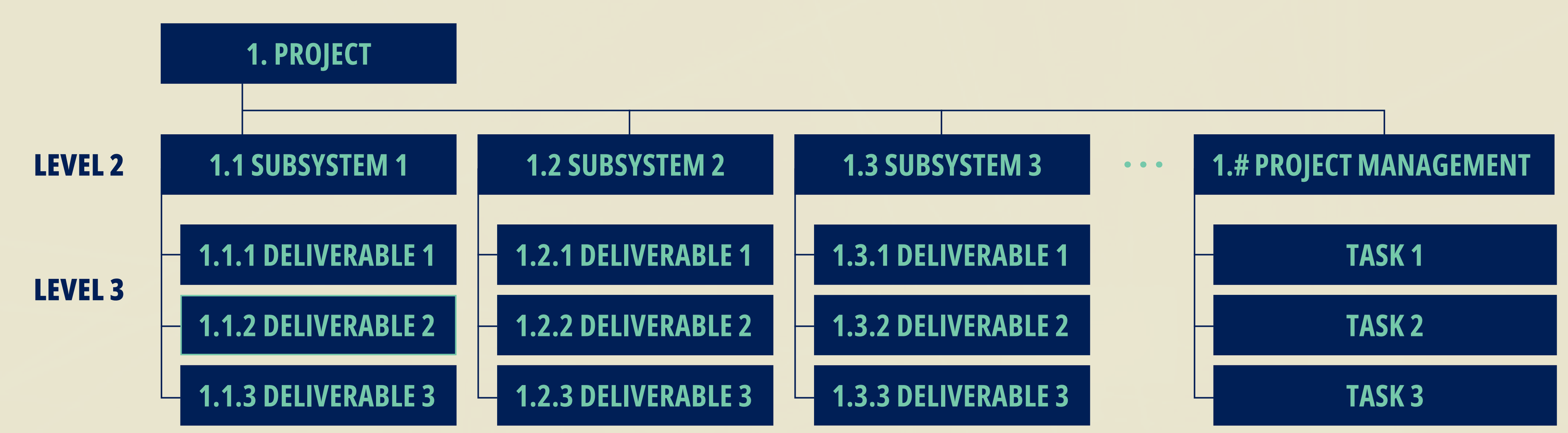
EXAMPLES

Work Break Down Structure (WBS)

> *...Generally, the number of levels employed should be sufficient to identify and measure progress towards achieving deliverables, assign responsibility, and enable effective management and reporting. The number of decomposition levels varies depending on the project's size and complexity, technical maturity, organizational constraints, acquisition and construction strategies, and management's assessment of need. 2021 NSF RIG, 4.2.2.7 Work Breakdown Structure (WBS)*
>
> NSF Research Infrastructure Guide

WBS is the essential cornerstone of every project because it defines in detail the work necessary to accomplish a project's objectives. For construction, the WBS is a **deliverable-based and hierarchical framework structure** that provides specific, manageable, and schedulable tasks and may be composed of products, material, equipment, services, data, and support facilities that the project should yield.

This graphic illustrates a generic WBS:



This table, to left illustrates a generic WBS tailored for many NSF RI projects :

- 1.0 Project Administration and Management Office
  - 1.1 Project Management Office
  - 1.2 Site Office
  - 1.3 Science Office
  - 1.4 Education and Public Outreach
  - 1.5 Safety and Environmental Assurance
- 2.0 Facility Infrastructure and Civil Construction
  - 2.1 Sub-element X
  - 2.2 Sub-element Y
  - 2.3 Sub-element Z
- 3.0 Scientific Equipment and Instrumentation
  - 3.1 Subcomponent X
  - 3.2 Subcomponent Y
  - 3.3 Subcomponent Z
- 4.0 Computers and Cyber-Infrastructure
  - 4.1 Data Infrastructure
  - 4.2 Data Products
- 5.0 Systems Integration, Testing, and Commissioning
  - 5.1 Common Utilities and Support Equipment
  - 5.2 Early System Assembly, Integration, and Testing
  - 5.3 Acceptance Testing
  - 5.4 Training
  - 5.5 Science Verification

