Technology, Planning and Integration for Observation (TPIO) Trade-Space Analysis Guide

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Introduction

Trade-space analysis consists of examination and evaluation of alternative ways of achieving outcomes within the context of a specific decision to be made or problem to be addressed. The Technology, Planning and Integration for Observation (TPIO) program has developed trade-space analysis processes to support the National Oceanic and Atmospheric Administration (NOAA) Observing System Council (NOSC) in its responsibility to review observing system initiatives and provide funding recommendations to NOAA leadership. The emphasis in those processes is on evaluating performance of observing alternatives with respect to functional (observing) requirements.

Based on that experience, as well as experience with and research into other Government trade-space analyses, TPIO has developed this trade-space analysis guide (TSAG). It is intended for NOAA personnel who participate in, execute, and lead studies that fall under the umbrella of trade-space analysis (e.g., an analysis of alternatives, a cost-benefit analysis, or an integrated (portfolio) analysis of observing capabilities). The TSAG focuses on the *essential* information of the analysis process to allow users to more rapidly establish an understanding of the key efforts to be accomplished. It provides guidance and selected examples to explain how to perform trade-space analyses and provides tips for executing a trade-space analysis. Use of this TSAG is intended to promote targeted and robust analysis, improved consistency of these studies within NOAA, and further effectiveness, efficiency, and affordability of NOAA's overall portfolio[1].

Trade-space analysis can be applied to different levels of decision-making, at different times in the fiscal year, and at different organizational levels. Trade-space analysis can scale from examining fulfillment of different levels of requirement(s) within a single system/program; to examining alternative solutions to fulfill a single new requirement or capability need; to fulfilling multiple requirements/capability needs at a system, system-of-systems, portfolio, or enterprise level. Trade-space analysis may be conducted at specific times (e.g., supporting the regular budget cycle) or may be triggered by specific events (e.g., when a program is defining its system requirements and program baseline, or undergoing a high level external review). Trade-space analysis is particularly pertinent in times of significant budget constraints and reductions; if constructed and conducted properly it provides insights to evaluate and balance cost, schedule, risk, performance and capability objectives and to define "reasonable" solutions that offer NOAA greatest overall value.

Appendices to this guide are used to provide selected details regarding key elements of the trade-space analysis process; this information should help provide a deeper understanding of this subject matter. A glossary of terms is also provided for clarity (particularly where information or definitions are used that require additional explanation).

This guide should be considered a "living resource" and will be updated based on feedback and new information from implementation experience.

[1] In this case the overall NOAA portfolio consists of resources used to execute NOAA's Next Generation Strategic Plan.

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1 NOAA Trade-Space Analysis Overview

General information regarding the focus of trade-space analysis, the analyses that can fall under the "trade-space analysis" umbrella, motivation/triggers for doing trade-space analysis, and relationship to organizational processes within NOAA are discussed within this section.

In general, *trade-space analysis*[2] consists of examination and evaluation of alternative ways of achieving outcomes within the context of a specific decision to be made or problem to be addressed. The "trade-space" addresses the multiple criteria relevant to the decisions; these can be traded off against one another to achieve specific outcomes and are reflected in the form of specific alternative solutions. Typical criteria include performance/benefits, schedule, risk, and cost. Political, societal, environmental, and cultural dimensions may also be considered; for example, the potential socio-economic impact of proposed new fishing regulations on fishing communities may have to be assessed. These criteria are assessed for each alternative and compared to determine their relative influence on desired outcomes. The analysis reveals possible additional trade-offs, potential points of diminishing returns, areas where further analysis might be needed, and the relative value of each alternative or combination of alternatives vis-à-vis the outcomes to be achieved.

1.1 Types of Trade-Space Analysis

Within the Federal Government there are many types of trade-space analyses that are common; these include *alternatives analysis*, *analysis of alternatives*, *business case analysis*, *cost-benefit and cost-effectiveness analysis*, *economic analysis*, and *portfolio analysis* (a major element of portfolio management). Most of these share a common analysis thread that compares alternatives based on assessment of cost and some measure(s) of benefit. Specific considerations of non-quantifiable benefits as well as consideration of risk and schedule differ across these analyses. This common thread as well as these differentiated elements will be tailored to NOAA for the purposes of this guide. Key to all of these analyses is assessment of overall value, efficiency, and affordability.

1.2 Process Triggers

There are multiple directives and processes (both internal and external) that require or strongly suggest that NOAA organizations perform trade-space studies. These directives come from NOAA (e.g., studies directed through the Annual Guidance Memorandum (AGM) or Corporate Portfolio Analysis, or supporting the budgeting process), the Department of Commerce (DoC), the Office of Management and Budget (OMB), and the Government Accountability Office (GAO).[3] In addition, there are specific events (e.g., an upcoming system "end of life" issue, or schedule and cost overruns) that could trigger a trade-space analysis within a program or at a broader portfolio level.

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[2] Terms in blue italic font are defined (with references, when appropriate) in the Glossary of Terms at the end of the document. They are highlighted only on their first occurrence.

[3] See references 1 through 7 for some key directives and guides. References 8 and 9 provide GAO guidance relevant to trade-space analysis.

While some studies cannot be anticipated (e.g., a new responsibility or new requirement for NOAA), the need for others may be identified based on a thorough understanding of regulatory requirements (e.g., whether an acquisition or investment is classified as information technology) and NOAA roles as a user and a trusted provider of specific information and capabilities.

Given the diversity of analyses that may be needed, and the various directives and guides that may drive them, study leaders and participants should consult with appropriate NOAA or Departmental leadership to determine which directives and guides apply to their plans or situation, and to what degree.

1.3 Relationship to TPIO's Processes

NOAA organizations considering performing a trade-space analysis should be aware of the processes and capabilities employed by the *Technology Planning and Integration for Observation* (TPIO) program, particularly if the alternatives being considered involve observing systems. TPIO's processes were developed to support the *NOAA Observing Systems Council* (NOSC) in its responsibility to review observing system initiatives and provide funding recommendations to NOAA leadership. Their focus is on observing alternatives and, to a more limited extent, data management systems associated with observing. TPIO's processes address several analysis elements discussed in this guide, with a particular emphasis on evaluating the performance of observing alternatives with respect to documented functional (observing) requirements.

For example, TPIO developed and implemented a portfolio analysis approach that was used to identify portfolios of environmental observing systems that best satisfy NOAA's mission-critical observing requirements at target budget constraints [10]. TPIO is also supporting the NOAA Observing System Integrated Analysis (NOSIA), a pilot study that is examining NOAA's upper air observation requirements and observing systems in order to develop a recommended multi-year portfolio investment strategy/roadmap for NOAA's upper air observing systems. The NOSIA analysis is being conducted for the NOSC by a team that includes members from line offices across NOAA and the NOSC's Observing Systems Committee (OSC).

TPIO's processes provide a concrete example of trade-space analysis that has been tailored to address NOAA-specific organizations and processes and that may provide support for similar studies performed by other NOAA units. It is suggested that organizations preparing to conduct such analyses consult with TPIO to take advantage of this experience.

As of FY 2012, TPIO's processes are undergoing revision to reflect the changes accompanying NOAA's transition from the *Planning, Programming, Budgeting, and Execution System* (PPBES) to the *Strategy Execution and Evaluation (SEE)* process and basic elements of the TPIO process are expected to persist. For example, TPIO will be re-mapping the program-specific observing requirements to the new NOAA strategic objectives. Also, since 2005, TPIO has worked with NOAA leadership and program managers to prioritize observing requirements with respect to the agency's goals and mission, and these priorities will need to be updated to align with the new NOAA strategic goals and objectives.

1.4 Report Outline

Section 2 discusses planning and management of a trade-space analysis. Section 3 provides an overview of the trade-space analysis process, including its component analyses (cost,

performance/benefit, risk, and schedule assessments). Section 4 provides tips for successful completion of a trade-space analysis, and Section 5 presents a summary and conclusions.

Several appendices, provided in a separate volume, provide details of key elements of the trade-space analysis process; this information should help provide a deeper understanding of this subject matter.

2 Planning for and Managing a Trade-Space Analysis

In order to achieve desired outcomes, the analysis team must spend significant time in planning for, coordinating, and managing the analysis. In particular, specific attention must be paid to the decisions the analysis is intended to inform, the people, the funding, the schedule, and required communication/documentation. These elements are linked and should be aligned to ensure consistency. In addition, the team may be required to update the analysis in the future; thus it is important to plan for the retention of the analysis artifacts.

2.1 Define the Decision

At the outset of any trade-space analysis, it is essential to identify the decision(s) the analysis is intended to support, as specifically as possible. This includes not only understanding the "who" and "how" (the decision making authorities and their processes) and the "why", but also defining the level of criticality of the decision (how severe is the impact if we make the wrong decision, or don't make a decision?) and when the decision is needed. In addition, the scope of the trade-space analysis that will be required to support the decision should be defined (e.g., is this a portfolio analysis or analysis of individual solutions to meet a specific requirement?). This information will shape the entire effort, helping determine data/information requirements, participants, analysis methods to provide the necessary level of rigor, and the resources and time needed. (Alternatively, if the resources available to conduct the study are fixed, the scope and level of rigor of the study may have to be adapted to that constraint.)

2.2 Identify the People

Typically multiple individuals and organizations participate in, guide or influence a trade-space analysis. At various levels and with specific roles and responsibilities, these include organization leaders, decision makers, decision stakeholders, as well as the analysts and subject matter experts (SMEs) tasked to conduct the analysis. Identifying early the individuals with the appropriate skills, organizational perspectives and authorities; specifying 'rules of engagement' for interaction throughout the analysis; and gaining and maintaining "buy-in" on objectives and execution plans are all critical to the success of the trade-space analysis. It is vital to develop and implement an outreach plan to identify the right people and gain commitment from their organization for timely access and support for their continued participation. This may require developing new contacts and outreach strategies.

Key individuals or groups of individuals that should be identified are:

- *Decision Maker*. The decision maker (or decision-making body) will typically be outside of the trade-space analysis team. In many but not all cases the person or organization that directed the analysis will be the decision maker. The analysis leader should ensure that the decision maker is known and agrees with the trade-space analysis structure, execution plan and key products intended to inform the decision(s). Learning about the decision environment is advantageous early in the process. Understanding how best to engage with the decision maker (e.g., when to obtain a vector check) should be part of this process.

- *Core Team*. The core team consists of a leadership team for the overall analysis and those persons responsible for specific analytic or foundational components (e.g., cost analysis). The core team will drive the approach, content, contributions, coordination, progress, and completion of the analysis. The composition and size of this team will vary based on the decision, the domain, the available resources, the timeline, and the criticality of the analysis. It is essential to have a Government lead who can readily engage with individuals/organizations outside the core team responsible for the overall effort; the Government lead may appoint a co-lead or director to share leadership of the core team and shape the overall direction and content of the work. The remaining core team members provide specific analytic, technical, and foundational elements. *Integrated product teams* (IPTs) may be formed to provide the necessary work in these elements with the IPT leads being part of the core team. The core team members are the chief communicators (internally and externally) and must be coordinated and aligned in their work and their messages. It is crucial for the core team to discuss and coordinate the interdependencies across the technical, cost, performance/benefit, risk, and schedule assessment elements of the analysis.
- *Subject Matter Experts*. Specific domain or technology expertise (e.g., forecasting methods and products, information ingest and processing techniques) may be needed to provide the core team critical information to support the analysis. Ensuring timely access to these SMEs must be planned for and likely worked through specific line or staff offices.
- *Other Stakeholders*. Multiple organizations and individuals may have "equities" within the trade-space. Stakeholders are generally defined as those individuals and groups that perceive themselves to be impacted, either positively or negatively, by a decision or outcome and therefore have an interest or stake in that decision; stakeholders are also those who have influence or power in a process. Stakeholders' interests in an issue can be monetary, mission/operational, professional, personal, cultural, or can arise from a host of other motivations. A stakeholder analysis can be performed to identify and understand the stakeholders (e.g., who they are, what they want, and how much influence they have). NOAA's Coastal Services Center has developed useful guidance on stakeholder analysis [11].

2.3 Obtain the Funding

The amount of funding required for a trade-space analysis should align with the scope and schedule of the effort and the number of core team and SME participants (and their need for support). Required funding will include contracting for appropriate personnel (primarily non-Government), purchase of tools, gaining access to necessary data (via subscription, service, or purchase), travel, etc. To estimate required resources, it is best to define detailed work plans for the core team and identify and allow for potential changes in scope, approach and schedule. Commitment of funds from the funding sources should be obtained against an established and well documented analysis scope and work plan. Changes that fall outside the scope of the defined plan may warrant additional funds only if they can be shown to be beyond the scope of the plan.

2.4 Define the Analysis Schedule

A schedule for the analysis must be created to actively monitor, measure, and manage individual tasks and overall progress. It should have enough detail to enable appropriate planning by all contributors. Starting with the deadline for the final product or agency decision point, the lead for the analysis must work backward and establish the overall schedule, with specific milestones for reviews/status updates with the decision maker and other stakeholders, internal team and external meetings, and interim and final product deliverables. The overall schedule provides the basis for identifying specific activity timelines, due dates, and deliverables and should provide insight into linkages/dependencies among specific activities. It should also allow determination of the *critical path*[4] providing insight to the feasibility of meeting decision maker deadlines.

When building a schedule, key questions to be answered include the following:

- Can the analysis be conducted in the time allotted overall, to meet milestones, and to complete all efforts?
- Have we accounted for possible delays in obtaining needed data, for travel to support data gathering and face-to-face meetings?
- Have we allowed sufficient time for integrating all analysis components and developing key findings?
- Have we accounted for all reviews?
- Have we accounted for documentation needs—including rework—and ensuring consistency (a "single voice")?
- Is there any slack—"wiggle room"—in the schedule in case something is missed or guidance requires changes or additional efforts?
- Is there any way to reduce the time required for, or scope of, certain activities without compromising quality?
- Is there any practical way to perform some tasks in parallel without compromising the individual tasks?

