ICEAA 2019:

Overview of GAO's Best Practices Guides

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GAO Applied Research and Methods

May 2019

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Outline

- Introduction to GAO
- Overview of Current GAO Best Practice Guides
- What's coming in 2019?
  - Cost Guide Update
    - Best Practices
    - Case Study
  - Technology Readiness Assessment Guide
    - Steps and Best Practices
    - Case Study
  - Agile Assessment Guide
    - Adoption, Execution, and Program Controls

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  - Investigating allegations of illegal and improper activities
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About GAO
Our Work

- In 2018, GAO published 620 audit products (reports, briefings, testimonies, and special publications)
- GAO also closed 2,642 legal cases in 2018 (e.g. bid protests, cost claims, etc.)
- 96% of work requested or mandated by Congress
- 4% of work initiated under Comptroller General Authority

OVERVIEW:
GAO BEST PRACTICE GUIDES

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GAO's Best Practice Guides

Why are best practice guides important?

- Legislators, government officials, and the public want to know
  - Whether government programs are achieving their goals
  - What these programs are expected to cost and when they will be finished
- Developing reliable program cost and schedule estimates are critical to
  - Effectively using public funds
  - Meeting OMB's capital programming process
  - Avoiding cost overruns, missed deadlines, and performance shortfalls

GAO Guides and Best Practices

Purpose of these documents is two-fold:

- Provide criteria for GAO to use when performing audits
- Provide guidance for agencies

- **Cost Estimating and Assessment Guide** (March 2009, GAO-09-3SP)
- **Schedule Assessment Guide** (December 2015, GAO-16-89G)
- **Technology Readiness Assessment (TRA) Guide** (August 2016, GAO-16-410G)

GAO Guides and Best Practices

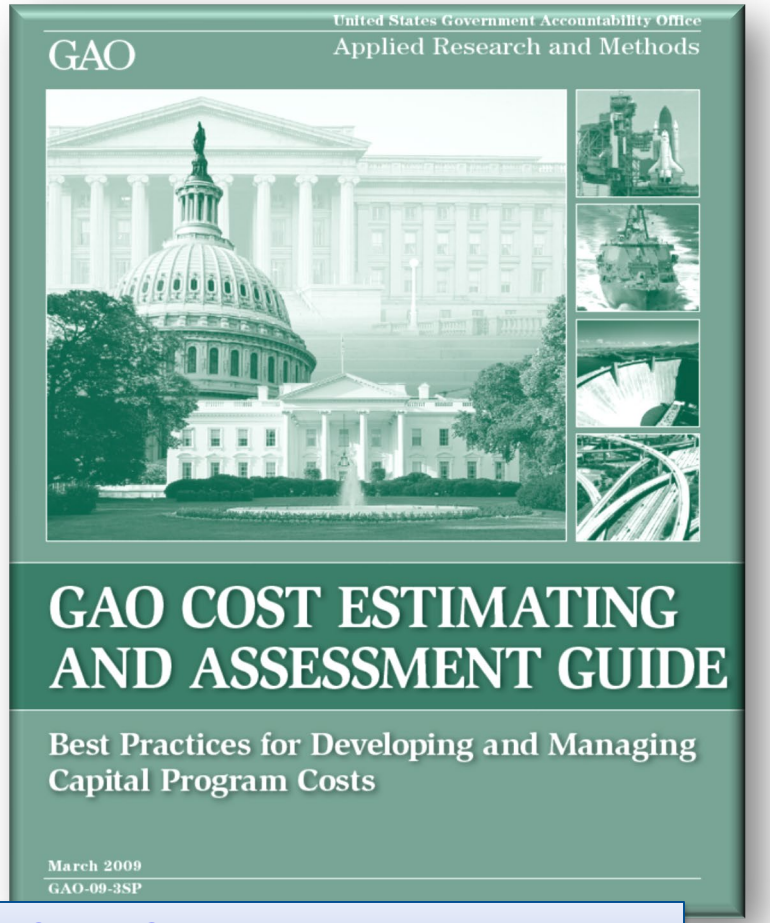
Expert Group Process

- To develop these guides, GAO compiles a list of experts in that area to discuss topics
- For example, the Cost Expert Group was established in 2005 and has since grown to include experts on schedule analysis and earned value management
  - Group meets twice a year to discuss a variety of related issues
  - Contributions have been invaluable both in
    - Providing historical information and experience
    - Keeping the Guide current with industry trends
- GAO has currently assembled an Agile Expert Group
  - The group's first meeting occurred on August 30, 2016