Performance Measurement and Management

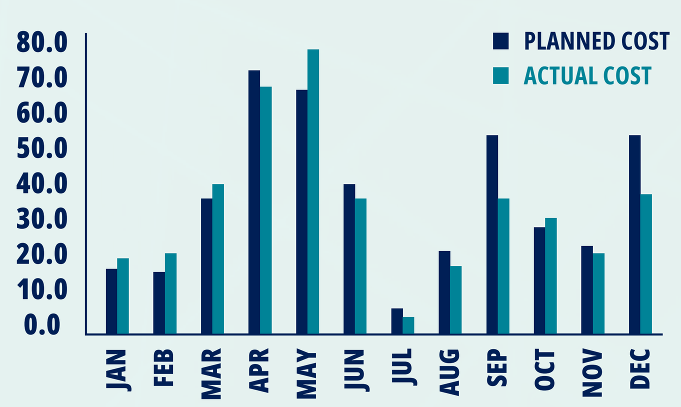
Scan this code for the
RESEARCH INFRASTRUCTURE GUIDE (RIG) - DECEMBER 2021 (NSF 21-107).

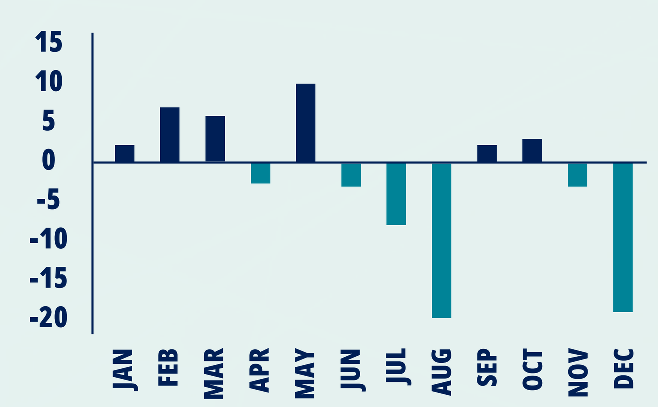
The project management controls identify the methods and quantitative measures to compare the technical progress and costs during execution to the planned schedule and budget. The scope and complexity of a project should be assessed to determine if the project can benefit from the earned value principles for performance management.

NSF does not require earned value management implementation for mid-scale projects. NSF has established a scaled earned value management approach with reduced administration burden, using the seven basic EVMS principles. [2021 NSF RIG, 6.8.4 NSF Scaled EVMS]

The graphics that follow illustrate the range of techniques that could be used to track project performance as part of project's controls:

Example 1: *Compare actual cost to planned budget. In this example the cost information is generated on a monthly basis with results of the cost variances highlighted.*