If the schedule seems infeasible, the lead may need to revisit the tasking with the decision maker to see if change is needed (e.g., additional time). The schedule should be kept up to date and communicated to all participants and stakeholders to ensure a common understanding of the timeline. All team members must buy into the established schedule and their critical path deliverables.

2.5 Plan for Communication and Documentation

Communication about the trade-space analysis across interested individuals and organizations is important to maintaining motivation, commitment, buy-in, and progress. It should also help, along with other planning elements, to minimize disruptions during the conduct of the work. The core team must determine what communication channels are best (e.g., face-to-face meetings, e-mails, written documentation, webinars, etc.) and what formal and

[4] The longest sequence of activities in a project plan, accounting for dependencies, which must be completed on time for the project to complete on the due date

informal products are required to communicate information about the analysis. To ensure efficient and effective communication, consider the purpose, the audience, and what drives and satisfies needs. Typical products include:

- *Terms of Reference (TOR)*. The TOR typically describes the purpose and structure of the trade-space analysis and can be considered the charter; it is typically not more than a few pages and summarizes background, scope, general approach, deliverables/milestones, structure of the final deliverable, and organizational structures/membership. The TOR is developed prior to the start of an analysis.
- *Analysis Plan*. A major step leading to a successful trade-space analysis is the creation of a well-considered analysis plan. The plan establishes a roadmap of how the analysis must proceed, including responsibilities of individuals (who, why, and for what part of the analysis). Time and effort spent on the plan before beginning the analysis helps to ensure a high quality analysis, on schedule and within budget. The plan should be structured so that it can be used in the development of the analysis report. It is a living document that should be updated throughout the effort to reflect new information and changing perceptions and direction. A team-wide review of the plan is useful in improving the plan and ensuring support for its execution. A draft plan may also serve as an analysis proposal for seeking resources.
- *Analysis Report*. The analysis report provides the results of the analysis and all supporting information. Typically interim and final reports are provided, primarily in a document form; however, briefings may be used for the interim report. The interim report presents information and results or findings up to a pre-determined date; it often serves a purpose of soliciting feedback or guidance concerning expectations for the final product. The final report should present the key findings (and recommendations, if warranted) aligned to the analysis purpose/objectives, in a form and length appropriate for the decision maker. It should document the analysis purpose, scope, methods and provide all supporting information including data/data sources, and results of each analysis component. Appendices can be used as needed to present detailed information (e.g., cost estimates) to avoid excess length of the main document. It is important that the target audience and distribution list for the report be determined, as there may be a need for different versions depending on the audience. Because these reports may in some cases be used in other analyses or studies conducted by different personnel or organizations, the data presented should be clear so that it is not easily misinterpreted or leveraged improperly in a different context. In all reports and briefing products, information that is sensitive to an organization or program must be identified and appropriate distribution controls placed on the document.
- *Briefings*. Briefings may be developed to convey information about the trade-space analysis targeted for specific purposes and audiences. These can include briefings for information only, for status updates, to solicit information/data, to present results, and to inform a decision. As the effort progresses, it may be possible to reuse materials developed for a particular purpose, for example, specific foundational information such as the background, purpose, and schedule/milestones. It is critical to understand each briefing's purpose and target audience so that relevant and appropriate material can be developed.

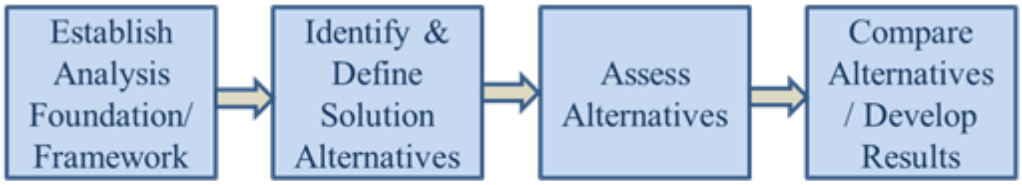
- *Other Products*. Other types of products may be required; these can include e-mail announcements, requests for information to support specific analytic components or objectives, short white papers for various audiences or stakeholders, and websites or data repositories that hold specific data and/or are used to provide updates to the core team and other stakeholders.
- *Lessons Learned*. Best practices dictate the collection of lessons learned at the completion of a trade-space analysis to determine what worked and what could be improved in the future. At a minimum, lessons learned should be collected and documented within a week of completion of the study while the experience is fresh. It may also be valuable to revisit lessons learned around a month after completion to allow for a considered assessment and to pick up things that may have been missed initially. Collection of lessons learned should be scheduled, specific questions/topics should be outlined (based on key elements of the trade-space analysis), and participants should be made aware of this activity at the outset of the analysis. Free-form discussion is also important to ensure stakeholders have the opportunity to provide feedback to the study team. In addition, for longer duration trade-space analyses, it may be helpful to collect lessons learned at a mid-point to aid in developing any course corrections.

2.6 Update the Analysis

The following sections discuss the process and conduct of an analysis; it is important to consider in the planning that updates may be required. There are multiple reasons why updates might be required or desired; these may include changes to key elements on which the analysis was predicated (e.g., a major change in technology availability), the need for additional analytic depth, the relationship to another analysis or study being conducted that requires current data, internal NOAA needs, and/or external needs (e.g., OMB). Having sufficient documentation for the original work to ensure understanding of the analysis and the traceability to recommendations is critical.

3 Trade-Space Analysis Process Overview

A process for conducting trade-space analysis is summarized in Figure 3-1. Each step is discussed in this section. The process is depicted serially; however, in reality it is iterative. Steps are revisited and updated as new information emerges from the individual analysis components and feedback is received from reviews within the team and with leadership and stakeholders. The process should be tailored for each analysis to ensure objectives are addressed within constraints.



While depicted as serial, this is an iterative process; as data is received, reviewed and analyzed, specific steps may need to be revisited and re-assessed/aligned

Figure 3-1. Overview of Trade-Space Analysis Process

3.1 Establish Analysis Foundation and Framework

In this step the foundation for the analysis is developed. Key elements are defined, including a clear statement of the problem, foundational information (information within and external to NOAA that will impact and provide a context for the analysis), the scope, and the analysis framework. In addition, specific analytic data needs are identified and an initial data collection plan is developed.

3.1.1 Develop Problem Statement

It is critical for the team to understand the motivation, purpose, and objectives for the analysis and be able to articulate a specific problem statement that is understood and agreed to by the decision maker and other stakeholders. The problem statement should reflect the decision to be made. The analysis motivation and purpose are sometimes discussed in the context of the organization's mission and needs to examine alternatives to overcome some operational or financial deficiency. Two examples of problem statements are provided below [12, 13].

***Example Problem Statement 1**: The continuous and consistent record of Ocean Color (OC) data is at risk of being interrupted, primarily due to end-of-life issues with current OC observation sources. By December 2009, the NOSC must decide how to mitigate the potential disruption of OC data. This analysis will examine and assess near term mitigation alternatives, from satellite sources only, to determine and recommend to the NOSC, by September 2009, the best approach to ensure continuity of OC data until the 2011 launch of the Visible/Infrared Imager Radiometer Suite (VIIRS) on the National Polar-orbiting Operational Environmental Satellite System (NPOESS) Preparatory Project (NPP).*

***Example Problem Statement 2**: NOAA relies on Earth observations from more than 200 observing systems. As the size, complexity, and cost of these systems increase, the question of which systems or combinations of systems add the greatest value becomes foremost. Motivated by an increasingly austere budget environment, NOAA leadership identified the need to analyze NOAA's observing system architecture in an integrated way, such that the relative contributions of each system to the system-of-systems as a whole could be more clearly understood and used to inform investment decisions. In 2012, this analysis will produce a recommended roadmap, based on a set of optimized observing system portfolios, which address NOAA's upper air observing needs. The roadmap will include recommendations needed to execute time-phased investments to achieve a more cost-effective integration of existing and future observing systems.*

3.1.2 Identify and Collect Foundational Information

Key information that relates to the analysis must be identified, collected, and/or developed to set the context for the trade-space analysis. Foundational information includes the needs that must be met (e.g., capabilities, specified requirements, identified gaps, etc.) and the time frame in which a solution is needed. In addition, it is imperative to understand the pertinent operational and regulatory aspects of the problem, including the missions supported, the concept of operations (CONOPS) or concept of employment (CONEMP), the environments in which these capabilities will be operated (there may be one or more scenarios that capture this aspect of the trade-space), architecture, infrastructure, regulations, standards, policies, and agreements (to include agency-to-agency and international partnerships).

A starting point must also be established; we call this the "current situation". It describes how the problem or area of interest is being addressed today. The team will delineate the extent to which the defined needs are currently met and how they are being fulfilled, including identifying what systems and supporting infrastructure are being used (and what they are dependent upon), specifying the programmatic information for these systems and infrastructure (e.g., schedules, funding profiles, and risk profiles), defining what (if any) products are being supported, delineating what policies and agreements are being maintained, and describing what organizations support and benefit from these capabilities.

3.1.3 Define Analysis Scope

Based on the problem statement, decision for which the analysis is being undertaken, and the foundational information, the analysis scope is defined. The core team must work closely with the decision maker to develop a reasonable and executable analysis scope and must revisit (and possibly update) the scope if the situation changes and as information and knowledge evolve during the conduct of the work. Note the scope should align with the schedule and resources committed to accomplish the analysis.

Ground rules and *assumptions* (GR&A) for the analysis should be developed at the inception of the trade-space analysis and evolved to reflect new information received as it progresses. Ground rules (also called constraints or boundary conditions) delineate what will and will not be addressed within the analysis to fulfill its stated objectives (e.g., specific elements of a typical trade-space analysis cannot be addressed or need to be deferred until boundary conditions are eased (e.g., more resources are provided). Assumptions that define other conditions that apply to the analysis may also be established. An assumption may be that legacy capabilities will meet a

certain level of needs up to some point in time. As guidance, issues, or changes, occur in the planning and execution of the analysis, the core team needs to understand what GR&As are changed and how this impacts the conduct of the trade-space analysis.

3.1.4 Develop Analysis Framework

In this step, the structure for the overall analysis and its components is established, defining methods and information needed to evaluate and compare alternatives. Specific criteria and associated measures to assess success in meeting objectives are defined. Typically criteria focus on cost, performance/benefit, risk, and schedule for delivering needed capability. Additional information on these criteria is presented in Section 3.3.

Typical criteria evaluated in a trade-space analysis are cost, performance/ benefit, risk, and schedule.

In some cases one or more financial metrics may also be derived to assess the relative merits of the alternatives under consideration; this assumes particular criteria have been evaluated and *monetized*.[5] A typical financial metric is *net present value* (NPV), which reflects the comparison of alternative costs and monetized benefits over time. Appendix A provides additional information about financial metrics with particular focus on NPV, including an example calculation.

3.1.5 Identify and Collect Necessary Analytic Data

Trade-space analyses must be data driven, and the goal of data collection is to obtain sufficient, robust data (i.e., high fidelity data from appropriate/authoritative sources that directly supports the defined criteria and measures for evaluating the alternative under consideration.

Earlier in this section we discussed collecting foundational information to set the context for the remainder of the trade-space analysis. Information also must be collected to ensure that alternatives are defined properly and that criteria (and related metrics) can be measured/assessed. Data must be analyzed to ensure its applicability and relevancy to the alternative under assessment in technical/functional, economic, operational, and other terms. Like ground rules and assumptions, data sources may come under great scrutiny and need to be vetted with the decision maker and other stakeholders for acceptance, particularly for data pertinent to analysis drivers.

The core team needs to determine what specific data they will need; identify and define data sources; and develop and plan a strategy to obtain data needed *within the identified schedule*. Sources can include internal or external SMEs (e.g., operations personnel); technical specialists; historical data; studies on similar subject matter, academic and government reports; program technical documentation and cost/engineering reports; contractor/ industry data; internal databases such as the *Consolidated Observation Requirement List* (CORL) and the *NOAA Observing Systems Architecture* (NOSA); external databases and data repositories; line/staff/ program offices, and engineering analysis and models. If needed data is not readily available, the team may need to conduct a data call, survey, request for information (RFI) within NOAA and/or external to NOAA (e.g., academic and industry partners), or issue a formal request to another Government organization (e.g., the military regarding specific technology). It is

[5] Monetized benefits are benefits expressed in terms of dollars. Monetizing may be relatively straightforward, or may require one or more assumptions to be made in order to derive a dollar value for an anticipated benefit—for example, the dollar value of more accurate predictions of the future path hurricane tracks.

important to understand whether some type of information request will be needed, as there could be significant time required to prepare, coordinate, and administer it to get the appropriate data.

3.2 Identify and Define Alternatives

In this step, multiple alternatives (sometimes known as courses of action) are identified to address the defined problem within the context and boundaries (scope) defined. These alternatives can be materiel solutions (i.e., new or modified physical equipment/systems) and non-materiel solutions (e.g., changes in policies or training). Initial research and brainstorming among the core team, with input from SMEs and stakeholders, should be completed to define a superset or wide range of alternatives that could be considered for the analysis. Within the brainstorming effort it is useful to consider, both individually and collectively, the multiple needs that the alternatives must satisfy to help broaden the number and types of alternatives considered. These alternatives should be vetted and a smaller set of feasible alternatives confirmed. For the final set of alternatives, a detailed definition or *technical baseline*[6] must be formulated for each to ensure appropriate and consistent evaluation of criteria (cost, schedule, performance/benefit and risk).