COST GUIDE:
COST ESTIMATING PROCESS AND BEST PRACTICES

Cost Estimating and Assessment Guide

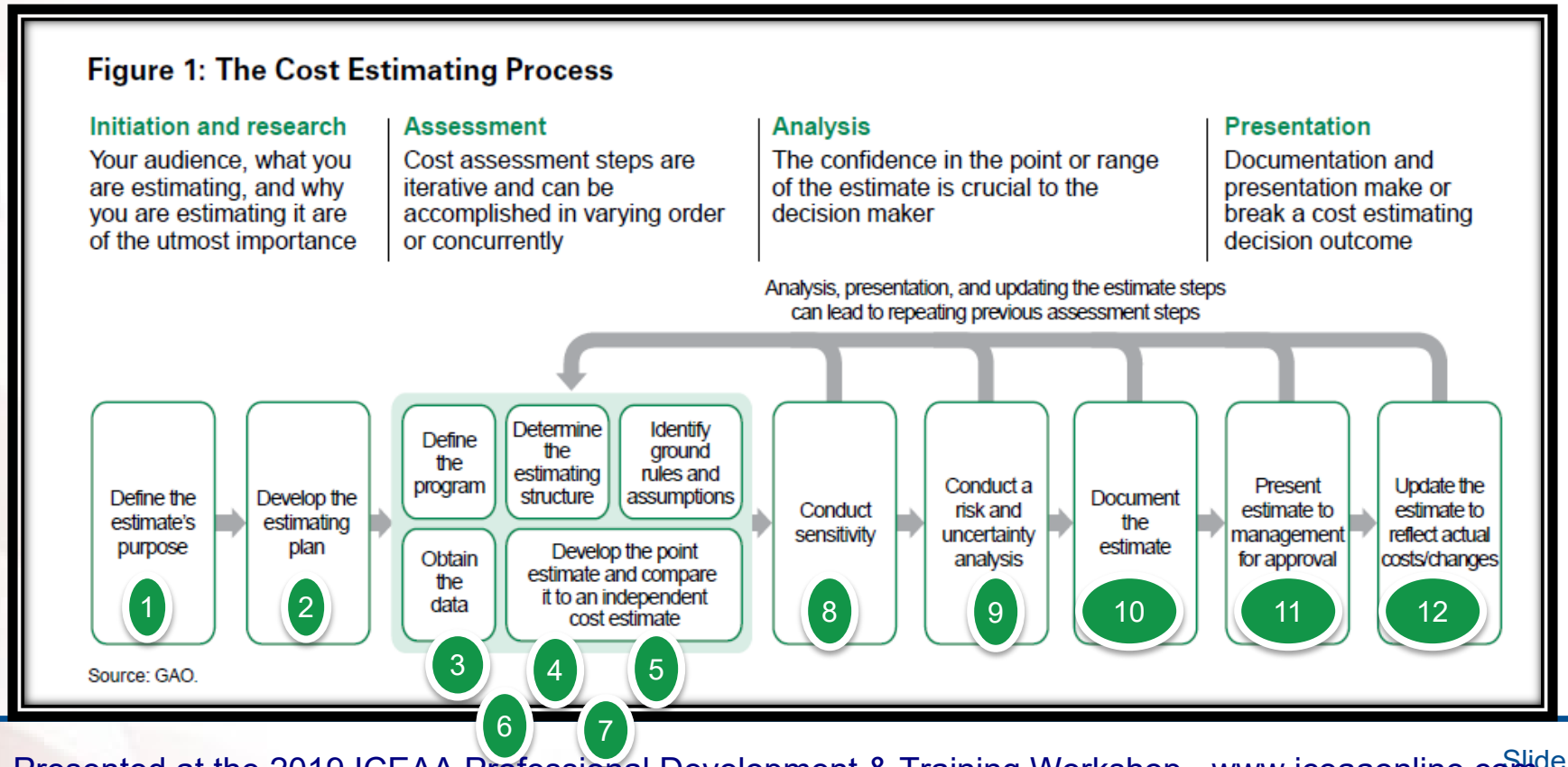
- Drafted 2005-2007, published in 2009
- Outlines GAO's criteria for assessing cost estimates during audits
- Contains 20 chapters with supporting appendixes
- Chapters 1-17: developing credible cost estimates and the 12-step cost estimating process for developing high quality cost estimates
- Chapters 18-20 address managing program costs once a contract has been awarded and discuss Earned Value and risk management
- Also provides case studies of prior GAO audits to show typical findings related to the cost estimating process



GAO is currently working to update the Cost Guide. Expected out on the GAO webpage: Summer 2019

Cost Estimating Process

- The following figure shows the GAO Cost Estimating Process as established in GAO-09-3SP:



Four Characteristics of a Reliable Estimate

Are all costs included?	Can the estimate be recreated?	Is the estimate unbiased?	What is the uncertainty?
Comprehensive	**Well-Documented**	**Accurate**	**Credible**
• Develop the estimating plan • Determine the estimating approach	• Define the program • Identify ground rules and assumptions • Obtain data • Document the estimate • Present estimate to management	• Develop the point estimate • Compare the point estimate to an independent estimate • Update the estimate with actual costs	• Create an independent cost estimate • Conduct sensitivity analysis • Conduct risk and uncertainty analysis

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What Else is in the Cost Guide?

- The Cost Guide also discusses Earned Value Management (EVM)
  - The Cost Guide presents a 13-step EVM process
  - Identifies best practices for cost management using an EVM system
- Appendices cover other topics, including
  - Cost-related legislation, regulations and guidance
  - Data collection instrument and rationale
  - Work Breakdown Structure (WBS) examples
  - Learning curves
  - Integrated baseline review (IBR)

Cost Estimating and Assessment Guide
Proposed Updates

- Integration with and references to the Schedule, TRA, and Agile best practices guides
- Alignment to the Standards for Internal Control and GAO's work on enterprise risk management
- Improved definitions and clearer mapping of the 12 step-process to the 4 characteristics of a reliable estimate
- New appendixes on the estimating process and internal controls, risk allocation and phasing, and Analysis of Alternatives
- Updated laws, guidance, and case studies
- New format to match best practices series

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Past GAO Assessments

What Is Typically Missing from LCCEs?

- In general, program offices
  - Do not include all life cycle costs and do not break costs into sufficient detail
  - Rarely use standardized product-oriented WBS with common support elements
  - Do not document the cost estimate to a level that would allow an analyst unfamiliar with the program to replicate the results
  - Do not properly account for risk or uncertainty while developing the estimate
  - Fail to crosscheck estimating methodologies or reconcile with an independent cost estimate
  - Cannot demonstrate management approval
  - Fail to update the cost estimate.

- Additionally, many government program offices lack effective internal controls
  - No centralized cost estimating organization
  - No policy or guidance
  - No established databases or data collection process
  - No independent estimating organization.

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Case Study on Cost Estimating Best Practices: Cost Risk and Uncertainty

TRANSPORTATION SECURITY ADMINISTRATION (TSA)

GAO-16-19

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TSA Case Study

TSA SPP GAO-16-19: Background

- After a 2-year pilot, in 2004 (in accordance with the Aviation Transportation Security Act), TSA established the Screening Partnership Program (SPP); any airport authority may request a transition from federal screeners to private, contracted screeners to screen passengers and checked baggage

- TSA estimates the cost it would incur for federal screeners to operate at an SPP in a given year and compares those costs to the proposed private screening costs (21 privately screened airports as of July 2015)

- Relevant objectives:
  - (1) the extent to which TSA has developed and reported reliable cost estimates
  - (2) how TSA uses cost estimates in selecting contractors and the extent to which TSA monitors contractor costs relative to its cost estimates

TSA Case Study

TSA SPP GAO-16-19: Findings

- GAO found that TSA's cost estimates were not reliable because they partially met the characteristics of Accurate and Credible

- GAO found TSA's approach to risk and uncertainty analysis did not meet best practices
  - Contingency reserves were calculated as high-level factors of the total cost based on airport category
  - Did not account for risks specific to each airport
  - Did not provide decision makers with information about the probability associated with the point cost estimate