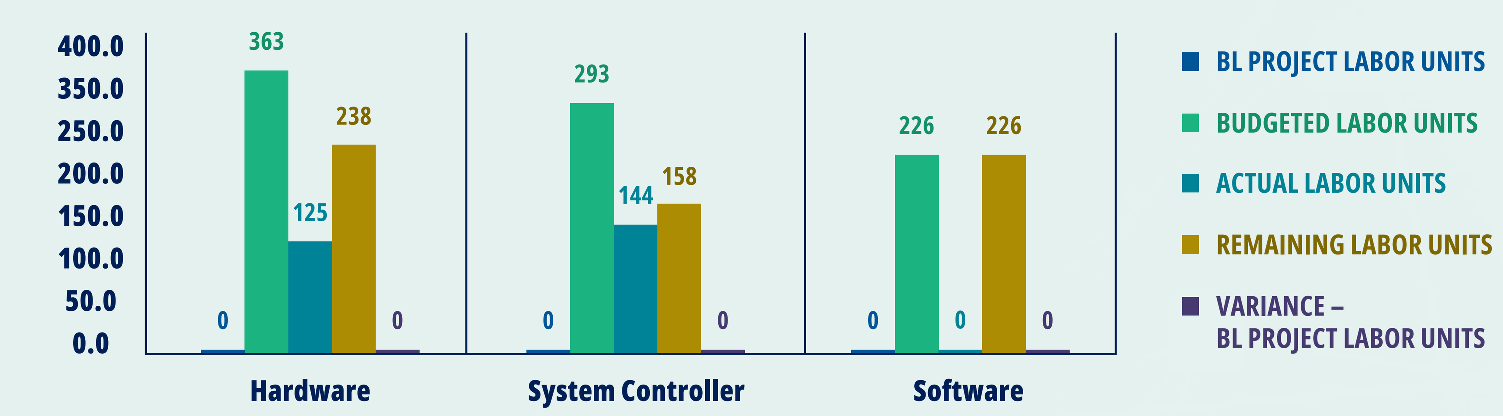




TYPE OF COST	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
PLANNED COST	50	100										150
ACTUAL COST	100											100
VALUE DIFFERENCE	50	-100	0	0	0	0	0	0	0	0	0	-50

Example 2: *Also compares actual cost to planned budget. This report provides more details, showing data by WBS element.*

WBS Code	WBS Name	BL Projec...	Budgete...	Actual La...	Remainin...
MFG00659	Deerfield - Autom...		0h	0h	0h
MFG00659.Sys-Eng	System Engineering		960h	962h	0h
MFG00659.Hard	Hardware		363h	125h	238h
MFG00659.Hard....	Temperature Cont...		725h	762h	0h
MFG00659.Hard....	Robot Controller		158h	106h	59h
MFG00659.Hard....	System Controller		293h	144h	158h
MFG00659.Soft	Software		226h	0h	226h
MFG00659.Train	Training		0h	0h	0h
MFG00659.Train....	Manuals		25h	0h	25h
EC00515	City Center Office ...		0h	0h	0h
EC00515.Mechan...	Mechanical/Electri...		0h	0h	0h
EC00515.Ex-Finish	Exterior Finishes		0h	0h	0h
EC00515.Int-Finish	Interior Finishes		422h	0h	422h
EC00515.D&E	Design and Engine...		1330h	1952h	0h
EC00515.Found	Foundation		4339h	305h	3994h
EC00515.Structure	Structure		3878h	0h	3878h
EC00515.Int-Finis...	Plumbing and Light...		154h	0h	154h
EC00515.Ex-Finis...	Doors and Windows		115h	0h	115h
EC00515.Int-Finis...	Floor and Carpeting		2893h	471h	2527h
EC00515.Int-Finis...	Paint		96h	0h	96h
EC00515.Int-Finis...	Carpentry		384h	0h	384h

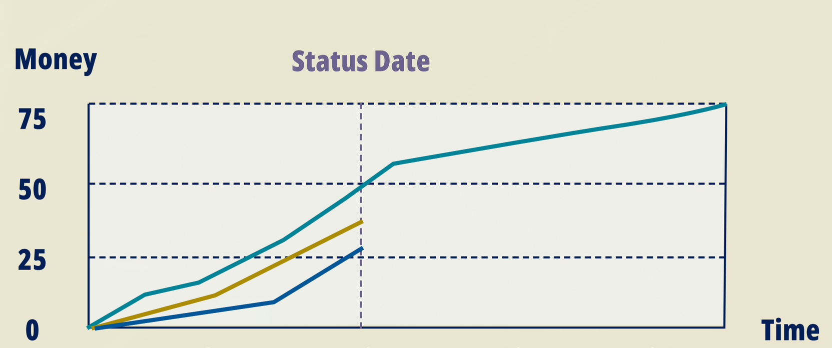


Earned Value Management (EVM)

EVM is a recognized project management methodology that provides insight into a project's technical, cost, and schedule progress. Progress can be determined with several key calculations. The formulas for calculating the earned value performance indices are:

Cost Variance: **CV = EV - AC**
Schedule Variance: **SV = EV - PV**

Cost Performance Index: **CPI = EV/AC**
Schedule Performance Index: **SPI = EV/PV**



- PV – PLANNING WORK
- AC – WHAT THE WORK ACTUAL COST
- EV – ACTUAL WORK ACCOMPLISHED

These data points can also be graphed to provide an illustration of the progress. This is a typical graph showing PV, AC and EV is shown here.