> *Experience has shown that selecting **too many** (versus too few) alternatives is the greater danger. It is important to consider the pros & cons of the number of alternatives before proceeding with additional analyses. The goal is to identify a set of feasible alternatives representing the solution space. The time needed to complete the analysis increases with the number of alternatives considered.*

It is typical to include an alternative that reflects continuation of the current course of action or "status quo" to show comparative cost/benefits of other alternatives over the system life. In some cases, however, the status quo can't be continued as is (e.g., system at end of useful life, spare parts are no longer available); in this case the status quo might not be included as an alternative, or an alternative that modifies/upgrades the current system is defined.

In general, the following factors should be considered in brainstorming and development of alternatives.

- Performance: The ability to meet (or nearly meet) defined performance requirements;
- Platform: Platforms that could be used to deliver the required functionality/capability as part of an alternative, e.g., aircraft, ships, satellite;
- Technology: The technologies needed to implement the functionality, e.g., space-based sensors, ground based radar, in-situ gauges, unmanned aircraft system; and the maturity and risks of these technologies;
- Operational environment: The environment(s) in which the alternatives must operate, e.g., desert, atmosphere, ocean, or space, or within specific temperature ranges;
- Schedule: The realistic timeframe in which it is feasible for the alternative to be fully deployed/operational, compared to the timeframe when the capability is needed;
- Other U.S./commercial/international capabilities: existing capabilities external to NOAA/U.S. Government (including Military Services) that can be adapted;

[6] A technical baseline defines and describes an alternative in sufficient detail to support estimating its life cycle cost and to allow evaluation of its technical, operational, cost, and implementation attributes in comparison to alternative approaches.

- External interfaces: Other systems with which the system must interface or has dependence upon;
- Architectures: The need for interoperability and integration with other architectures; and
- Supplementary Elements: Impacts on existing infrastructure, support capabilities, and personnel resources.

Once alternatives are developed, additional factors should be considered as a basis for initially filtering[7] non-feasible alternatives. This is important to do, both to keep the scope of the effort manageable and to make sure that only relevant information is presented to decision makers. These factors include:

- Cost: Unacceptably high cost (acquisition investment as well as operations/sustainment) based on a preliminary cost assessment, e.g., cost well in excess of budget plus uncertainty;
- Risk: Technical, cost and schedule risk is high relative to other feasible approaches for achieving the same level of performance, based on preliminary risk assessment;
- Assumptions: Dependence on assumptions that may be unrealistic, e.g., new algorithms will be developed and tested within the proposed schedule; additional funding will come through as hoped;
- Policy: Non-compliance with law, regulations, and/or policy;
- Technology maturity: Maturity level of proposed technology is not high enough or will not be high enough when needed[8];
- Political/economic factors: Political considerations such as international agreements, environmental controls, treaty compliance. What constraints might these put on the project?
- Logistics: Executability of alternative given the required logistics support;
- Resources: Availability of appropriate numbers and skill mix of staff (Government, contractor) for the life cycle of the alternative.

For many of these factors, it is likely that detailed information will not be available at the time the alternatives are being defined and filtered; however, there may be enough information or insight available to support a first pass at filtering considering relative merits and disadvantages of the alternatives.

There are no formulas for the number of or content for alternatives. Project complexity, the time available, and team resources (staffing and funding) will influence the depth and breadth of the alternatives developed. Materiel solutions (e.g., systems) tend to be the focus of many trade-space analyses; however, when appropriate, non-materiel solutions(e.g., policy) should be investigated as well.

The alternative set is revisited, filtered, and refined during the early stages of the trade-space analysis as new information becomes available. Feasibility of each alternative will be assessed and revisited during this process; in some cases, information will change that may allow a filtered alternative to come back into

[7] Removing one or more alternatives from consideration at a particular point in the trade-space analysis based on limitations that constrain their ability to be implemented as viable solutions.

[8] Technology maturity is an important filter for alternatives intended to satisfy operational needs. However in an Research and Development (R&D) context, the objective may be to apply resources aimed at increasing technical maturity and retiring risks.

consideration. This screening process requires some initial or high-level analysis or assessment of alternatives' abilities to meet objectives (e.g., assessing potential ability to deliver in the timeframe needed) but has the advantage of eliminating non-feasible alternatives before resources are expended analyzing them fully. Both descriptions and rationale for those alternatives ultimately deemed unfeasible must be documented (e.g., technology would not be mature at the time needed, the system would not be available when needed, one or more key requirements cannot be met, or the type of platform is not able to provide functionality) to provide an audit trail.

It is preferable that the final set of alternatives be distinct and independent. During the course of the trade-space analysis, it is often desired to examine variations of existing alternatives (e.g., changing a specific instrument that has slightly different resolution; adding risk mitigations) to understand drivers, how change affects criteria assessments, or to address certain stakeholder perspectives. Each variation should be treated as a separate alternative, and these variations may or may not end up in the final set of alternatives. Relationships across the alternative set must be identified for the decision maker and stakeholders to be clear about any similarities and dependencies.

The final set of alternatives chosen for assessment should be the product of thorough research and evaluation and vetted with SMEs, and the decision to use this set should be traceable and defensible. Typically, the final set of alternatives is defined halfway through the analysis timeframe to allow detailed criteria assessments to be completed and to provide margin for variations; the exact timing is dependent on the scope of the effort.

3.3 Assess Alternatives

The first two steps yield the analysis foundation, the definition of the alternatives, the evaluation framework (including the criteria), and the data needs and collection strategy to support the consistent assessment/evaluation of the alternatives. In this step, the cost, performance/benefit, risk, and schedule for each alternative are assessed. In addition, *uncertainty analysis* and/or *sensitivity analysis* are conducted.

Uncertainty analysis addresses the unknowns/risks within a defined alternative; it modifies inputs that created the initial assessment of criteria (e.g., life cycle cost) to reflect these unknowns or the likelihood of different events happening. It is used to provide a confidence interval range for the analysis results. [14]

Considering criteria in isolation may lead to incorrect conclusions. For example, an alternative with promising potential benefits or performance may turn out to have risks that negate or substantially diminish the performance and benefits or be too costly. In some cases, a change in schedule or adding resources can mitigate the risks and restore the benefits, albeit at increased cost or schedule or both.

Insights gained as to unfavorable criteria relationships can also prompt reformulation of alternatives to provide more accommodating options.

Sensitivity analysis, on the other hand, focuses on the impact of doing something different; it focuses on "what-ifs." Sensitivity analysis can be defined [15, 16] as a tool for assessing the extent to which costs and benefits (or other elements of an analysis) are sensitive to changes (e.g., in key assumptions or technical parameters). Sensitivity analysis repeats a prior analysis using different quantitative values to determine their effects on the results; if a small change in an assumption or parameter results in a significant change in the results, the results are said to be sensitive to that assumption or parameter. Such assumptions or parameters are significant "drivers" of the analysis.

Evaluating all criteria (rather than a subset) gives the decision maker a more complete picture of each alternative and better supports an informed decision about proposed alternatives. The criteria analyses are intertwined, that is, analysis and results for one criterion may influence results in another. The core team (and any analysis IPTs) must understand the relationships among cost, schedule, risk, operational performance/benefits and ensure the influences or impacts of changes in one criterion are appropriately reflected in other criteria. To be successful, it is essential to provide traceability from assessment/evaluation of the alternatives against each criterion to the overall conclusions and recommendations made which must consider all criteria.

A summary of the steps to execute the assessment of each criterion (analysis area) is described below, with additional or more detailed information in appendices. You will notice the common steps for each analysis area dealing with establishing ground rules and assumptions, developing a structure to support criteria assessment/evaluation, making an initial assessment/evaluation, conducting sensitivity and/or risk analysis, and finalizing results.

Steps to conducting evaluations for each criterion are described linearly, however, they are frequently performed in varying orders and sometimes in parallel. Analysis will be iterative and cyclical in nature; steps within the analysis may be repeated as analyses in other areas progress and resulting data matures.

Though not listed as an explicit step, it will be necessary to determine the depth and detail of the analysis that can be completed considering the trade-space analysis objectives, the decision to be made, and the constraints of resources, time and data available or possible to obtain.

3.3.1 Cost Analysis

Cost analysis is a key component of trade-space analysis; it is used to assess resources needed for each alternative considered. Typically life cycle cost is used to represent the total resources that are required from inception of the alternative, through acquisition, operations and maintenance, to retirement/disposal. In addition, cost uncertainty is measured based on the risk and uncertainty inherent in the alternative. Cost analysis facilitates broader understanding of the

trade-space and plays a significant role in shaping alternatives within constraints of limited budgets and life cycle affordability. This section will introduce cost analysis and will focus on a summary level process for building cost estimates to support trade-space analysis. Significant detail in terms of conducting cost analysis and developing cost estimates is provided in Appendix B; not all trade-space analyses will require or support this level of detail due to decision needs or resource and data constraints. An estimate of the life cycle costs is prepared for each alternative under consideration in the trade-space analysis.

Defining Cost Analysis and Cost Estimating. The GAO *Cost Estimating and Assessment Guide* [17], hereinafter referred to simply as "The GAO Guide," presents the following definitions:

"Cost analysis…can be defined as

- The effort to develop, analyze, and document cost estimates with analytical approaches and techniques;
- The process of analyzing, interpreting, and estimating the incremental and total resources required to support past, present, and future systems—an integral step in selecting alternatives; and
- A tool for evaluating resource requirements at key milestones and decision points in the acquisition process"

Cost estimating "combines science and art to predict the future cost of something based on known historical data that are adjusted to reflect new materials, technology, software languages, and development teams."

There is not a prescribed method applicable to all cost analysis or cost estimates; each analysis or estimate is unique and requires tailoring to the specific situation. As well, good cost analysis requires good inputs and experienced analysts. Cost analysis must also be objective.

Cost estimating and analysis in a trade-space analysis face numerous challenges. The cost component is sometimes neglected in the early stages of a trade-space analysis which does not allow appropriate planning or time to execute a reasonable analysis. High quality data upon which to build an estimate sometimes does not exist. Difficulty in communication in defining the technical baseline of the alternatives can hinder estimate development. Alternatives may have components or implementation aspects the costs of which are very difficult to quantify (e.g., new technology). Cost analysis needs to be conducted with sound judgment, understanding of uncertainty, and consideration of realism. The cost analysts should work closely with members of the core team to ensure appropriate cost elements are defined, and to maintain consistency with other analysis components. The experienced estimator recognizes the highly integrated way that cost analysis is performed with definition of the alternatives.

Estimating Process Overview. A well-defined process is essential to creating defendable and repeatable estimates. The GAO Guide establishes a 12-step process as a structure to be used and tailored according to the needs of the using organization, as shown in Figure 3-2.

Considering the overlap of many of the steps, and the needs of NOAA, it is possible to combine several steps from the GAO Guide into an eight-step process tailored for NOAA, as shown below in Figure 3-3, followed by brief definitions of each step. Greater detail on each of these steps is presented in Appendix B.

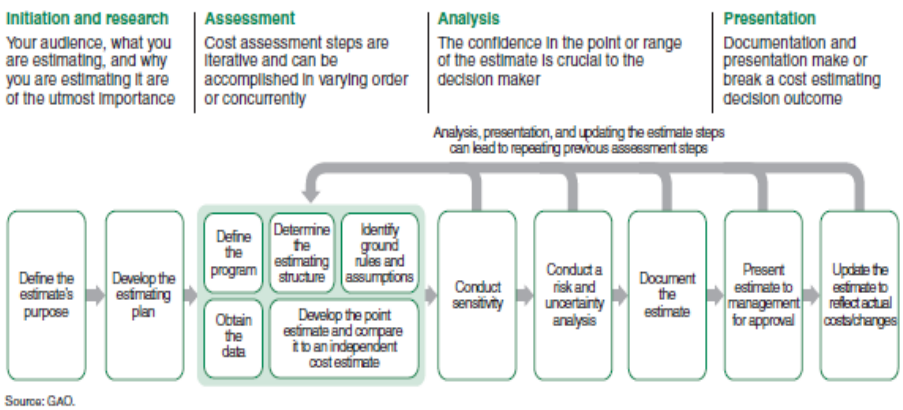


Figure 3-2. GAO Cost Estimating Process

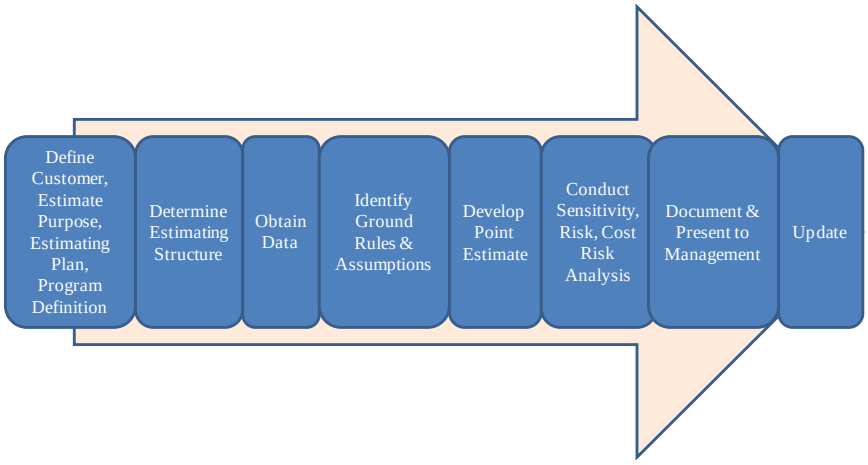


Figure 3-3. Tailored GAO Process for NOAA Cost Analysis

Step 1 – Define Customer, Estimate Purpose, Estimating Plan, Program Definition. Certain elements such as *who* the ultimate recipient is and *why* the estimate is needed (e.g., how the cost estimate fits into the decision that is the focus of trade-space analysis) are considered here if not already defined (see Section 2). *What* is being estimated (the estimate scope, see also Step 4 below) and *how* the entire cost analysis will be accomplished are also considered in this step.