TSA Case Study

TSA SPP GAO-16-19: Uncertainty Analysis

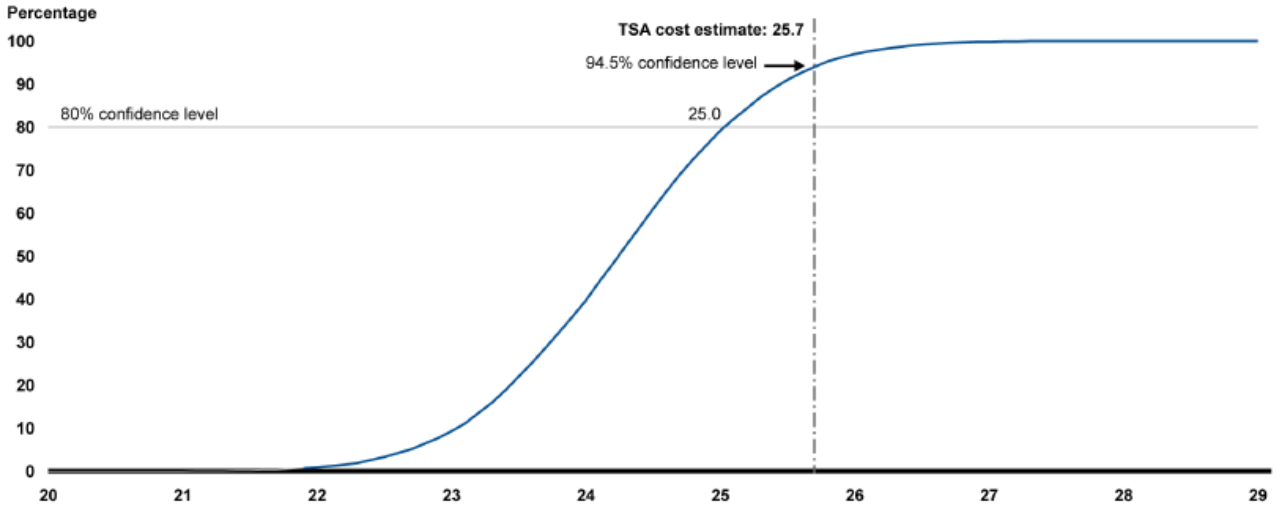
- To further illustrate the importance of a risk and uncertainty analysis and how this analysis can be incorporated into TSA's estimates, GAO conducted a limited cost risk and uncertainty analysis for one SPP airport which accounts for variability in wages, staffing, and attrition

- In conducting our analysis, we followed the steps identified as practices in the GAO Cost Guide and interviewed SPP personnel regarding the variables examined for the limited cost risk and uncertainty analysis

TSA Case Study

TSA SPP GAO-16-19: Uncertainty Analysis Results

Figure 5: Confidence Level Results of the Transportation Security Administration's (TSA) Cost Estimate of an Example Airport



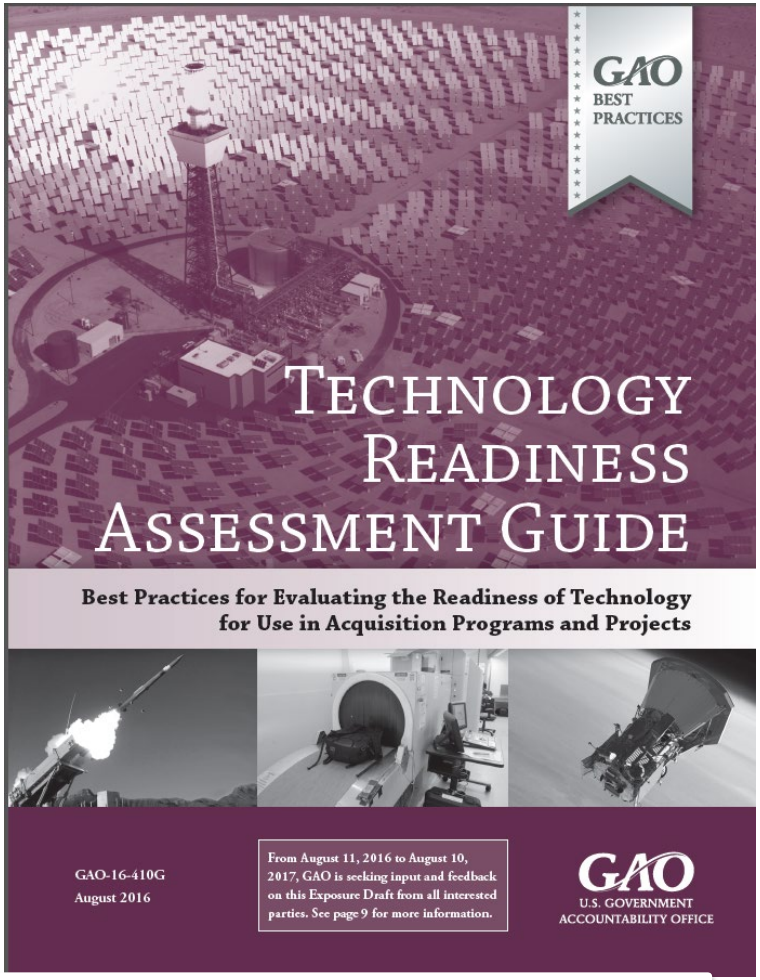
Source: GAO analysis of TSA data. | GAO-16-19

TSA's estimate was at the 94.5% confidence level. In DHS's response, they stated they were "pleased…GAO found the estimate to have an exceptionally high 94.5 percent interval….it is likely that similarly high confidence intervals exist for all cost estimates…."