Earned Value Management System (EVMS)

EVMS is an integrated set of processes, people and tools for managing projects using earned value management. The primary purpose for establishing an EVMS is to support successful management of the project by the Recipient.

NSF recognizes that the full implementation of 32 EVMS guidelines may add unnecessary administrative burden. To allow benefit from earned value management (EVM) methodology without adding extra burden, NSF established the **framework of scaled EVM for smaller scale and less complex projects.** See NSF RIG 6.8.5 Practice Guide. It organizes the scaled EVM implementation into four processes and identifies the minimally required components from the 32 Guidelines needed to realize the benefit of EVM and to meet the seven basic principles of EVMS.

Process 1: Define and organize the project (Principle 1 and 2) The goal of this process is to ensure the project scope is well defined with clearly assigned responsibility for each of its components.

Process 2: Establish project cost, schedule, and contingencies (Principle 3) The goal of this process is to establish the project's cost and schedule baseline against which the project's progress will be measured during execution. In addition to setting the project's cost and schedule baseline, the cost and schedule contingencies will also be estimated. Project level milestones should also be defined and identified in the project baseline schedule.

Process 3: Progress and performance monitoring (Principles 4, 5, 7) The goal of this process is to ensure the project uses the EVM concept for quantitative measurement of progress and that the project's progress data is reliable and used by management to achieve project goals.

Process 4: Management analysis and control (Principles 6 and 7) The goal of this process is to ensure the project uses EV data and forward-looking metrics to forecast the project's cost and schedule performance and to allow for early detection of potential issues. The forward-looking metrics are valuable input that EVM can provide, in addition to reporting on the past performance. The project should use the forward-looking metrics to inform management decisions and make timely adjustments to the project plan that are necessary for the project's success. The changes to the project's performance measurement baseline should be controlled to ensure the integrity of the baseline and the reliability of the EV data.

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SCHEDULE

A schedule is a management tool used for planning and executing work. It address both how and when the work is to be performed by identifying the activities needed to accomplish the scope of work and by time-phasing these activities with durations and schedule logic. Time-phasing involves identifying the key relationships between activities to determine the proper sequence necessary to accomplish the work.

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A project schedule, also referred to as a schedule model, identifies the necessary activities with interdependencies along a timeline to complete a specific deliverable or defined scope of work with a beginning and an end.