Step 2 – Determine the Estimating Structure. Seasoned estimators will begin estimating a large, complex alternative by breaking the problem into manageable pieces. They will look to the technical definition (technical baselines) of the alternatives and work with those that developed them to construct a *cost estimating structure* (CES) or *work breakdown structure* (WBS). The WBS provides the overall decomposition of the functional system and all the efforts to develop/ acquire it into discrete "estimatable" pieces.

Step 3 – Obtain Data. Cost estimating is, in the simplest terms, predicting the future based on observations/experiences from the past (which are captured in historical data). One of the hardest steps for any estimator is gaining access to and developing an appropriate and relevant data set. Generally, an analyst will be collecting technical, programmatic, and cost data. Preparing a data collection plan is useful in helping the analyst determine what types of data to collect and from what sources.

Step 4 – Identify Cost Ground Rules and Assumptions. While there are GR&A for the overall trade-space analysis (see Section 3.1.3), each analysis area (cost, performance/benefit, risk, schedule) will have its own GR&As to address specific boundaries and other conditions pertinent to executing that analysis; these are defined and evolved as the analysis progresses. For example, cost analysis GR&A can include the labor rates that are used and in which base year costs will be presented. Cost analysis GR&As should be coordinated with the overall analysis GR&As and those for the other analysis areas to ensure alignment. Any of the overall GR&As that are applicable to the cost analysis should be noted.

Step 5 – Develop the Point Estimate. The *point estimate* is the arithmetic sum of all the cost elements estimated for the alternative. There are many methodologies (e.g., *bottom-up*, *analogy*, *parametric*, *extrapolation from actuals*) available to support development of cost estimates. (These methods are discussed in Appendix B.) Methods are chosen based on appropriateness to the cost element that will be estimated, the available data, and the knowledge/experience of the analyst. Through application of the information developed in the previous steps with the appropriate methodologies, a single estimate is developed for each element within the WBS.

Step 6 – Conduct Sensitivity, Risk, Cost Risk Analysis. Uncertainty analysis is the process of identifying, evaluating, and quantifying the uncertainties associated with an alternative's technical and program definition, technical parameters, and other input into the cost methods used in creating the estimate (e.g., *cost estimating relationships* (CERs)). The probability that a specific cost target will be exceeded is derived from the total uncertainty of the estimate. Sensitivity analysis examines how changes to key assumptions and technical definition affect the estimate. Assessment and adoption of specific uncertainty analysis and sensitivity analysis results should be completed prior to finalizing and documenting the estimate.

Step 7 – Document and Present to Management. The documentation must explain in detail how the cost estimate was developed; not only does this facilitate answering questions in the future, but it also eases the cycle time for independent reviews. Detailed documentation should allow a reviewer to follow the logic from assumptions to results.

Step 8 – Update Estimate. Finally, an estimate should be updated routinely, in response to changes… in technical baselines, budgets, requirements, and program composition (implementation). This effort is typically done for the alternative(s) or course(s) of action chosen.

It is important to recognize that although the steps are shown and described linearly, they are frequently performed in varying orders and often even in parallel. The process should be understood to be iterative and cyclical, often repeating parts of the process as the program and resulting data matures. Therefore, an analyst should not despair if good data (or any data) is not available prior to developing the WBS and many of the ground rules and assumptions, since these steps will be visited multiple times.

3.3.2 Performance and Benefits Analysis

The basic objective of *benefits analysis* and *performance analysis* in a trade-space analysis is straightforward: to estimate the benefits or performance that could potentially be obtained from each alternative, using common metrics and measurement scales. Criteria in this area focus on the operational and societal value of an alternative.

The terms "benefits" and "performance" have different but related meanings in this guide. The term "benefits" will be used when the objective is to estimate the potential positive effects of capabilities provided by alternatives with respect to their functional end-use (e.g., improved forecast accuracy from using a wind measurement provided by an alternative) or using a metric that considers the relative "importance" or "impact" of the alternatives. *Societal benefit*, in particular, reflects value delivered to society/various sectors of the economy by each alternative, including, but not limited to, individual citizens and industries. Examples of societal benefit criteria are percentage reduction in operational delays in the aviation industry due to convective weather or percentage reduction in accidents due to weather in the trucking industry. In many cases, these benefits can be monetized to show specific cost avoidance; this requires research into how the improved measurement or information derived from an alternative has an impact within a larger societal context.[9]

In contrast, the term "performance" will be used when the measure is in terms of more fundamental technical merits of each alternative. Performance typically reflects the degree to which one or more attributes of a requirement (e.g., measurement accuracy) are met. One or more measures are typically developed and are assessed qualitatively or quantitatively (preferred).

An example of benefits analysis would be an estimate of the economic benefits to end-users or the general public of an investment in a new observing system or forecasting capability. An example of performance analysis would be how well different alternatives satisfy a specific technical requirement, such as a requirement to observe certain phenomena at a specified measurement accuracy. These definitions are inclusive in the sense that alternatives generally cannot have "benefits" without positive "performance." However, specific performance improvement (with respect to internal NOAA metrics) may not translate directly into identifiable or significant economic or societal benefits to external users/stakeholders; given this, the trade-space analysis must maintain a "so what" and "at what cost" posture when it comes to examining benefits and alternatives.

Summary steps for performance and/or benefit analysis are discussed below. Appendix C provides a taxonomy and discussion of methods for benefits and performance analysis, including key characteristics, potential measures and evaluation scales, and known examples of NOAA studies.

Step 1 – Identify Performance and Benefit Analysis Ground Rules and Assumptions. While there are GR&A for the overall trade-space analysis (see Section 3.1), each analysis area may have its own GR&A to address specific boundaries and constraints pertinent to executing that analysis; these are defined and evolved as the analysis progresses. For example, performance/benefit

[9] OMB Circular A-4 [18] provides useful guidance on estimating the value of benefits, including those that can be quantified but are difficult to monetize and those that are difficult to quantify. Though the circular applies specifically to regulatory analysis, the methods it discusses have broader applicability.

analysis GR&A could address the definition of current performance or performance from the "status quo" alternative. Performance/benefit analysis GR&A should be coordinated with the overall GR&A and those for the other analysis areas to ensure alignment. Any of the overall GR&A that are applicable to the performance/benefit analysis should be noted.

Step 2 –Define Performance and Benefit Analysis Structure. For the performance and/or benefits analysis, defining the analysis process consists of determining metrics, defining and selecting methods and tools to evaluate the metrics, and defining evaluation scales. This structure will be used with the data collected and developed to complete the evaluation.

Step 2A. Determine/Define Metrics. Metrics must be relevant to the decision, meaningful to the decision maker and stakeholders, and measurable in practice. They must also reflect specific outcomes achieved from a technical perspective (e.g., measurement accuracy), operational perspective (e.g., tornado warning lead time), and/or economic perspective (e.g., lives saved due to tornado warning lead time). Each alternative will be evaluated against each metric to ensure a consistent (apples-to-apples) comparison; the set of metrics should help differentiate amongst the alternatives when assessed and should be independent. In some cases, multiple assessment steps may be needed to derive a final metric; in this case the analysts should ensure that the chain of causality is demonstrated and clearly understood at each step (i.e., from technical capabilities of the alternative to positive operational/economic outcomes).

Step 2B – Define and Select Evaluation Methods and Tools: A variety of methods and supporting tools are used to conduct performance and/or benefit analyses and evaluate the associated metrics; these methods can be used alone or in combination. Methods and tools used are determined by the scope of the trade-space analysis (e.g., portfolio vs. individual system or capability) as determined by the decisions it will support, and whether the performance/benefit analysis is to be quantitative or qualitative. The choice of quantitative or qualitative typically depends on analysis motivation and objectives, constraints (including time and resources to perform the work), and availability of data. Quantitative analysis is most desired due to its perceived objectivity and rigor (particularly when complying with needs of external agencies such as OMB); however, qualitative analysis can be very robust and insightful in evaluating relative performance/benefits of alternatives. Survey instruments can be constructed to elicit the judgments and operational experience of those who will benefit from improved performance. In general, quantitative analysis will take more time than qualitative analysis.

When choosing methods and tools the core team must understand how data will be applied in those methods and tools; methods and tools are only as good as the data applied. The team must also ensure that the tools have the ability to produce consistent and repeatable results (given the same inputs) and to support the analysis scope. The core team can look within NOAA or engage with external organizations such as academic (or affiliated) institutions, Federally Funded Research and Development Centers (FFRDCs), other Government Agencies, or Government contractors to determine best method and tools. Appendix D provides information on different tools that have been applied to trade-space analyses led by TPIO.

Step 2C – Define Evaluation Scales. For each metric, an evaluation scale must be defined. The evaluation scale needs to consider how the metric will be measured and the range of

values that could occur. When measuring overall benefits, a 0-100 scale would likely be appropriate; when measuring an operational outcome such as tornado warning lead time, the scale would likely be in minutes or hours; and when looking at a performance metric such as measurement accuracy of an observation, the scale would be in percentage terms. In economic benefits analyses, the benefits are monetized, defined in terms of dollars saved or gained.[10] In contrast, if a benefits analysis is to estimate non-monetary, non-quantified societal benefits, a scale must be defined with which to characterize the positive societal impacts of each alternative; typically a consistent adjectival scale (e.g., very satisfactory, satisfactory…) is used [20]. In some cases, color coding is used to support quick visual interpretation of the assessment across the alternatives.

Step 3 – *Complete Initial Performance or Benefits Analysis*. Executing the above steps provides ground rules and assumptions, metrics to be assessed, analysis methods and tools, and evaluation scales. In this step, data collection is completed and brought together with the above to conduct the evaluation of the defined metrics for all alternatives. In some cases the data will come from SMEs (engaged in the planning stage of the trade-space analysis). In other cases the data may come from a database, from actual data, from application of models, other studies and analysis, and/or a request for information, as discussed in Section 3.1.5. These data sources also may be used in combination to produce the analysis. Once initial results have been calculated and compared, a sanity check should be done by assessing/comparing benefits or performance through other methods/means and/or examining results for realism based on what is known/ experienced; that is, when looking across the alternatives, do the results and differences in the metric evaluations make sense?

Step 4 – *Conduct Uncertainty and Sensitivity Analysis*. It is likely that one or more elements of the analysis will have uncertainty, and the analysis approach must include ways to address this uncertainty (e.g., establish a reasonable or plausible range of inputs to capture it). It may seem paradoxical, but experience indicates that stakeholders' confidence in the results often depends on how well the analysis report identifies and evaluates areas where uncertainty exists. Levels of certainty with respect to elements in a performance/benefits analysis are often variable; some elements may be extremely sound and well documented while other areas are based entirely on expert judgment. This part of the analysis done in coordination with the cost, schedule, and risk analysis can be very valuable because it can highlight additional risks and additional cost and schedule impacts. In some cases, the analysts will not have time to fully address/model uncertainty due to resource constraints. One approach to dealing with uncertainty in this case is to be conservative in the calculation of expected benefits; that is, when there is uncertainty, the number or value used in measuring a benefit of an alternative should be realistic but less favorable to the alternative relative to other possible values. A benefits analysis for the Geostationary Operational Environmental Satellite – R (GOES-R) followed this principle [21].

[10] An example is the monetization of human life and injuries which is a standard practice in cost-benefit studies conducted by various Federal agencies, including the Federal Aviation Administration (FAA) and Environmental Protection Agency (EPA). See reference [19] for more information.

In addition, certain sensitivity analysis or "what-ifs" may be completed to better understand the robustness of the initial results and/or to explore the impacts of possible changes to underlying information used in the initial benefit analysis. Sensitivity analysis will provide insight into how small changes in the assessed performance or technical capability of an alternative impact the overall result; for large impacts, it will be important to validate the technical baseline, input values, and relationships used to calculate benefit metrics to ensure their fidelity and ability to stand up to scrutiny.

Step 5 – *Finalize Benefit and Performance Analysis*. Based on the initial analysis and considering the uncertainty and sensitivity analysis performed, the final benefit and performance analysis should be developed for each alternative in a consistent manner. It may be that the uncertainty and sensitivity analysis provided additional information or insights that required question, clarification, and repeat of previous analysis.

3.3.3 Risk Analysis

Understanding the ability of a proposed alternative to be successfully implemented and deliver on its promised benefits within proposed schedule and cost is critical to conducting a trade-space analysis. *Execution risk assessments* are used to evaluate and differentiate various alternatives. The essential question asked when conducting an execution risk assessment is, "Will the alternative deliver its promised benefits within the proposed schedule and cost?" A standard set of risk areas or categories (e.g., "Technical Performance," "Political Advocacy," "Personnel/Skill Mix") is often used to evaluate the risk of each alternative. The assessment consists of developing a risk score (per individual risk area and overall risk) and the rationale for each score. This section summarizes the major steps for an execution risk assessment of the alternatives. Appendix E provides advice for tailoring to your specific needs.

Step 1 – Identify Risk Ground Rules and Assumptions. Risk analysis GR&As can include the selection of risk categories, the level at which risk measures will be assessed, and the method of roll-up across risk measures that will be used. Risk analysis GR&A should be coordinated with the overall GR&A for the trade-space analysis (see Section 3.1.3) and those for the other analysis areas to ensure alignment. Any of the overall GR&A that are applicable to the risk analysis should be noted.

Step 2 – Define Risk Analysis Structure. A risk analysis structure is used to develop a consistent assessment of the proposed alternatives. To define this structure, a standard set of risk categories and a combined quantitative and qualitative evaluation scale are defined and used to assess and score alternatives. The evaluation scale defines the levels of risk associated with each risk category and associates a numerical range (between 0 and 100) to each level of risk (low, low-medium, medium, medium-high, high, and catastrophic). A detailed risk assessment structure, including 14 risk categories, risk category definitions, levels of risk, and descriptions of the risk for each category and level, is provided below in Figure 3-4. This structure would be tailored to ensure alignment with the particular trade-space analysis being conducted.