TECHNOLOGY READINESS ASSESSMENT GUIDE

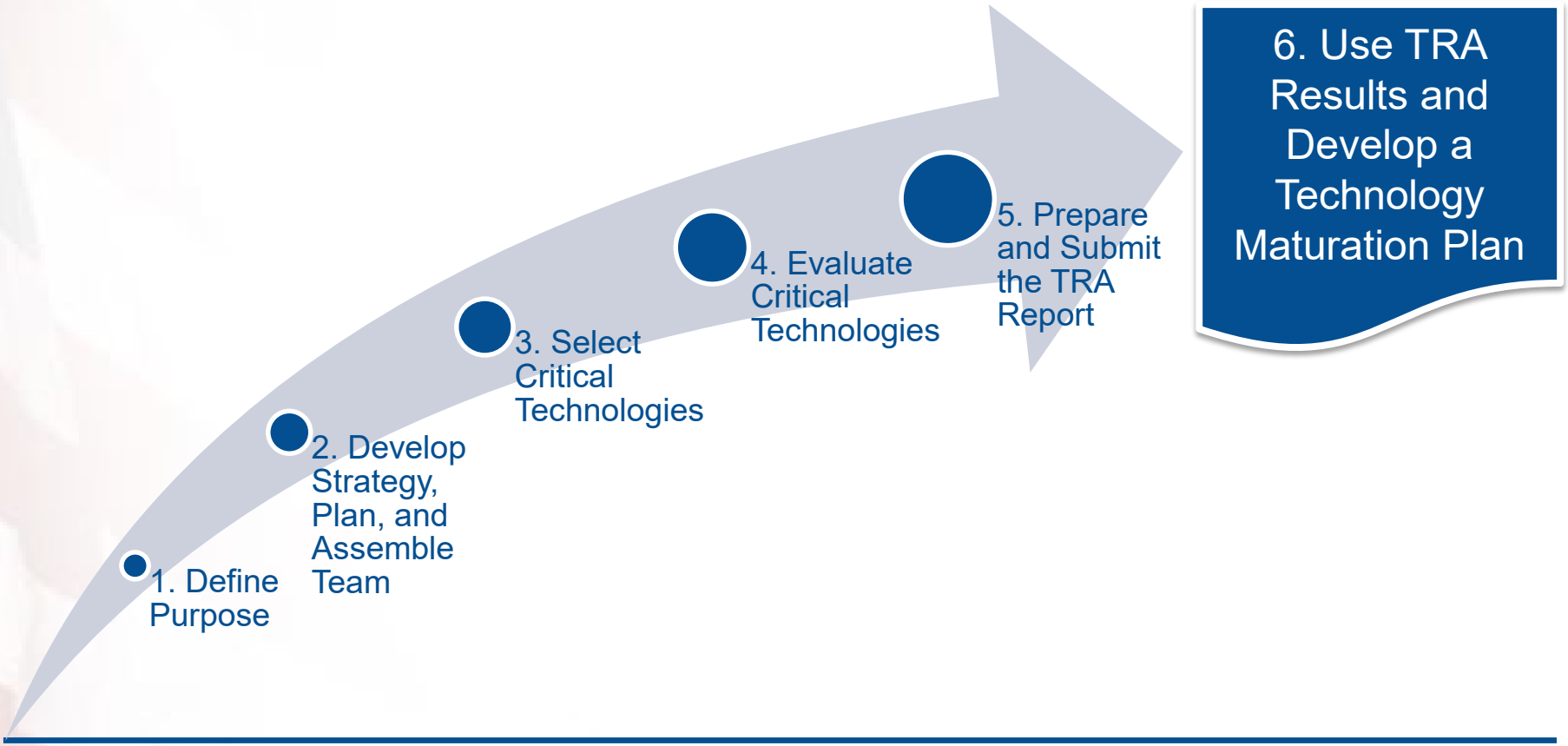
Technology Readiness Assessment Guide

- Public exposure draft released on August 11, 2016
- Outlines criteria for evaluating technology maturity and readiness to move past key decision points where major resource commitments are made
- Contains 6 steps and related best practices for conducting TRAs
- Provides case studies from prior GAO audits to show typical findings related to technology readiness assessment
- Public comment period has concluded and adjudication process is underway



. Final TRA Guide issuance expected: Fall 2019

Six Steps to Develop a High Quality TRA



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Six Steps to Develop a High Quality TRA (Cont)

Develop TRA Strategy for Project	• Determine technology needs of a program and match up with assessment strategy • Document schedule for conducting assessments • Align assessment strategy to systems engineering management plan
Define Purpose, Develop Plan, and Assemble Team	• Determine purpose, level of detail, scope, TRL definition • Develop schedule and events • Determine specific team members and needed expertise • Outline the approach • Identify a plan for handling dissenting views
Select Critical Technologies	• Identify purpose, system, and performance characteristics in a technology baseline document • Use a Work Breakdown Structure that characterizes the system to select critical technologies • Use key questions and environment to determine if a technology is critical

Six Steps to Develop a High Quality TRA (Cont)

Evaluate Critical Technologies	• Determine TRL definitions and required evidence prior to assessment • Determine acceptability of test articles and environments • Determine if testing results are sufficient and acceptable • Document all relevant information
Prepare and Submit the TRA Report	• Prepare an official report that documents actions from previous steps • Obtain report comments and explain dissenting views
Use TRA Results and Develop a Technology Maturation Plan	• Use TRA results to make decisions about the program's development priorities • Program management identifies TRA-related concerns and risks, including potential effects on cost and schedule estimates • Develop a technology maturation plan to track progress

Four Characteristics of a High Quality TRA

Credible	Objective	Reliable	Useful
• Assessment design, execution, and reporting activity reflects understanding of requirements, critical technologies, relevant or operational environments • Assessment team has right knowledge and expertise	• Assessment is based on objective, relevant and trustworthy data, analysis, and information • Free from internal and external organizational bias or influence	• Uses disciplined processes that facilitate repeatability, consistency, and regularity	• Stakeholders understand information • TRA has sufficient detail and is timely and can be acted upon

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Case Study on Technology Readiness Assessment (TRA)

COLUMBIA CLASS SUBMARINE

GAO-18-158

Case Study: Columbia Class Submarine

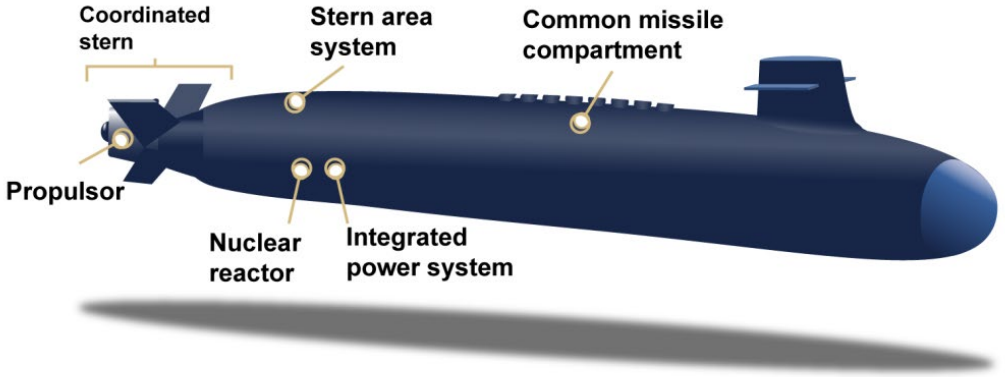
GAO-18-158: Background

- The Navy's Columbia class ballistic missile submarine will replace the 14 Ohio class that currently provide the sea-based leg of the US nuclear triad, slated to begin retiring in 2027
- The first Columbia must begin patrols in 2031 to prevent a gap in deterrent capabilities and will ultimately carry up to 70% of the nation's strategic nuclear capability
- The program is a top Navy priority with an expected cost of $267 billion over its life-cycle (including $128 billion to research, develop, and buy 12 submarines)
- The Navy is introducing new technologies to improve capabilities where required while leveraging systems from existing submarine programs (e.g. the Virginia and Seawolf attack submarines and the Ohio class SSBNs) to ensure commonality with the submarine fleet and reduce development needs for the Columbia class to limit technical risk

Case Study: Columbia Class Submarine

GAO-18-158: Background

- The Columbia class program comprises several major lines of effort (hull and supporting systems, strategic weapons system, and nuclear reactor-based propulsion plant)
- The Navy has identified several key technology efforts:
  - Common Missile Compartment
  - Integrated Power System
  - Stern Area System
  - Propulsor



Source: GAO analysis of of Navy documentation. | GAO-18-158

Case Study: Columbia Class Submarine

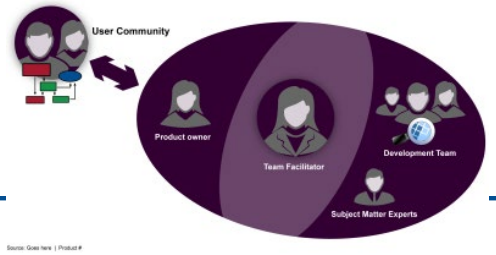
GAO-18-158: What did GAO find?