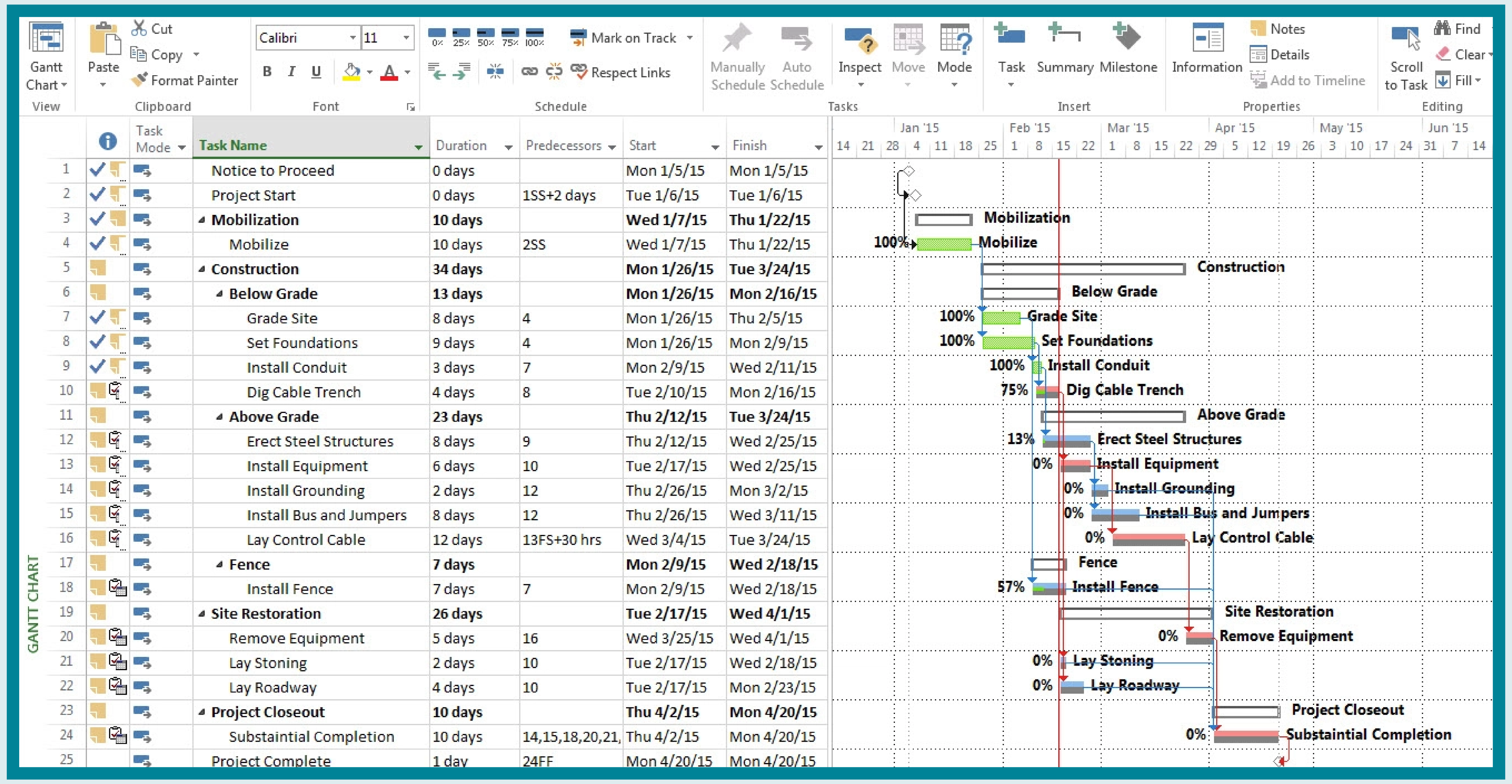
If the award is for a project in the construction or implementation stage, a schedule is required. The level of detail in Mid-scale RI project schedules should be based on the scale and complexity of the project scope and may be as simple as a milestone schedule.

> *...schedules for Mid-scale implementation awards should be developed following the applicable best practices the GAO Schedule Guide to establish a reliable schedule - comprehensive, well-constructed, credible, and controlled.*
> *... The Performance Measurement Baseline (PMB) for the project is set by the proposed scope, budget, and schedule as defined at the time of the award. All reporting is done against this project baseline.*
>
> **NSF Research Infrastructure Guide**

Example 1. *This is a simple table with milestones defined for each WBS element, and information on the planned deadline and actual.*

WBS CODE	MILESTONE	SCHEDULED DEADLINE	ADAPTED DEADLINE	ACTUAL DEADLINE
1.1.1	Project launched	03.12.2020	-	03.12.2020
1.2.5	As-is analysis completed	04.01.2021	15.01.2021	17.01.2021
1.3.5	Rough concept created	31.01.2021	29.02.2021	-
1.4.5	Detailed concept created	20.03.2021	31.03.2021	-
1.5.7	Techical implementation done	15.05.2021	-	-
1.6.9	All tests completed	15.06.2021	-	-
1.7.5	Operational start-up done	30.06.2021	-	-
1.8.5	Project completed	15.07.2021	-	-

Example 2. *This is a schedule model created in MS Project.*



MID-SCALE RESEARCH INFRASTRUCTURE

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PROJECT EXECUTION PLAN

Project Execution Plan (PEP) is required for all mid-scale projects in order to document the foundation for how the project will be managed by the Recipient during the construction stage (also referred to as implementation). Concurrence on an initial PEP must be reached between NSF and the proposing organization. It is reasonable to expect the PEP to evolve during the execution of the award. The following list provides the minimum required components of the PEP for a mid-scale project. The contents of each PEP component should be tailored in both detail and scope to the specifics of the project.