Category	Details score This refers to:	Low 0 < 20 The risks in this area will have a **little to no impact** on the Alternative's achieving its stated outcome objectives.	Low-Med 20 < 40 The risks in this area will have a **minor impact** on the Alternative's achieving its desired result, to the extent that one or more of its stated outcome objectives will fall below goals but well above minimum acceptable levels.	Med 40 < 60 The risks in this area will have a **moderate impact** on the Alternative's achieving its desired result, to the extent that one or more of its stated outcome objectives will fall well-below goals but above minimum acceptable levels.	Med-High 60 < 80 The risks in this area will have a **significant impact** on the Alternative's achieving its desired result, to the extent that one or more of its stated outcome objectives will fall below minimum acceptable levels.	High 80 < 100 The risks in this area will have a **severe impact** on the Alternative's achieving its desired result, to the extent that one or more of its critical outcome objectives will not be achieved.	Catastrophic 100 **Showstopper.** The Alternative **will not achieve** any of its outcome objectives.
Funding / Resources	Funding and resource availability in the time increment needed.	High confidence that the funding and resources are available and secured in the timeframe needed. Budgets reflect full funding support for component programs.	Strong confidence that the funding and resources are available and supported in the timeframe needed. Budgets reflect funding support for component programs.	Reasonable confidence that the funding and resouces are likely in the timeframe needed. Budgets reflect funding support for components but with a focused interest on other requirements.	Low confidence that the funding and resources are being pursued in the time increment needed. Organization is investigating purchasing alternative equipment that negates Alternative capabilities.	Little/no confidence that the funding and resources have been identified and are supported. Organization is purchasing or has purchased alternative equipment that negates Alternative capabilities.	Funding and resources are not available for successful execution of the Alternative.
Personnel / Skill Mix	Availability of needed personnel / skill mix to support the mission.	High confidence that the required personnel / skill mix will be available.	Strong confidence that the required personnel / skill mix will be available.	Reasonable confidence that the required personnel / skill mix will be available.	Low confidence that the required personnel / skill mix will be available.	Little/no confidence that the required personnel / skill mix will be available.	Showstopper concern that the required personnel / skill mix will be available.
Confidence in Cost Estimate	Confidence that the cost estimate reflects the necessary resources to execute the alternative	High confidence in the cost estimate.	Strong confidence in the cost estimate.	Reasonable confidence in the cost estimate.	Low confidence in the cost estimate.	Little/no confidence in the cost estimate.	Showstopper concern about the cost estimate.
Political Advocacy	Internal or external agency opposition for this Alternative to be developed and deployed.	There is little to no internal or external opposition to the Alternative.	Internal or external opposition will have minor impact to the implementation of this Alternative.	Internal or external opposition will have moderate impact to the implementation of this Alternative.	Internal or external opposition will have significant impact to the implementation of this Alternative.	Internal or external opposition will have severe impact to the implementation of this Alternative.	This Alternative is completely opposed by one or more internal or external stakeholders. Opposition is a showstopper for this Alternative.
Schedule	Confidence that the alternative's schedule is appropriate and will execute on time and that the alternative will be available in the timeframe needed	High confidence the Alternative will execute on schedule and be available for the timeframe needed.	Strong confidence the Alternative will execute on schedule and be available for the timeframe needed.	Reasonable confidence the Alternative will execute on schedule and be available for the timeframe needed.	Low confidence the Alternative will execute on schedule and be available for the timeframe needed.	Little/no confidence the Alternative will execute on schedule and be available for the timeframe needed.	The Alternative's schedule cannot be executed.
Statutory - Regulatory	The appropriate legal/legislative issues, policies, and acquisition processes have been addressed/considered (compliance) for the alternative; any specific waivers, treaties, MOUs will be in place when needed	This Alternative is in compliance with all current statutes, acquisition processes, treaties, MOUs; there is a low risk of any regulatory guidance, waiver needs that would delay this Alternative	This Alternative is in compliance with current statutes and regulations, acquisition processes, treaties, and MOUs; however, investigation is needed to determine whether this Alternative will require future waivers, legal, or policy change.	This Alternative has a need for regulatory guidance or waiver that is common, but has a chance to delay this Alternative's development, deployment, and operations.	This Alternative has a need for regulatory guidance or waiver that is common, but may not be successful, that would impact this Alternative's development, deployment, and operations.	Alternative development and operations will require changes to the current statutes, regulatory guidance, acquisition processes, policy, treaties, or MOUs.	Alternative require waivers, legal, policy, or treaty change that will not be supported.
Data Availability	Availability of data to support the mission	High confidence that the required data will be available.	Strong confidence that the required data will be available.	Reasonable confidence that the required data will be available.	Low confidence that the required odata will be available.	Little/no confidence that the required data will be available.	Showstopper concern that the required data will be available.
Technology Maturity	Maturity of technologies associated with the alternative; technologies for the alternative will be sufficiently developed when needed	Key technologies are ready and mature and require little/no effort to execute the Alternative.	Key technologies are expected to be ready and mature in time to execute the Alternative.	Key technologies are not ready and mature and require moderate effort to execute the Alternative.	Key technologies are not ready and mature and require significant effort to execute the Alternative.	Key technologies will not be ready and mature and will have a severe impact on this Alternative.	Key technologies will not be available and no alternative is available.
Technical Performance	Confidence that expected performance and capabilities will be delivered	There are no technical performance problems identified that will have any impact on achieving the stated outcome objectives expected from the Alternative.	Limited technical performance problems have been identified that will have a minor impact on achieving the stated outcome objectives expected from the Alternative.	Technical performance problems have been identified that will have a moderate impact on achieving the stated outcome objectives expected from the Alternative.	Technical performance problems have been identified that will have a significant impact on achieving the stated outcome objectives expected from the Alternative.	Serious technical performance problems have been identified that will have a severe impact on achieving the stated outcome objectives expected from the Alternative.	Major technical performance problems have been identified that will prevent achieving any of the stated outcome objectives expected from the Alternative.
Operational - Deployability	Reflects deployment capacity and fielding readiness (opportunity for denied access/operations, operational disruption introduced) of the alternative	The Alternative's functionality is currently deployed with full permissions and no additional actions are needed to be taken to ensure Alternative functionality. No risk to planned operations due to Alternative functionality.	The Alternative is currently semi-deployed or anticipated to have few deployment or permission issues. Some operational functionality planning, such as deployment with other required components remain.	Deploying the Alternative requires permissions and supporting assets that may compete with other requirements. This could delay deployment and/or impact the required operational functionality.	Deploying the Alternative requires significant permissions and assets that compete with other requirements. This will probably delay deployment and impact the required operational functionality.	Deploying the Alternative is at risk because of the assets and permissions that are needed, and/or the Alternative requires significant on-site support to ensure functionality; if it is not granted, the Alternative has severely reduced functionality.	The Alternative is incompatible with planned operations and deployment, and permissions are not available, therefore deployment is not viable.
Dependencies	Reflects the extent the alternative relies on other programs, or their contributions, to achieve its stated outcome objectives and how that alternative is impacted by the dependencies	Dependencies associated with this Alternative are such that delays from other programs, or their contributions, are expected to have negligible impacts on the execution of this Alternative and its ability to achieve its stated outcome objectives.	Dependencies associated with this Alternative are such that delays from other programs, or their contributions, are expected to have minor impacts on the execution of this Alternative and its ability to achieve its stated outcome objectives.	Dependencies associated with this Alternative are such that delays from other programs, or their contributions, are expected to have modest negative impacts on the execution of this Alternative and its ability to achieve its stated outcome objectives.	Dependencies associated with this Alternative are such that delays from other programs, or their contributions, are expected to have significant negative impacts on the execution of this Alternative and its ability to achieve its stated outcome objectives.	Dependencies associated with this Alternative are such that delays from other programs, or their contributions, are expected to have severe negative impacts on the execution of this Alternative and its ability to achieve its stated outcome objectives.	Dependencies associated with this Alternative are such that delays from other programs, or their contributions, are showstoppers with respect to the execution of this Alternative and its ability to achieve its stated outcome objectives.
Partnerships	Forming and/or maintaining interagency (and international) partnerships to support the alternative; considerations include motivation for partnership and the vested interest of US in partnership (ability to execute partnerships -- maturity, initiated, productive dialog, experience with partner in past)	No partnership required to implement this Alternative or there is little to no concerns regarding forming or executing partnerships for this Alternative.	There are minor concerns regarding forming and executing partnerships required for this Alternative.	There are moderate concerns regarding forming and executing partnerships required for this Alternative.	There are significant concerns regarding forming and executing partnerships required for this Alternative.	There are severe concerns regarding forming and executing partnerships required for this Alternative.	Partnerships required for this Alternative are showstoppers and can not be formed or executed.
Integration Complexity	Reflects the difficulty associated with integrating multiple components	Integration issues are understood and will have little to no impact on the implementation of this Alternative.	Integration issues are somewhat complex and will have a minor impact on the implementation of this Alternative.	Integration issues are complex and will have a moderate impact on the implementation of this Alternative.	Integration issues are rather complex and will have a significant impact on the implementation of this Alternative.	Integration issues are highly complex and will have a severe impact on the implementation of this Alternative.	Complexity of integration issues are a showstopper and prevent implementation of this Alternative.
Interoperability	Reflects the ability to interconnect (physical, receive/transmit, formats, frequency, licensing, synchronization) to ensure processing of data from multiple sources	Connections & formats are specified and understood and will have little to no impact on the implementation of this Alternative.	Connections & formats are specified and understood and will have a minor impact on the implementation of this Alternative.	Connections & formats are somewhat specified and understood and will have a moderate impact on the implementation of this Alternative.	Connections & formats are not well specified and understood and will have a significant impact on the implementation of this Alternative.	Connections & formats are not very well specified and understood and will have a severe impact on the implementation of this Alternative.	Connections & formats are showstoppers and prevent implementation of this Alternative.

Figure 3-4. Risk Analysis Structure Example

Step 3 – Complete Initial Risk Analysis. The initial evaluation is formulated through facilitated meetings to elicit risk assessments from SMEs and application of a "roll-up" methodology to summarize results.

Step 3A: Establish and Conduct Elicitation Meetings with SME team. A risk assessment team is formed from the appropriate set of subject matter experts and stakeholders; this may be done at the outset of the trade-space analysis. One or more facilitated sessions with the risk assessment team, orchestrated by the risk or core team lead, are used to elicit and complete the risk assessments for each alternative based on the evaluation scale. It is important to have the consistent participation of the stakeholders, so coordination and advance scheduling are required.

Working with the risk team lead, who also serves as facilitator, the assessment team determines risk scores for each category based on the defined evaluation scale, and develops a rationale for each score, called a *basis of assessment* (BOA). The BOA captures the key considerations driving the evaluation/score, and describes why that risk score was assigned. BOAs are important in communicating the risk drivers for each alternative and the rationale of the risk rating for each category. Each category will typically have an individual rating from 0 to 100 and a BOA. The BOAs for each alternative (and any dissenting views) should be made available to decision maker to fully explain the nature of each alternative's risk.

The example below illustrates a risk assessment for a notional trade-space analysis considering three alternatives: the status quo, Alternative 1, and Alternative 2. Figure 3-5 shows sample scores and BOAs for selected risk categories for the status quo alternative. Figure 3-6 shows a summary of the initial risk scores for the three alternatives.

Risk Category	Score	BOA (rationale for scoring)
Status Quo		
Funding / Resources	70	Currently there is funding for personnel; however there is not strong program support. Funding advocacy is below the goal level. Funding for certain functions and data needs are not planned.
Personnel / Skill Mix	40	Dependent on small core of staff. Limited capacity to deal with problems. Dependent upon external expertise for certain functionality.
Advocacy (programmatic, political)	50	Conflicting priorities and the lack of strong advocacy puts support in jeopardy, Currently there is no strong opposition to current approach.
Technical Performance	70	Current capability will continue to degrade or be non existent over the time period.

Figure 3-5. Sample BOAs

Alternative Risk Assessment			
Alternatives > / **Risk Category** (below)	Status Quo	Alternative 1	Alternative 2
Funding / Resources	70	75	90
Personnel / Skill Mix	40	75	90
Confidence in Cost Estimate	20	50	50
Advocacy (programmatic, political)	50	65	50
Schedule	5	40	90
Statutory-Regulatory	5	5	5
Data Availability	95	20	20
Technology Maturity	5	20	80
Technical Performance	70	20	80
Operational Deployability	20	60	80
Dependencies	70	35	35
Partnerships	5	40	40
Integration Complexity	5	50	80
Interoperability	5	50	50

Low	**0 < 20**
Low-Med	**20 < 40**
Med	**40 < 60**
Med-High	**60 < 80**
High	**80 < 100**
Catastrophic	**100**

Figure 3-6. Example of Alternative Risk Scores

After each session the facilitator will document the results and provide them to all participants for review and comment. The facilitator will then incorporate participants' feedback into the assessment and send out updated results. The final risk assessment documentation should be treated in the same manner, with the potential need for additional reviewers (e.g., leadership within participants' chain of command and leadership of the trade-space analysis).

Step 3B – Summarize Initial Risk Assessment Results. The risk assessment methodology facilitates the display of risk factors for each of the alternatives being evaluated, as shown in Figure 3-6 above, which quickly showcases problems areas via the color coding. Additionally, it is useful to compute an overall risk score based on the category risk scores. While an average or weighted average may be used to determine the overall risk score, this approach can sometimes mask high risk areas that could prevent an alternative from being successful. An alternative approach which ensures that high risk areas are given appropriate weight in the overall risk score is described in Appendix E, Section E.3.

Step 4. Conduct Sensitivity Analysis. It may be useful to conduct sensitivity or "what-if" analysis based on the initial inputs and results. To do this the team can examine bounds on risk scores of interest to ascertain how the overall score would change. The team can bound the score based on exploring changes based on dissenting inputs, changes to GR&A, or changes of interest from the evaluation team or other stakeholders (including the decision maker). Assessing the impact of these changes may help ascertain whether drivers of the overall risk score change and whether modifications are required prior to finalizing the risk assessment for all alternatives. Once sensitivity analysis is completed, you can finalize and document results.