- We used the criteria in GAO's TRA Guide to evaluate the quality and completeness of the Navy's assessment of technology readiness and risk.
- GAO reviewed the Navy's technology readiness assessment, technology development plan, and the status of key prototyping efforts and compared them with GAO's best practices for shipbuilding programs and technology readiness assessments.
- GAO found that the Navy did not follow best practices for identifying the critical technologies for the program, resulting in an underrepresentation of the technical risk. The Navy's definition of critical technology was more restrictive than GAO's criteria.

2018 National Defense Authorization Act (NDAA) includes Navy Reporting requirements for the Columbia class program

AGILE ASSESSMENT GUIDE

GAO Agile Assessment Guide



- Chapter 1 – Background
- Chapter 2 – Compliance and Past Work
- Chapter 3 – Agile Adoption Best Practices
  - Team activities, Program processes, and Organizational Environment
- Chapter 4 – Agile Implementation Challenges
- Chapter 5 - Agile Metrics
- Chapter 6 – Requirements Decomposition
- Chapter 7 – Agile and the Federal Acquisition Process
  - Agile and Federal Contracting Process / Budget Process
- Chapter 8 - Agile and Program Management Factors
  - Program Planning and Tradeoffs, Team composition
- Chapter 9 – Agile Program Control Best Practices
  - Cost estimating, Scheduling, and Earned Value Management

Appendices:

- Agile Glossary
- Effects of not following best practices
- Agile Methodologies
- Debunking Agile Myths
- Questions for Auditors and Managers
- Case Study Descriptions

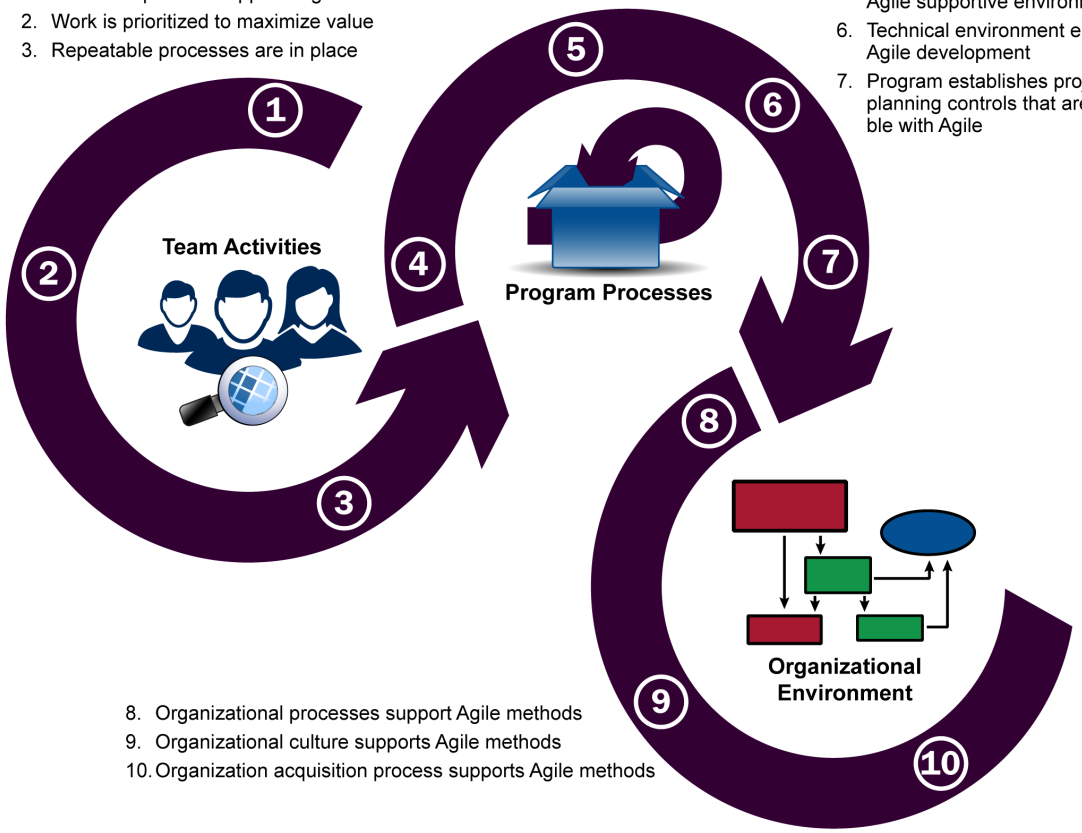
GAO is currently working to develop the Agile Assessment Guide exposure draft. Expected out on the GAO webpage: Fall 2019

Agile Adoption Best Practices

Chapter 3

1. Team composition supports Agile methods
2. Work is prioritized to maximize value
3. Repeatable processes are in place

4. Staff are appropriately trained in Agile methods
5. Management has established an Agile supportive environment
6. Technical environment enables Agile development
7. Program establishes project planning controls that are compatible with Agile



8. Organizational processes support Agile methods
9. Organizational culture supports Agile methods
10. Organization acquisition process supports Agile methods

Source: Goes here | Product #

Agile and Contracting Best Practices

Chapter 7

Best Practice	Summary
Tailor contract structure and inputs to align with Agile practices	• Encourage the use of modular contracting. • Establish contract with sufficient structure to protect all parties and achieve the desired mission outcomes, while offering flexibility for adaptation of software requirements. • Decide whether the contract should be structured for deliverables or services.
Incorporate Agile metrics, tools, and lessons learned from retrospectives during the contract oversight process	• Ensure that contract data requirements rely extensively on Agile metrics • Collect actual data from the program's releases, features, and capabilities to enable contract oversight and hold contractors accountable for producing quality deliverables • Enable retrospectives to allow stakeholders to interact with the development team and the product owner to continually improve Agile methods based on lessons learned. • Ensure that contract oversight reviews align with the program's Agile processes and cadence.
Integrate the program office and development teams	• Develop a common understanding of Agile techniques among the development and the acquisition teams so that an acquisition strategy can be properly structured. • Train contracting personnel to enable an Agile mindset. • Identify clear roles for contract oversight and management, including a designated user with authority to make decisions quickly and to prioritize requirements within the scope of the project road map. • Ensure that all personnel are familiar with the contract's scope to identify and minimize when a contract needs to be modified .