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The following list provides the **minimum required components of the PEP** for a mid-scale project. The contents of each PEP component should be tailored in both detail and scope to the specifics of the project.

1. INTRODUCTION
2. ORGANIZATION
4. CONSTRUCTION PROJECT DEFINITION
6. RISK AND OPPORTUNITY MANAGEMENT
8. CONFIGURATION CONTROL
9. ACQUISITIONS
10. PROJECT MANAGEMENT CONTROLS. DESCRIBE THE METHODS FOR PERFORMANCE MEASUREMENT AND MANAGEMENT
12. CYBER-INFRASTRUCTURE
13. COMMISSIONING, INCLUDING CONCEPT OF OPERATIONS

NSF has created a PEP template for mid-scale RI projects. An updated version of this is coming soon. Scan this code for the

MID-SCALE PROJECT PEP TEMPLATE

Components of a Project Execution Plan

The typical elements of each PEP component are outlined in the following Table.

COMPONENT	SUB-TOPICS	DESCRIPTION OF SUB-SECTION REQUIREMENTS
1. Introduction	1.1 Scientific Objectives	• Description of the research objectives motivating the facility proposal.
	1.2 Scientific Requirements	• Comprehensive statement of the Requirements Matrix/ Key Science Requirements to be fulfilled by the proposed facility (to the extent possible identifying minimum essential as well as desirable quantitative requirements), which provide a basis for determining the scope of the associated infrastructure requirements.
	1.3 Facility / Infrastructure	• Description of the infrastructure necessary to obtain the research and education objectives.
	1.4 Scientific & Broader Societal Impacts	• Description of the Broader Societal Impacts associated with the purpose of the facility, including the scope of work, budget and schedule related to science community or society related actions or interactions.
	1.5 Facility Divestment Plan	• Description of plans and estimate of divestment liabilities at the end of facility life for transfer, demolition, site remediation, decontamination, etc., where appropriate.
2. Organization	2.1 Internal Governance & Organization and Communication	• Internal Project Governance and Organization Structure with clear lines of authority, responsibility, and communi¬cation between Internal and institutional governance and oversight and advisory committees.
	2.2 External Organization and Communication	• External Project Organizational Structure and Governance, showing clear lines of authority, responsibility, and communication between NSF, any partners, and the Recipient.
	2.3 Partnerships	• Role of interagency or international partners in future planning and development and/or construction. Plans, agreements, and commitments for interagency and international partnerships. Description of the project's stakeholders and their roles, responsibilities and meeting schedules.
	2.4 Roles and Responsibilities	• Roles and Responsibilities of key project personnel and governance groups.
	2.5 Community Relations and Outreach	• Description of plans and estimate of divestment liabilities at the end of facility life for transfer, demolition, site remediation, decontamination, etc., where appropriate.
3. Design and Development	3.1 Project Development Plan	• Description of activities that will be undertaken in order to achieve readiness for construction, such as design, prototyping, manufacturing process validation, vendor qualification, modeling and simulation, creation of required project management plans, forming partnerships, etc.
4. Construction Project Definition	4.8 Funding Profile	• Show the proposed NSF Funding Profile by year with baseline commitment and anticipated contingency allocation profiles. Also provide a total funding profile from all sources if applicable.
	4.9 Baseline Schedule Basis Document and Integrated Schedule	• Schedule (without contingency) for the overall project and each major subsystem, including system integration, commissioning, acceptance, testing and transition activities; as well as major milestones and milestones for reviews, critical decisions and deliverables. It uses formal scheduling programs, is based on the WBS hierarchy, and is resource-loaded before the construction/implementation stage. Baseline schedule does not include schedule contingency.