Step 5. Finalize Risk Analysis. Based on the initial evaluation/assessment and considering the sensitivity analysis performed, the final risk assessments (by category and overall) for each

alternative should be developed. It may be that the sensitivity analysis provided additional information or insights that required question, clarification or repeat of previous analysis and assessments.

In summary, the risk assessment methodology facilitates the display of risk factors for each of the alternatives being evaluated. The display of the category risk assessments allows the decision maker to see the key risk areas at a glance. Additionally, an overall risk score is a useful summary measure that can be combined with benefit and cost assessments. It is important that the risk summary communicates the risks to the alternative successfully delivering its promised benefits in the defined schedule and cost. The BOAs for each alternative should be made available to the decision maker so they can fully understand the nature of each alternative's risk.

Note: The decision maker should be informed of mitigation activities that could reduce an alternative's risks. However, the results of conducting risk mitigation activities should not be considered in the analysis of the alternative, because adding mitigations to an alternative will likely change the cost/risk/schedule and performance/benefit profiles. One or more separate alternatives should be created if risk mitigations are to be considered in the analysis.

3.3.4 Schedule Analysis

Schedule analysis within the trade-space analysis provides a means to examine conditions under which desired capability (e.g., improved wind measurement, environmental information sets) can be delivered within a specified timeframe, and to provide a basis for evaluating each alternative's feasibility to do so. A schedule should be developed for each alternative to understand its likely acquisition and implementation timeline and potential risks of delay, and to support other analyses (e.g., cost). The schedule identifies and sequences the programmatic and technical activities that must be undertaken to implement the alternative.

Each alternative should have an estimated schedule that covers its full life cycle and identifies its phases and milestones, including expected delivery dates of operational capability (e.g., an initial operating capability and a full operating capability). This information will support the estimation of cost elements that are schedule driven. It is also critical to understand risks involved in achieving the milestones identified; this information should align with the risk analysis and will support assessment of uncertainty within the schedule.

While there is not a single or definitive methodology or tool set for conducting a schedule analysis, there are a number of accepted practices which are discussed in the remainder of this section. Appendix F provides additional information in the form of checklists for assessing schedule completeness and realism. The level of rigor applied to schedule analysis may vary due to resources allocated, constraints levied, and the information available. Discussions below focus on significant rigor to provide the big picture with respect to schedule analysis.

Typical elements considered in estimating or analyzing a schedule are the effort and duration of each activity/task, the number and skill mix of staff needed for each activity (relative to the available workforce this may require extending a scheduled activity), the interdependencies among the activities, and the risk inherent in specific elements affecting the schedule. The schedule analysis should answer, at a minimum, the following questions:

- When will the project finish?
- Is the schedule realistic and achievable?
- What are the constraints that restrict development or implementation actions?
- For those alternatives currently being acquired or operated, what is the schedule performance? What, if anything, is not meeting schedule objectives?
- What can past performance of similar programs tell us about the realism of the schedule?
- What is the critical path of the estimated schedule? Is adequate slack built in at key points (where schedule uncertainty is high, to address known risks as well as unexpected problems, to allow for activities that likely will be repeated)?
- How can we get done sooner, recover from a delay, or work around a problem?

Some key considerations for schedule analysis are:

- Understanding the nature and impacts of links with/dependence on external partner systems or activities beyond the control the alternative;
- Understanding the relationships (dependencies) between tasks. Knowing which tasks need to be sequential (vs. concurrent) will help determine limits to schedule acceleration;
- Assessing the reasonableness of project milestones based on technical, programmatic, and other risks that will impact the duration and effort of each activity and task (e.g., funding availability);
- Understanding the impacts and assessing the reasonableness of potential changes in the schedule. For example, one might look to compress the schedule, but this could result in not having enough slack to address risk or could require the addition of resources, which impacts costs; and
- Assessing how technology maturity will affect the schedule. Technology must be at an appropriate level of maturity before incorporating it into an alternative.

Overall steps for schedule analysis are:

> The schedule analysis, in conjunction with the other analyses, will support the ability to arrive at an affordable balance among cost, performance, risk, and schedule.

Step 1 – Identify Schedule Analysis Ground Rules and Assumptions. Schedule GR&As may address elements including activity interdependencies; policies, regulations, certifications; and external dependencies such as availability of interfacing systems. Schedule analysis GR&A should be coordinated with the overall trade-space analysis GR&A (see Section 3.1.3) and those for the other analysis areas to ensure alignment. Any of the overall GR&A that are applicable to the schedule analysis should be noted.

Step 2 – Define Schedule Analysis Structure. Executing any alternative typically requires a large number of interrelated activities. A network—the arrangement of those complicated interrelationships—is the typical structure used to define the schedule for each alternative. The network provides links between individual activities to indicate predecessor activities (which must be completed prior to the start of another activity) and successor activities (which cannot start until another activity is completed).

Step 3 – Complete Initial Schedule Analysis. There are four major steps in completing the initial schedule analysis for each alternative: creating the initial schedule, identifying schedule drivers, assessing schedule completeness, and identifying the critical path. Each step requires use of data collected pertinent to the schedule.

Step 3A – Create the Initial Schedule. Using the concept of a schedule network, define individual tasks and activities required to develop, procure, and deliver the alternative. Ensure that connections between tasks are understood and delineated. It is helpful to:

- Break the process flow into small steps of clearly defined activities, identifying predecessor and successor relationships among steps to reflect interdependencies among the activities;
- Determine the order in which activities must be completed;
- Define rework loops that reflect the effort for correcting defective, failed, or non-conforming items identified at inspection or testing, as well as the required retesting;
- Identify milestone activities and choke points (points at which multiple activities come together, which may strain available resources);
- Estimate activity duration times; and
- Evaluate project completion time based on above efforts.

Step 3B – Identify Schedule Drivers. It is important to identify and assess the key elements of the alternative that drive the duration of the schedule. Identification of risk areas is an important component of the analysis, as these risks typically translate to schedule drivers and increase schedule (activity duration) uncertainty. Types of drivers include technical immaturity, specialized production requirements, software development risks, supplier performance, coordination among multiple contractors, dependency on other systems or organizations, potential for rework and re-test, and staff experience.

Step 3C – Assess Schedule Completeness. In this step, we look to ensure that the schedule makes sense and that we have accounted for all activities. The schedule should address task relationships and constraints, account for deliverables and needed resources, reflect lead times for vendor and supplier activities and for establishing any needed external partnerships, include government furnished elements, and consider non-work periods (e.g., full plant shutdown for vacation).

Step 3D – Identify the Critical Path. As previously stated in Section 2.4, the critical path is the longest sequence of activities in a project plan, accounting for dependencies, which must be completed on time for the project to complete on the due date. (There may be more than one critical path.) Late completion of activities on the critical path will have an impact on the project end date or delay a key milestone. The initial critical path should be determined through examination of the schedule activities to gain insight into the key activities that if changed could impact the delivery date. A number of software tools for schedule analysis and critical path analysis are available. For example, Microsoft® Project, a commonly used tool for schedule development and analysis, supports critical path analysis; it provides several ways to view and assess the critical path.

Step 4 – Conduct Schedule Risk Analysis and Sensitivity Analysis. *Schedule risk analysis* is the process of associating a degree of confidence with each schedule duration estimate. The combination of defining probability distributions for various scheduled task durations and establishing network relationships among the tasks allows one to forecast the probability of meeting the targeted dates of key milestone events. Schedule risk analysis examines the likelihood and amount that an estimated schedule will be exceeded. It allows an assessment of schedule realism. Past performance of similar efforts provides one approach for assessing realism.

> *The essence of risk is uncertainty: uncertainty of an event's occurrence, specified by a probability; and uncertainty of its impact, specified by a range of durations.*

Probabilistic schedule models may be used to conduct schedule risk analysis; one example is the @RISK add-on (from Palisade Corporation) for Microsoft® Project. These models require the user to express duration values in terms of a probability distribution. They allow the user to assess the probability of completing a schedule given the defined tasks and the durations and uncertainty assigned to those tasks. In particular, these models allow assessment of the effects of technical, schedule, cost, and funding uncertainties on the target completion dates, help identify areas for risk reduction actions, and identify common scheduling mistakes.

Sensitivity analysis or "what-ifs" may also be conducted on schedule inputs by modifying the parameters used in the activity/task probability distributions to examine the impact of changes in assumptions or other factors.

> *The results of the schedule risk assessment include the identification of key contributors to uncertainty and/or undesirable performance.*

Step 5 – Finalize Schedule Analysis. Once the schedule network has been defined and assessed and the schedule risk analysis is completed the core team can begin critically analyzing the analysis and results for consistency and agreement. Key actions to take to finalize the schedule include:

- Revisit and review all data/information sources;
- Examine all input values for realism and defensibility;
- Re-examine all probability distribution definitions;
- Re-examine "what-ifs" conducted;
- Converge on a definitive set of input values; and
- Finalize the critical path.

3.4 Compare Alternatives and Develop Results

In this step, all the information developed in the previous steps for each alternative is compiled and structured so that alternatives may be compared consistently. The raw data and assessments that have been completed, including the uncertainty and sensitivity analysis, are organized to determine the relative merit of the alternatives considering all the trade-space criteria. The analysis, results, insights and conclusions are documented in appropriate detail for decision maker consumption. Recommendations from the core team may also be presented in this step, if required or desired by the decision maker. All conclusions and recommendations should be traceable to and supported by the completed analysis.

It is useful to consider early in the study how to best present information to provide greatest insight to the trade-space and to highlight similarities and differences among alternatives. Thinking through the desired presentation of the results at the outset of the study can have great benefit for keeping the analysis focused and efficient, though new data and findings in the course of the trade-space analysis may refine this initial view. Several examples showing how results might be presented are provided below.

Figure 3-7 is an XY scatter plot showing a comparison of eight alternatives with respect to overall benefit, cost, risk, and schedule. The X axis shows overall benefit, the Y axis shows cost, the size of the bubble reflects risk level (larger sphere is higher risk), and the number within the bubble presents the expected date for a final operational capability. Initially, one might consider only how to obtain the highest overall benefit at the lowest cost, and thus might look first at the alternatives at the lower right on the graph. However, when risk and schedule are also considered, different alternatives may be preferable. For example, if 2018 is the assumed need date for operational capability and $120 million is the assumed budget, Alternatives 4, 5, and 7 (circled) may look to be the better alternatives if risk is not considered. However, if risk *is* considered, then Alternatives 4 and 5 may drop out, as they have significant risk assessed; Alternative 7 may represent the most preferred combination of benefit and risk subject to the cost and schedule constraints.

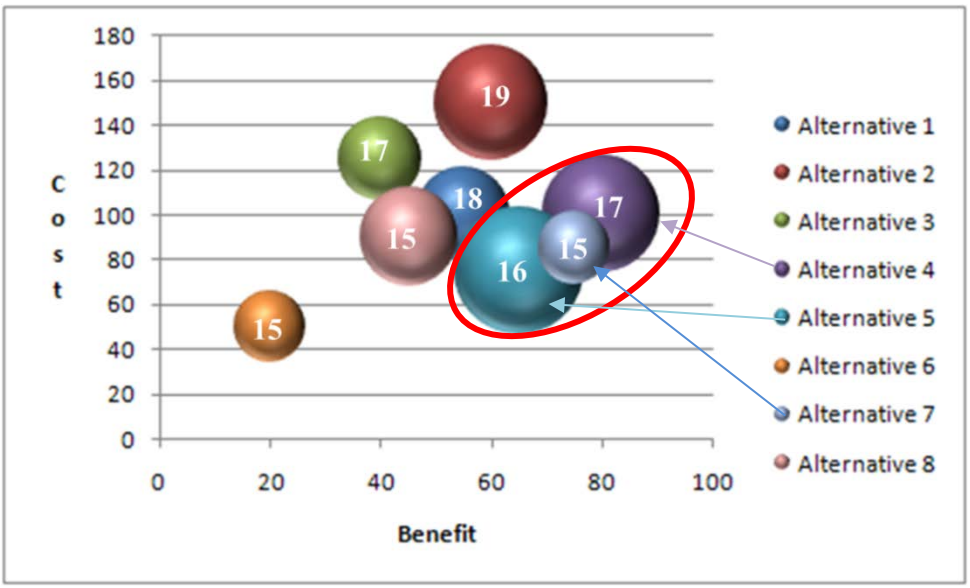


Figure 3-7. Example Summary Visualization #1, XY Scatter Plot

Figure 3-8 displays similar information (cost, benefit, risk, and schedule assessments for a set of alternatives) in matrix form; with both cost and benefit measured on a 0-100 scale. Here the performance/benefit of the alternatives is assessed in terms of a set of merit metrics (MMs, 1 through X) rather than an overall benefit measure as was shown in Figure 3-7. In addition to scores, color-coding is provided to highlight the good and bad points of individual alternatives.

	Life Cycle Cost ($M)	Risk Assessment	Schedule (initial/final capability)	Performance/Benefits			
				MM* (1)	MM (2)	. . . .	MM (X)
Status Quo	$ 50	80	existing	10	50	. . . .	55
Alt A	$ 60	65	2017/2020	60	70	. . . .	60
ALT B	$ 75	20	2018/2019	95	80	. . . .	35
ALT C	$ 30	65	2016/2017	20	45	. . . .	40
ALT D	$ 60	35	2019/2020	40	55	. . . .	25
ALT E	$ 45	55	2015/2018	55	35	. . . .	40
ALT F	$ 100	25	2018/2021	80	90	. . . .	50
. .	. .	. .	. .	. .	. .	. .	. .
ALT Y	$ 35	40	2016/2018	25	50	. . . .	75

MM - merit metric

Figure 3-8. Example Summary Visualization #2, Matrix

Figure 3-9 shows an *efficient frontier*,[11] represented by the black dots, which displays portfolios—combinations of alternatives—that provide the highest possible benefit level for a specific cost. (Gray dots represent less efficient portfolios.) In this example, risk is considered by adjusting the benefit (a riskier alternative is less likely to provide the maximum potential benefit). Schedule is not shown specifically but can be considered within a multi-year analysis.