Agile and Program Controls
Chapter 9: Overview

- The chapter discusses developing a work breakdown structure (WBS) used by management and Agile teams to provide a clear picture of the total scope of work necessary to meet a program's requirements

- Cost estimating, scheduling, and earned value management (EVM) best practices established in earlier guides are still applicable to Agile projects
  - The chapter also highlights considerations for each item. For example
    - Cost Estimating: Sizing
    - Scheduling: Minimizing constraints
    - EVM: Calculating variances

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Conclusions

- The GAO TRA Guide, Cost Guide, Schedule Guide and Agile Guide provide criteria to evaluate many types of large technology-oriented, capital acquisition projects, and other government programs.
- Risk assessments such as technology readiness assessments, and independent cost and schedule assessments are often not performed – or are incomplete or lacking in independence, resulting in significant program risk and cost overruns.
- GAO recommendations have been aimed at improving oversight to keep projects on cost and schedule and to manage critical technologies in complex acquisitions.
- Programs/projects which follow the best practices demonstrate greater success in terms of outcomes and resource utilization.

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Thank you

Guides Available Online and Downloadable in PDF:

GAO Cost Estimating and Assessment Guide:
http://www.gao.gov/products/GAO-09-3SP

GAO Schedule Assessment Guide:
http://www.gao.gov/products/GAO-12-120G

GAO Technology Readiness Assessment Guide:
http://www.gao.gov/products/GAO-16-410G

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GAO ARM Cost Engineering Sciences

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GAO on the Web

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Additional Case Studies

BACK UP

COST BEST PRACTICE INFO

Step 1: Define the Estimate's Purpose

- A cost estimate's scope is determined by the customer's needs
  - Scope is driven by the program phase and the availability of data.
- A program's purpose should relate to agency missions, goals, and objectives
  - The estimate's purpose should address benefits and performance measures.
- The following are examples of what an estimate's purpose can be
  - Help managers evaluate and select alternative systems and solutions
  - Support the budget process by providing estimates of the funding required to efficiently execute a program
  - Provide valuable data for use in trade studies, independent reviews, and evaluating baseline changes.

Step 2: Develop the Estimating Plan

- The following should be included as part of the estimating plan
  - Determine the estimate's schedule
  - Determine members of the estimating team.

- In order to ensure that a consistent plan is used across estimates, it is beneficial to develop a centralized cost team and process. This results in
  - Standardized processes
  - A strong institutional structure and leadership support
  - Identification of resident experts
  - Sharing of resources
  - Commonality of cost estimating tools and training
  - More independence and less bias
  - Opportunities for advancement in the cost estimating field.

- The level of detail in the estimating plan is driven by the type of estimate to be developed.

Step 3: Define the Program

- Adequate information must be available to identify the technical and programmatic parameters on which to base the estimate.
- A best practice is to include this information in a single document called a Technical Baseline Description
  - The technical baseline should be developed by qualified personnel
  - The technical baseline should include technical, programmatic and schedule information.
- The accuracy of the cost estimate depends on how well the program is defined
  - The program definition serves as the basis for developing any cost estimate.

Step 4: Determine the Estimating Approach

- A Work Breakdown Structure (WBS) defines in detail the work necessary to meet program objectives
  - The WBS should be product-oriented and hierarchical
  - In addition to product-oriented elements, a WBS should include other common elements like program management, systems engineering, and systems test and evaluation.
- The WBS is updated as the program changes and becomes better defined.

Step 5: Identify Ground Rules and Assumptions

- Cost estimates are based on limited information.
- Ground rules and assumptions (GR&A) help establish the estimate's boundaries
  - **Ground rules**: a common set of agreed upon estimating standards that provide guidance and minimize definition conflicts
  - **Assumptions**: are made in the absence of ground rules; they are judgments about past, present, or future conditions.
- Both ground rules and assumptions should be tested and adjusted for risk (see steps 8 and 9).

Step 6: Obtain Data

- Data are the foundation of every cost estimate
  - The quality of the data affects the overall credibility of the cost estimate
  - Crosschecking different data sets for concurrence provides a high degree of confidence in the data.
- Estimators rely on data from existing programs in order to estimate the cost of new programs.
- All WBS elements will need data for support
  - Both cost and noncost data are needed to support various estimating techniques.

Step 7: Develop the Point Estimate and Compare It to an Independent Cost Estimate

- In order to develop a point estimate, an estimator must
  - Develop the cost estimate for each WBS element
    - Add all WBS elements to develop the overall point estimate
  - Include all estimating assumptions in the cost model
  - Express costs in constant-year dollars
  - Time-phase the results by spreading the costs in the years they are expected to occur based on the program schedule.

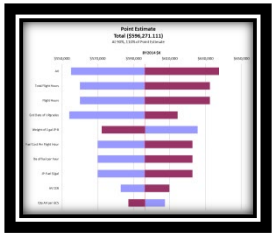
- Once the overall point estimate has been developed, the estimator must then
  - Validate the estimate
  - Compare the estimate to an independent cost estimate
  - Perform crosschecks on cost drivers
  - Update the model as more data become available.

Step 8: Conduct Sensitivity Analysis

- All estimates are uncertain and sensitivity analysis helps create a range of best and worst case costs.

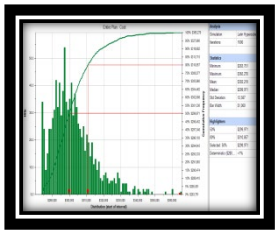
- What is sensitivity analysis?
  - Sensitivity analysis is the examination of the effect of changing one assumption or cost driver at a time while holding all other variables constant
  - The result is that it is easier to understand which variable most affects the cost estimate.

- Sensitivity analysis is useful because it
  - Establishes a method for performing what-if analysis
  - Provides a range of possible costs in addition to a point estimate
  - Provides a careful assessment of what drives that range
    - Identifies the underlying risks
    - Supporting data are necessary for making informed decisions
  - Can help determine what level of risk reserve may be required
  - Can help decision makers choose alternatives.



Step 9: Conduct Risk and Uncertainty Analysis

- Risk vs. Uncertainty
  - **Risk** is the chance of loss or injury; it is the probability of an unfavorable event
  - **Uncertainty** is the indefiniteness about the outcome of a situation; it is assessed in cost estimate models to estimate the probability that a specific funding level will be exceeded.
- Uncertainty analysis is used to capture the cumulative effect of risks
  - Uncertainty is present in all estimates since the future is always unknown. Therefore, a point estimate, by itself, is meaningless.