	4.10 Schedule Contingency	• Schedule contingency amounts and project end date with contingency; state method of calculating contingency, including confidence level for meeting project end date.
5. Staffing	5.1 Staffing Plan	• Staffing FTE plan, per NSF and other project-specific job categories, over time. Application of indirect cost rates must be articulated in Cost Estimating Plan (CEP) and Basis of Estimate (BOE) per Section 4.2 of this Guide.
	5.2 Hiring and Staff Transition Plan	• Schedule and requirements for hiring and training staff, including timelines for increasing or decreasing staffing levels. Required qualifications for key staff.
6. Risk and Opportunity Mgt	6.1 Risk Management Plan	• Risk Management Plan describes the methodology/ process for identifying, ranking, analyzing, tracking, controlling, and mitigating risks. Describes both qualitative assessment and quantitative analysis methods.
	6.2 Risk Register	• A tracking document or tool that provides a ranked list of identified risks, with risk impact analysis and prioritization, responsibilities, mitigation plans and opportunities of risk reduction, and risk status over time. Documents data and assumptions used in risk analysis.
	6.3 Contingency Management Plan	• Contingency management plans and approval process using change control. Describe NSF approval requirements per cooperative agreements (CAs).
7. Systems Engineering	7.1 Systems Engineering Plan 7.2 Systems Engineering Requirements	• Systems Engineering Management Plan; roles and responsibilities. • System-level design and technical feasibility study, including definition of all functional requirements and major systems. Identifies all technical design requirements, drawings, and specifications.
8. Configuration Control	8.1 Configuration Control Plan 8.2 Change Control Plan	• Configuration Control plans. • Change Control Plan to manage accounting changes and changes in the baseline or PMB plan: changes in scope, modifications to budget or schedule, and movement of contingencies into or out of the PMB. Includes approval and documentation processes plus roles and responsibilities.
	8.3 Document Control Plan	• Document Control Plan for managing version control, access, and archiving of project related documentation.
9. Acquisitions	9.1 Acquisition Plans	• Describe acquisition plans, processes, subawards, and contracting strategy, including evolving technologies and assumptions for design definition. Provide a time-based list of acquisitions and procurement actions.
	9.2 Acquisition Approval Process	• Describe the approval process for acquisitions (NSF, internal), and create a year by year Acquisition Plan of actions that are estimated to require NSF approval.
10. Project Mgt. Controls	10.1 Project Management Control Plan	• Description of the project management organization and processes.
	10.2 Earned Value Management System (EVMS) Plan	• Description of the EVMS plans, processes, software, and tools.
	10.3 Financial and Business Controls	• Description of Financial and Business processes and controls.
11. Site and Environment	11.1 Site Selection 11.2 Environmental Aspects	• Site selection criteria and description of selected site(s). • List need for any Environmental Impact Statements, permitting, site assessments, etc.
12. Cyber-Infrastructure	12.1 Cybersecurity Plan	• Plan for protecting access, confidentiality, and integrity of key information assets of the facility.
	12.2 Code Development Plan	• Plan to enable critical scientific/engineering capabilities and data flows within the facility as well as interoperability with key external collaborators or stakeholders.
	12.3 Data Management Plan	• Plans for acquisition and integration of equipment or services from third parties.
13. Environmental, Safety and Health	13.1 Environmental, Safety and Health Plans	• Environmental, Safety and Health plans (ES&H).
14. Review and Reporting	14.1 Reporting Requirements	• Statement of reporting requirements, including notifications for specific events and periodic reports on progress and project technical and financial status per NSF contractual requirements or CAs.
	14.2 Audits and Reviews	• Statement of the required and proposed reviews, audits, and assessments for progressing during project life cycle through project close-out.