[11] Efficient Frontier developed using MITRE's Portfolio Analysis Machine (PALMA). PALMA is a trademark of The MITRE Corporation. For more information about PALMA, see reference [22].

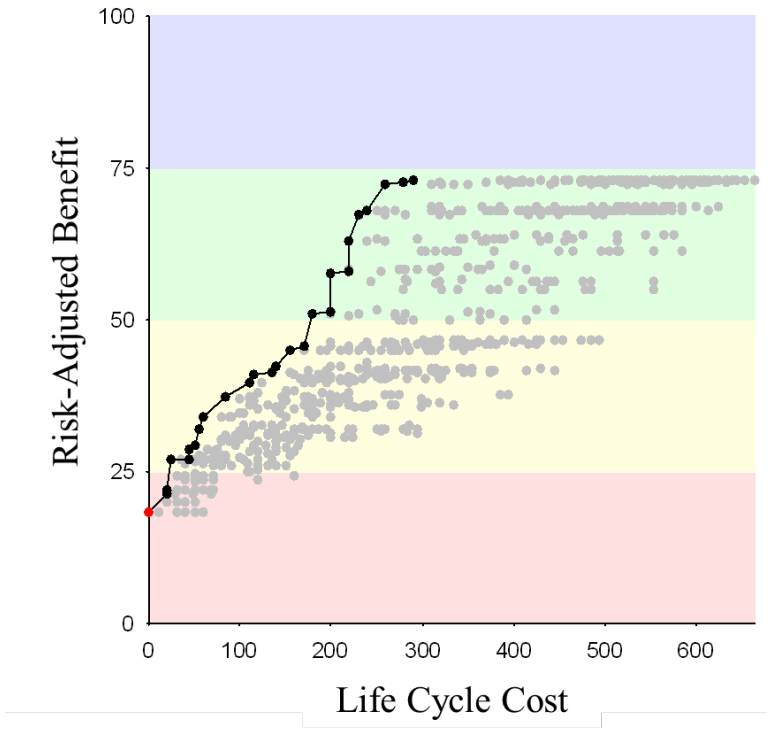


Figure 3-9. Example Summary Visualization #3, Efficient Frontier

4 Tips for a Successful Trade-Space Analysis

Tips specific to individual activities, based on experiences and lessons learned, are woven throughout prior sections; below we provide general tips to keep in mind as you plan for, participate in and conduct any trade-space analysis. The tips in this section are grouped into three general categories: planning, considering the broader context, and ensuring the quality and usefulness of the study results. Additional tips pertinent to specific elements of trade-space analysis are discussed in the appendices.

4.1 Planning

Planning is one of the most important elements of a successful trade study. The following are some tips on this subject.

- *Begin with the end in mind*. In conducting a trade-space analysis it is critical to understand the data the decision maker (and other stakeholders) will require to inform the decision at hand. There may be different levels of detail in the information that is required by different individuals and organizations; the trade-space analysis team must understand how much they will need to "peel back the onion." It can be useful to define the content of a final or summary analysis visualization as a guide for planning and structuring the analysis work.
- *Have back-up plans.* You can count on needing back-up plans in the course of any analysis, so plan ahead and have them in place. Plan for substitute study participants, alternative data sources, different methodologies (and understanding the potential impact of these substitutions), and for rescoping the study itself if study resources were cut (what would be the most valuable to accomplish). You may be able to identify areas that are more likely to change, to provide some focus to this effort. Back-up plans must be feasible and the team must understand the impacts of using them, particularly in terms of credibility of the analysis, meeting the schedule, and maintaining buy-in.
- *Schedule the meetings of the core team.* Meetings of the core team must be put on people's calendars at the outset of the trade-space analysis to ensure critical mass participation. Meetings should be kept to a reasonable time (a good rule of thumb is not more than 90 minutes) as these studies are not typically the only responsibility of participants.
- *Plan ahead for remote participants.* Some participants may attend meetings by phone, video conference, and/or via the web on a regular basis. In this case, the core team must plan ahead to ensure effective remote participation, including scheduling and having (enough) call-in lines, using a facilitator to record inputs and to minimize "cross-talk"; providing the schedule and information ahead of the meetings; and using feedback from participants to improve experiences.
- *Plan for the scale of the analysis*. In some cases you will need to address combinations of alternatives (e.g., portfolio analysis) and your methods, criteria, and metrics will need to allow for this. Considerations include potential synergies or compounding effects in

cost, benefit, risk, and schedule; assessing the effect of these synergies; and understanding how alternatives work together to provide capabilities.

- *Be flexible and adaptable.* Things will change and the team will need to adapt to these changes; having those back-up plans and personnel dedicated to this effort will help.

4.2 Considering the Broader Context

In conducting a trade-space analysis, it is important not to forget about the world beyond the trade-space.

- *Remember that the end may be the beginning.* The analysis and its results may ultimately be used as input into a larger-scale analysis; for example, an analysis conducted to determine the best alternative to meet a specific requirement may be used as input to a portfolio analysis that considers multiple requirements. Your analysis, insights, conclusions, results, and any recommendations should be well documented and discussed in appropriate detail for larger-scale analysis consumption; conclusions and recommendations should be supported by and traceable to the completed analysis. Note that it may not be only your "best alternative" that is incorporated into the larger-scale analysis due to an expanded scope.
- *Consider the overall "value chain."* It is important to consider your subject broadly and understand its relationship to other internal NOAA and external activities, investments, systems, capabilities, and stakeholders. If the relationships have real impact on your trade-space analysis and are not realized until later in the effort, you may have significant rework in order to properly include them; this may jeopardize the schedule. The broader context relates to the *value chain*, the other capabilities/elements that complement or interact with the issue under consideration within the trade-space analysis to produce end-user value. The team needs to be aware of these other elements and to determine whether and how they should be addressed in the analysis.
- *Be aware of relationships beyond your trade-space analysis*. In some cases the elements or outcomes of your analysis may be linked to external elements or outcomes. For example, certain alternatives considered within your analysis may provide capabilities beyond those addressed in your analysis that are needed elsewhere. In this case it would be important to understand these relationships and note them as part of the documentation, as assessment and choices could have secondary and tertiary impacts.

4.3 Ensuring Quality and Usefulness of Results

The results of the analysis must be of high quality—but achievable with the resources available—and must be focused on the decision at hand.

- *Be realistic and practical.* Focus on developing recommendations that are meaningful and based on robust analysis. In planning and execution, the team will need to strike a balance between "heroics" and practicality; analysis plans, processes, and implementation need to be feasible and executable. To create this balance, more attention and resources may be required for those areas assessed to be most important to driving results/outcomes, while less attention is paid to others. The team needs to find appropriate compromises that allow goals to be achieved in a timely manner.

- *Appropriately "size" the analysis*. In some cases extensive analysis is not needed to provide the decision maker with useful information; in these cases, the trade-space analysis team needs to judge whether additional information would enhance the value of the analysis enough to justify the additional resources required. It is also possible to spend too much time "slicing and dicing" information or performing sensitivity analysis (leading to *analysis paralysis*). It is best to focus on the drivers of the results (assumptions, specific variables or input parameters) and have these guide what analysis is needed and will be most important for the decision maker.
- *Use brainstorming*. Brainstorming provides valuable opportunities to expand thinking about the analysis and its various components without bounds or barriers. Brainstorming allows for broad discussion and exchange of ideas without critique, and can thus lead to "out of the box" ideas that create a more robust trade-space analysis. Used judiciously, brainstorming at various junctures of the analysis can be a productive tool for the analysis team. Areas for possible brainstorming include developing an overall "game plan" for the trade-space analysis, assessing possible risks to successful completion (and mitigations), identifying possible alternatives (is there an obvious solution?), developing criteria, defining data needed and data sources, as well as assessing a rough schedule.
- *Consider affordability*. Affordability can be a dominant attribute to consider when developing, evaluating, and selecting alternatives. Looking for more easily implemented solutions to increase the timeliness and efficiency of delivering a capability, even if they are "80% solutions," will have great value to decision makers now and for years to come.
- *Challenge constraints.* Determine which constraints have significant impact on the analysis and make sure that they are realistic. You may find that some do not make sense and should be challenged; in this case, a rationale should be developed and documented to modify or eliminate these constraints.
- *Assess the relevancy of available data*. It is critical to utilize the most authoritative data sources within the trade-space analysis. In some cases historical technical and cost data on systems or technologies similar to alternatives in the trade-space analysis will be collected. The team needs to determine how reasonably analogous the data is to one or more of the current alternatives (e.g., implemented with comparable functionality, utilized in a similar operating environment, meeting similar performance capabilities) and how much modification is required to "normalize" data to the alternative in question. *Normalization* should be supported with clear rationale and logic and should avoid complex adjustments or extrapolation that would jeopardize the credibility of the comparison.
- *Coordinate uncertainty/sensitivity analysis.* Uncertainty and sensitivity analyses conducted in different areas may be related (e.g., schedule risk would also have cost ramifications). Be sure to consider relationships and how they play out across the criteria analyses, and when incorporating these elements into final analyses ensure that there is consistency without "double counting."
- *Ensure external review of SME inputs*. It is important to establish a leadership review board to review subjective SME assessments, to ensure that a broader NOAA view is taken. This is especially important when there are potential shifts in personnel (due to other priorities, time commitment concerns, etc.), since these could change subjective assessments in process.

5 Summary and Conclusions

This guide provides an overview of trade-space analysis within the context of NOAA's work, outlines how to plan for and manage a trade-space analysis in order to achieve the desired outcomes, describes a top-level process for conducting trade-space analysis, and provides tips for conducting a successful trade-space analysis. Additional detail is provided in several appendices.

5.1 Review of Trade-Space Analysis Process

The analysis team must spend significant time up front in planning for, coordinating, and managing the analysis. In particular, the decision the study will support must be defined, the resources necessary to conduct the study must be identified and obtained, the schedule for conducting the analysis must be derived, and decisions must be made on how the results will be documented and communicated. In addition, the team should consider that they may be required to update the analysis in the future and plan accordingly.

The top-level steps in conducting a trade-space analysis are

- *Establish the analysis foundation and framework*. In this step the foundation for the analysis is developed. Key elements are defined, including the problem to be solved, contextual information, the scope (including ground rules and assumptions), and the analysis framework. In addition, data needs are identified and an initial data collection plan is developed.
- *Identify and define alternatives*. In this step, multiple alternatives are identified to address the defined problem within the context and boundaries defined. The final alternatives selected for analysis are defined in detail in a technical baseline to ensure appropriate and consistent evaluation of criteria (cost, performance/benefit, risk, and schedule).
- *Assess the alternatives*. In this step, the cost, performance/benefit, risk, and schedule for each alternative are assessed. In addition, uncertainty analysis and sensitivity analysis are carried out. For each component analysis, the basic steps are identifying the ground rules and assumptions specific to that analysis, defining the analysis structure, completing an initial analysis, conducting uncertainty and sensitivity analysis, and finalizing the analysis.
- *Compare alternatives and develop results*. In this step, all the information developed in the previous steps for each alternative is compiled and structured so that alternatives may be compared consistently. The analysis and results are documented and discussed; recommendations may also be presented in this step. All conclusions and any recommendations should be defensible and traceable to the analysis completed.

Although these steps are presented linearly, they are frequently performed in varying orders and sometimes in parallel. All analysis will be iterative and cyclical in nature as the program and resulting data mature.

5.2 Discussion

Trade-space analysis includes many types of studies, including alternatives analysis, analysis of alternatives, business case analysis, cost-benefit and cost-effectiveness analysis, economic analysis, and portfolio analysis. Trade-space analysis can scale from examining alternative solutions to fulfilling a single new requirement or capability need to fulfilling multiple requirements/capability needs at a system, system-of-systems, portfolio, or enterprise level. Key to all of these analyses is assessment of overall value, efficiency, and affordability. Trade-space analysis is particularly pertinent in times of significant budget constraints and shortfalls, allowing informed choices to be made when needed to give NOAA best overall value.

There are multiple directives, processes, and events that may drive NOAA organizations to perform trade-space studies. This trade-space analysis guide is intended for NOAA personnel who participate in, execute, and lead studies that fall under the umbrella of trade-space analysis.

NOAA organizations considering performing a trade-space analysis should be aware of the processes and capabilities employed by TPIO, especially if the alternatives being considered involve observing systems. TPIO's processes were developed to support the NOSC in its responsibility to review observing system initiatives and provide funding recommendations to NOAA leadership, and therefore focus on observing alternatives (and, to a more limited extent, data management systems associated with observing).

TPIO's processes provide an example of trade-space analysis that has been tailored to address NOAA-specific organizations and processes and that may provide support for similar studies performed by other NOAA units. It is suggested that organizations preparing to conduct such analyses consult with TPIO to take advantage of this experience.