- Cost risk analysis aims to
  - Identify program level confidence for development schedules
  - Provide credibility to the target estimate and budget
  - Identify technical, schedule, and cost estimating risk drivers for use in risk management.

Step 10: Document the Estimate

- Thorough documentation presents a convincing argument for why an estimate is valid
  - "Thorough" indicates that someone unfamiliar with the estimate will be able to update or recreate the estimate from its documentation.

- Good documentation describes the estimating process, data sources, and methodologies
  - Documentation should occur in parallel with the estimating process and not be done at the last minute as an afterthought.

Step 11: Present the Estimate to Management

- Management must approve estimates before they can be considered valid.

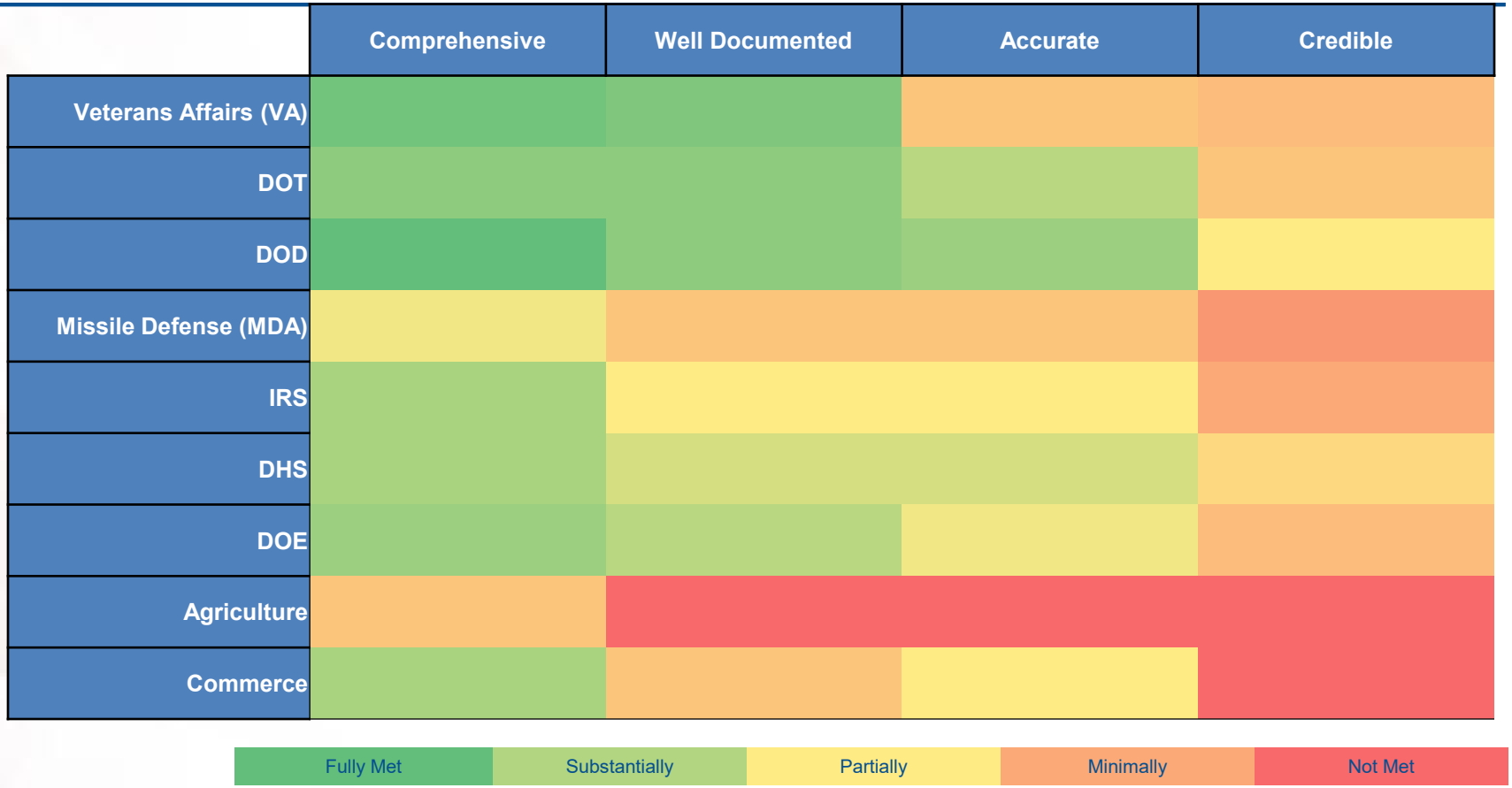
- Cost estimators should prepare a briefing for decision makers that
  - Provides the final cost estimate's outcome
  - Illustrates key points regarding the cost drivers
  - Provides program and technical information specific to the program
  - Displays budget implications.

- After the briefing, actions and management approval should be acted on and recorded as part of the cost estimate documentation.

Step 12: Update the Estimate to Reflect Actual Costs and Changes

- The estimate must be updated to reflect changes in assumptions and to keep it current
  - Replace estimates with independent estimates at completion (EAC) from the integrated Earned Value Management (EVM) system
  - Report progress on meeting cost and schedule estimates
  - Perform a post mortem and document lessons learned
  - Document all changes to the program and how they affect the cost estimate.

Cost Estimating: Audit Findings



Data based on agencies and departments with three or more GAO cost estimate assessments

COST GUIDE CONTINUED: EARNED VALUE MANAGEMENT (EVM) BEST PRACTICES

What is EVM?

EVM is an important management decision support tool

- EVM indicates how past performance may affect future performance
  - The data isolates cost and schedule variances by WBS elements allowing for:
    - An understanding of technical problems
    - Opportunities to reallocate effort to mitigate risk or address issues

- The two main purposes for implementing an EVM system are to:
  1. Encourage the use of effective internal cost and schedule management controls
  2. Allow the customer to rely on timely and accurate data for determining contract performance

EVM Data and Reliability

- For EVM data to be of any value it must be reliable
  - The data should be generated by a system that has been deemed compliant with ANSI EIA 32 guidelines
  - The performance measurement baseline should be validated by an Integrated Baseline Review (IBR) in a timely manner
  - EVM surveillance by independent and qualified staff should be continually monitoring the implementation of the system
  - The contractor's financial accounting system has received an unqualified opinion
  - Data anomalies like negative values for BCWS, BCWP, and ACWP or missing performance data (e.g., BCWP with no BCWS or ACWP) should be rare
    - If these anomalies occur they should be fully explained in the variance analysis portion of the report

Thirteen Steps in the EVM Process

1. Define the scope of work using a WBS
2. Identify who in the organization will perform the work
3. Schedule the work
4. Estimate the labor and material required and authorize budgets including MR
5. Determine objective measure of earned value
6. Develop the performance measurement baseline
7. Execute the work plan and record all costs
8. Analyze EVM performance data and record variances from PMB plan
9. Forecast EACs using EVM
10. Conduct an integrated cost-schedule risk analysis
11. Compare EACs from EVM in Step 9 with EAC from risk analysis in Step 10
12. Take management action to mitigate risks
13. Update the PMB as changes occur

Characteristics of a Reliable EVM System

Is the EVM system certified and comprehensive?	Is the EVM data reliable?	Is Management using the EVM data?
Comprehensive	**Accurate**	**Informative**
• Certified EVM system • IBR conducted • Reliable schedule • EVM surveillance	• No data anomalies • Consistent data • Realistic EAC	• Regular reviews conducted • Corrective action plans • Updated PMB

GAO and EVM Best Practices

Recent Audit Findings

Lack of product-oriented WBS	Underlying schedules do not meet best practices	IBRs not timely or robust
Programs often re-baselined due to optimistic cost and schedule estimates	EVM data anomalies are widespread and recurring	Variance analyses are often too vague to be useful and do not address corrective actions
EVM data not integrated with risk management process	Lack of training for government and contractor staff	Contractors not properly implementing their EVM systems

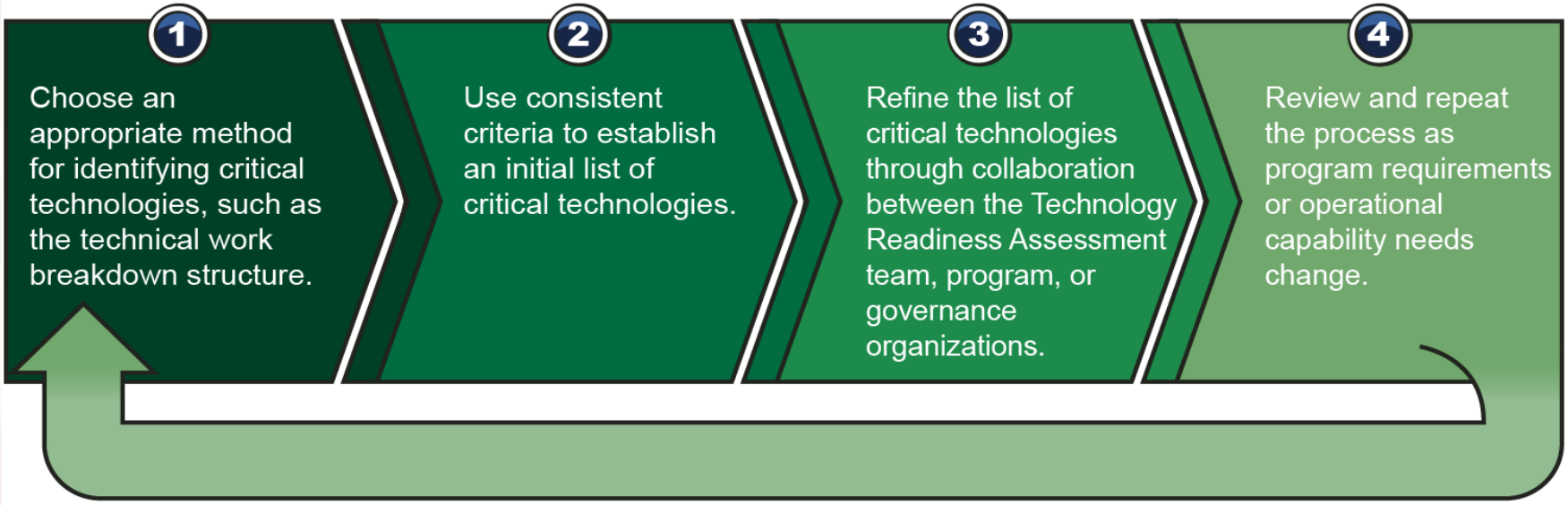
ADDITIONAL TRA INFO

Technology Readiness Levels

Technology readiness level (TRL)	Description
1 Basic principles observed and reported	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development. Examples include paper studies of a technology's basic properties.
2 Technology concept and/or application formulated	Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative, and there may be no proof or detailed analysis to support the assumptions. Examples are limited to analytic studies.
3 Analytical and experimental critical function and/or characteristic proof of concept	Active research and development is initiated. This includes analytical studies and laboratory studies to physically validate the analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.
4 Component and/or breadboard validation in laboratory environment	Basic technological components are integrated to establish that they will work together. This is relatively low fidelity compared with the eventual system. Examples include integration of ad hoc hardware in the laboratory.
5 Component and/or breadboard validation in relevant environment	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so they can be tested in a simulated environment. Examples include high fidelity laboratory integration of components.
6 System/subsystem model or prototype demonstration in a relevant environment	Representative model or prototype system, which is well beyond that of TRL 5, is tested in its relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high-fidelity laboratory environment or in a simulated operational environment.
7 System prototype demonstration in an operational environment	Prototype near or at planned operational system. Represents a major step up from TRL 6 by requirement demonstration of an actual system prototype in an operational environment (e.g., in an aircraft, a vehicle, or space).
8 Actual system completed and qualified through test and demonstration	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation of the system in its intended weapon system to determine if it meets design specifications.
9 Actual system proven through successful mission operations	Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation. Examples include using the system under operational mission conditions.

Source: GAO simplification of agency documents. | GAO-16-410G

Step 3: Select Critical Technologies



Source: GAO analysis and subject matter expert input. | GAO-16-410G

Best Practice Checklist: Selecting Critical Technologies

- A rigorous, objective, reliable, and documented approach, based on the WBS or other key program documents was used to initially identify critical technology candidates.
- The intended operational environment was considered, including potential adverse interactions with systems which the technology being developed must interface.
- A relevant environment was derived for each critical technology from those aspects of the operational environment that is determined to be a risk for the successful operation of that technology.
- Critical technologies were initially selected following a reliable process that is disciplined and repeatable with defined criteria using increasingly platform- or program-specific questions and requirements.
- Critical technologies were defined at a level that is testable, which could include the software needed to demonstrate their functionality.
- The assessment team documented the reasons why technologies were selected as critical, including reasons why other technologies were not selected.
- The number of critical technologies chosen for assessment was not arbitrary but was based on solid analysis using the WBS, process flows, or other technical documentation.
- When significant program changes occurred, critical technologies were reassessed possibly causing some to be added or removed from the list of critical technologies.
- Subject matter experts with appropriate and diverse knowledge selected and reviewed the critical technologies.