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Acronyms

Acronym	Definition
AGM	Annual Guidance Memorandum
BOA	Basis of assessment
CER	Cost estimating relationship
CES	Cost estimating structure
CONEMP	Concept of employment
CONOPS	Concept of operations
CORL	Consolidated Observation Requirement List
DoC	Department of Commerce
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FFRDC	Federally Funded Research and Development Center
GAO	Government Accountability Office
GR&A	Ground rules and assumptions
IPT	Integrated product team
MM	Merit metric
NOAA	National Oceanic and Atmospheric Administration
NOSA	NOAA Observing Systems Architecture
NOSC	NOAA Observing Systems Council
NOSIA	NOAA Observing System Integrated Analysis
NPV	Net present value
OMB	Office of Management and Budget
PALMA	Portfolio Analysis Machine
PPBES	Planning, Programming, Budgeting, and Execution System
SEE	Strategy Execution and Evaluation
SME	Subject matter expert
TOR	Terms of reference
TPIO	Technology, Planning and Integration for Observations
TSAG	Trade-Space Analysis Guide
WBS	Work breakdown structure

Glossary of Terms

This glossary provides definitions of terms that are used in the *Trade-Space Analysis Guide* and its appendices. It includes terms that are fully defined in the text (pulling them together in one place for the convenience of the reader) and expands on terms that are not fully discussed in the document. Terms that are included in the glossary are indicated in the text by *blue italic type*. They are highlighted on their first occurrence. References, indicated in square brackets, are listed at the end of the glossary. If no reference is listed, the definition is based on multiple sources or is defined in this report.

Alternatives analysis. Analysis of alternative approaches to addressing the performance objectives of an investment, performed prior to the initial decision to make an investment, and updated periodically as appropriate to capture changes in the context for an investment decision. [1]

Analogy. A method of cost estimating that attempts to compare the alternative to an existing or past system or program.

Analysis of alternatives. An analytical comparison of the operational effectiveness, cost, and risks of proposed materiel solutions to gaps and shortfalls in operational capability. [2]

Assumptions. Conditions that apply to an analysis, including suppositions about what will happen in the future.

Base year dollars (BY$). A point of reference representing a fixed price level or the purchasing power of money in a particular year. Comparative analyses are usually presented in BY$.

Basis of assessment. The documented rationale behind the scoring of a certain risk for a certain alternative, including risk drivers.

Benefits analysis. An analysis where the objective is to estimate the potential positive effects of the capabilities provided by alternatives with respect to their functional end-use, or using a metric that considers the relative "importance" or "impact" of the alternatives. An example would be an estimate of the economic benefits to end-users or to the general public of an investment in a new observing system or forecasting capability.

Build up (or bottom-up). A method of cost estimating that attempts to deconstruct the alternative into detailed, understandable activities and components, and estimate these individually, summing all the components to the next level of the WBS. This method is also called an engineering estimate or engineering build-up estimate.

Business case analysis. A decision support document that identifies alternatives and presents convincing business, economic, risk, and technical arguments for selection and implementation to achieve stated organizational objectives. [3]

Consolidated Observation Requirement List (CORL). An extensive database that documents NOAA observing requirements, developed by TPIO working closely with NOAA program leaders and subject matter experts. Information recorded in the database includes the priority of each requirement, based on its importance to the group's mission, as well as specific attributes

for each requirement. The database also allows program leaders to weight each attribute to indicate its level of importance in meeting mission objectives. [4]

Cost analysis. The effort to develop, analyze, and document cost estimates with analytical approaches and techniques; the process of analyzing, interpreting, and estimating the incremental and total resources required to support past, present, and future systems; and a tool for evaluating resource requirements at key milestones and decision points in the acquisition process. [5]

Cost-benefit analysis (CBA) and cost-effectiveness analysis. Analyses that compare a program's outputs or outcomes with the costs (resources expended) to produce them. When applied to existing programs, they are also considered a form of program evaluation. Cost-effectiveness analysis assesses the cost of meeting a single goal or objective and can be used to identify the least costly alternative for meeting that goal. Cost-benefit analysis aims to identify all relevant costs and benefits, usually expressed in dollar terms. [6]

Cost estimating. Combines science and art to predict the future cost of something based on known historical data that are adjusted to reflect new materials, technology, software languages, and development teams. [5]

Cost estimating relationship. A relationship used to calculate cost as a function of certain variables or parameter, developed from historical data from multiple programs of like-type. An example of a CER is y=0.27*W, where y is the cost of an item and W is its weight. CERs are developed using regression and other statistical techniques on large data sets.

Cost-estimating structure. See work breakdown structure (WBS)

Critical path. The longest sequence of activities in a project plan, accounting for dependencies, which must be completed on time for the project to complete on the due date.

Economic analysis. A systematic approach to identifying, analyzing and comparing costs and benefits of alternative courses of action that achieve a given set of objectives. In some cases a CBA and EA are viewed as equivalent. [7] In NOAA's context, the difference between CBA and EA is that the latter is typically more focused on estimating the economic impact of a policy change or the economic value of an intangible non-market item, such as improved information or a particular natural resource. Examples include the economic impact on fishing communities of closing a fishery, or the value of improved forecasts for specific stakeholders.

Economic benefit analysis. An analysis in which benefits to certain stakeholders are estimated and monetized. Economic benefits can include cost savings to NOAA, but are primarily concerned with benefits to the general public (societal benefits) and to specific stakeholders or economic sectors. Because NOAA's products and services are essentially informational, economic analyses of NOAA alternatives will focus on the economic value of this information.

Efficient frontier. On a graph of benefit vs. cost, the curve formed by the points at the upper left-hand edge of the graph; these points (which may represent individual investments or portfolios of investments) represent the maximum value achievable for any given cost. [8]

Extrapolation from actuals. A method of cost estimating that requires the collection and organization of cost reporting data on the program so as the program matures it becomes possible to extrapolate future costs based on the program's actual performance to date. This method is useful for predicting the program's final cost at completion.

Execution risk assessment. An assessment that evaluates the ability of each proposed alternative to successfully execute and deliver on its promised benefits within proposed schedule and cost, and uses these evaluations to differentiate among alternatives. A standard set of risk areas or categories is often used to evaluate the risk of each alternative. The assessment consists of a risk score (per individual risk area and overall risk) and rationale for each score.

Ground rules. A set of rules that delineate what will and will not be addressed within the analysis to fulfill its stated objectives. Also called constraints or boundary conditions.

Independent cost estimate (ICE). A life-cycle cost estimate produced by an independent organization outside the program management chain.

Integrated product team (IPT). A multidisciplinary group of people who are collectively responsible for delivering a defined product or process. Sometimes called an integrated process team. [9]

Life-cycle cost estimate (LCCE). An estimate of the entire cost of a program from concept development to disposal. LCCEs may be produced by the Program Office managing the program or by an independent organization outside the program management chain.

Monetize. To express a benefit derived from an alternative in terms of dollars.

Net present value (NPV). The discounted monetized value of expected net benefits (i.e., benefits minus costs). NPV is computed by assigning monetary values to benefits and costs, discounting future benefits and costs using an appropriate discount rate, and subtracting the sum total of discounted costs from the sum total of discounted benefits. It is the standard criterion for deciding whether a government program can be justified on economic principles. [10]

NOAA Observing Systems Architecture (NOSA). A comprehensive database containing information about all of NOAA's observing systems. This information was built with the assistance of NOAA observing system managers, research and operational, within and outside of NOAA. TPIO serves as the principal steward of the NOSA database. [12]

NOAA Observing Systems Council (NOSC). The focal point and principal advisory body to the NOAA Administrator for the agency's observing system activities and interests. The purposes of the Council include coordinating observational and data management activities across NOAA; proposing priorities and investment strategies for observation related initiatives; and identifying programs that might benefit most from integration. [11]

Non-recurring costs. Costs associated with activities or purchased items that are singular or not quantity dependent; for example, design engineering of a sensor, purchase of test equipment, or program management costs. These are costs for events that happen once, although it may be an ongoing effort for several years.

Normalization. The adjustment of historical cost data to be relevant to the alternative being estimated, reflecting its state of technology and programmatic realities.

Outcome-oriented WBS. A WBS that is organized along the lines of the operational outcomes the system is expected to produce when applied alone or with other systems within a mission context (e.g., military outcomes for the Department of Defense). Using a product-oriented (rather than outcome-oriented) WBS is considered the best practice by most sources. A key issue with an outcome-oriented WBS is that it is difficult to "allocate" costs to various outcomes,

particularly when multiple systems contribute to multiple outcomes and changes occur in these systems over time.

Parametric. A method of cost estimating that uses a cost estimating relationship (CER) developed from historical data from multiple programs of like-type. The CER calculates cost as a function of certain variables or parameters.

Payback period. The number of years it takes for the cumulative dollar value of the benefits to exceed the cumulative costs of an investment. [13]

Performance analysis. An analysis that uses measures reflecting the technical merits of each alternative. An example would be how well different alternatives satisfy a specific technical requirement, such as a requirement to observe certain phenomena at a specified measurement accuracy.

Planning, programming, budgeting, and execution system (PPBES). An integrated, requirements-based system designed to use NOAA's strategic vision to drive annual investment and management priorities, programmatic and policy choices, and budget development; and provide a systematic approach to allocating resources optimally and maximizing programmatic impact. At NOAA, now being transitioned to the SEE process.

Point estimate. The arithmetic sum of the costs of all component pieces (component point estimates) of the system, as defined in the WBS. A point estimate has no measure of likelihood or confidence until cost uncertainty is modeled.

Portfolio analysis/portfolio management. The management of selected groups of investments using strategic planning, architectures, and performance measures to achieve a mission capability. Key components of portfolio management are analysis, selection, control and evaluation. [14]

Product-oriented WBS. A WBS that is organized in accordance with, and accounts for the efforts and assets associated with, delivery and operations of a physical system or system-of-systems (e.g., the hardware, the software, the engineering, the personnel).

Program Office Estimate (POE). A life-cycle cost estimate produced by the Program Office managing the program.

Programmatic risk assessment. A methodology that identifies individual risks to a program and assesses the probability and impact of each risk, used primarily in managing the execution of a program.

Recurring costs. Costs addressing repetitive tasks or purchased items, essentially costs that are quantity dependent; for example, the production of multiple units of an end product such as a floating buoy, or regular operations/maintenance activities such as periodic inspections/repairs to aircraft engines.

Return on investment (ROI). A percentage calculated by dividing the total discounted net (benefits) by the total discounted costs and multiplying by 100. ROI can also be expressed as (total discounted benefits minus total discounted costs) divided by (total discounted costs). [13]

Schedule risk analysis. The process of associating a degree of confidence with estimates of schedule duration for individual tasks. The combination of defining probability distributions for

various scheduled task durations and establishing network relationships among the tasks allows one to forecast the probability of meeting the targeted dates of key milestone events.

Sensitivity analysis. A tool for assessing the extent to which costs and benefits (or other elements of an analysis) are sensitive to changes. Sensitivity analysis repeats a prior analysis using different quantitative values to determine their effects on the results; if a small change in an assumption results in a significant change in the results, the results are said to be sensitive to that assumption. It focuses on "what-ifs" and examines the consequences of changes (e.g., in key assumptions and technical definition). It can be used to identify the significant drivers of the analysis. [7]

Societal benefit. Benefits that reflect value delivered to society/various sectors of the economy by an alternative, including, but not limited to, individual citizens and industries. Examples of societal benefit criteria are percentage reduction in operational delays in the aviation industry due to convective weather, or percentage reduction in accidents due to weather in the trucking industry.

Statement of work. A contractual document that specifies the work to be done in developing or producing the system to be delivered or services to be performed by a contractor. The SOW defines (either directly or by reference) all work (non-specification) performance requirements for contractor effort. [15]

Strategy Execution and Evaluation (SEE). A seven-step strategy implementation process that helps NOAA learn from its programs' results and achieve its objectives, while simultaneously responding to ever-changing economic, governmental, social and environmental forces. The SEE process emphasizes results-based budgeting and evaluation. [16]

Sunk costs. Funds that have already been spent for/by an alternative. As sunk costs cannot be changed; they are not considered explicitly in evaluating alternatives.

Technical baseline. A description of the technical, programmatic, and schedule information necessary to estimate the costs of a program. For trade-space analyses, a technical baseline is developed for each alternative. The technical baseline characterizes the physical and functional representation of the intended capabilities. It provides a description and decomposition of hardware, software, and integration including non-recurring and recurring elements that make up the system. It also describes the context of the capabilities and their implementation including system dependencies, legacy capability migration or reuse, technologies, operating environment and performance. Engineering, management and support activities and resources to develop, test, acquire, deploy and sustain capabilities in operations are described. Developing a technical baseline ensures that cost projections are based on a clear definition of the system and the acquisition program.

Then-year dollars (TY$). The purchasing power of money in a future year when it is expected to be spent; includes the effects of inflation or escalation. Budgets are usually built in TY$.

Technology, Planning and Integration for Observation (TPIO) program. A NOAA program that manages the development of NOAA's Integrated Environmental Observation and Data Management System Architecture, otherwise known as NOAA's Integrated Architecture. This involves managing three major NOAA-wide capabilities: Observation System Architecture, Requirements and Planning, and Data Management Architecture. [17]

Trade-space analysis. The examination and evaluation of alternative ways of achieving outcomes within the context of a specific decision to be made or problem to be addressed.

Uncertainty analysis. The process of identifying, evaluating, and quantifying the uncertainties associated with a system's technical and program definition, technical parameters, and other input into the cost methods used in creating the estimate. The probability that a specific cost target will be exceeded (or stated differently, the confidence that an estimated cost will not be exceeded) is derived from the total uncertainty of the estimate. [18]

Value chain. The other capabilities or elements that complement or interact with the alternatives under consideration within the trade-space analysis to produce end-user value.

Value tree. A decision-support tool that provides a hierarchical decomposition of an organization's missions or objectives into lower level functions or tasks and reflects the value of those lower level functions or tasks in accomplishing those missions or achieving those objectives.

Wash costs. Costs that are identical between alternatives. Since for these costs no variation exists between alternatives, wash costs are usually removed from comparative analysis.

Work breakdown structure (WBS). A structure for decomposing an alternative into discrete pieces for which costs can be estimated. A WBS breaks down elements into a hierarchical structure that shows how elements relate to one another (i.e., parent-child relationships) as well as to the overall end product. [19] Also known as a cost estimating structure (CES).

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