Appendix J: Joint Cost and Schedule Confidence Level (JCL) Analysis

Joint Cost and Schedule Confidence Level (JCL) analysis is an integration of cost, schedule, risk and uncertainty. The result of a JCL analysis indicates the probability that a project's cost will be equal to or less than the targeted cost *and* that the schedule will be equal to or less than the targeted finish. The following topics are described in this appendix:

J.1.   JCL Introduction

Joint Cost and Schedule Confidence Level (JCL) analysis is a process that combines a project's cost, schedule, and risk into a complete picture. JCL is not necessarily a specific methodology (e.g., resource-

loaded schedule) or a product from a specific tool. The JCL calculation includes consideration of the risk associated with all elements, regardless of whether or not they are funded from NASA's appropriations or managed outside of the project (e.g. a partner contribution).

A JCL identifies the probability that a given project or program cost will be equal to or less than the targeted cost AND that the schedule will be equal to or less than the targeted schedule date. There are two fundamental ways that one could generate a JCL: 1) bivariate distributions[1] and 2) probabilistically cost loading a probabilistic schedule (Probabilistic Cost-Loaded Schedule [PCLS]). Both methodologies will fundamentally produce a JCL; however, to fulfill the intent of the NASA JCL policy requirement, it is intended that a project or program perform the latter (probabilistic cost loading of a probabilistic schedule). Because of this, JCL, as referred to in this appendix, will effectively mean a PCLS.

The rationale for the Agency focusing in on the PCLS methodology stems from the fact that the method forces the project and the review entity to focus on the project's plan. This improves project planning by systematically integrating cost, schedule, and risk products and processes. It also facilitates transparency with stakeholders on expectations and probabilities of meeting those expectations. Lastly, it provides a cohesive and holistic picture of the project's ability to achieve cost and schedule goals and helps the determination of reserves (or Unallocated Future Expenses [UFEs]) for cost and schedule to meet a desired confidence level.

In summary, JCL helps set the foundation to answer fundamental questions: Does the project have enough funds? Can the project meet the schedule? What are the areas of risk toward successful execution of the project? What risk mitigation strategies provide the best project benefit?

J.1.1. Purpose

A JCL number is the product of a type of process, with the intent to model the programmatic risk of the project or program plan. The purpose of the JCL is to model reality, not recreate it. As with most modeling, there are numerous ways to model any situation. The scope of this appendix does not cover all the procedural modeling techniques that can be performed, but it serves as a foundation for the expectations and understanding of NASA's JCL policy and provides insight to best practices.

It is important to note that the JCL requirement is more than just a policy requirement for an Agency Key Decision Point (KDP). It can also serve as a valuable project management tool that helps enforce some best practices of program planning and control, and it also potentially enhances vital communication to various stakeholders.

---

[1] Garvey provides material on using bivariate distributions: Garvey, P.R., 2000, *Probability Methods for Cost Uncertainty Analysis: A Systems Engineering Perspective* (New York: Marcel Dekker).

So before implementing a JCL analysis, consider the following questions. If you can answer in the affirmative to all of them, then implementing JCL should be fairly straightforward. However, if you cannot succinctly answer them, then JCL can help!

- Are current cost, schedule, and risk integrated?

- How confident are you that the project/program will accomplish the planned work with the available funds?

- Do you know where and how your project/program risks may impact the schedule?

- Have you identified and prioritized all of the cost AND schedule drivers to your project/program?

- Can you evaluate the cost effectiveness of your risk mitigation plans?

- Can you quantify and communicate what a reduction in funding will do to the likelihood of success of your project?

- Can you assess alternative scenarios and understand how they impact confidence levels?

J.1.2.   History of JCL Policy

The following section briefly describes the history of NASA current probabilistic policy (commonly known as JCL). The intent of this section is to give the "story" behind the rationale for the current policy. The history of the current Agency probabilistic policy can be best summarized in Figure J-1. The top swim lane illustrates the project, or advocacy, analysis, whereas the bottom swim lane illustrates the independent, or non-advocacy, analysis.
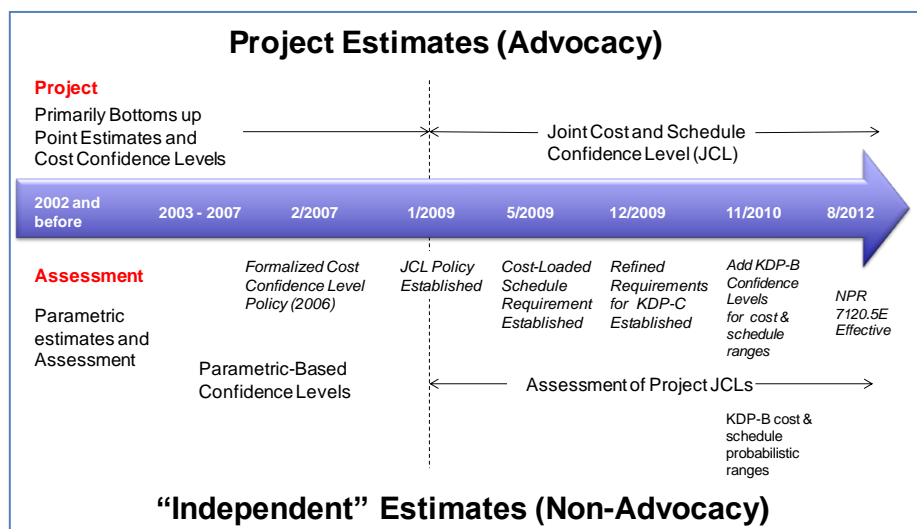

Figure J-1. JCL Policy Timeline

To understand the current situation, it is necessary to go back to 2002. Beginning in 2002, the United States General Accounting Office[2] (GAO) issued reports (United States General Accounting Office, 2002)

---

[2] Now known as the Government Accountability Office (GAO).

(United States General Accounting Office, 2004) that identified major causes[3] of cost growth including incomplete cost-risk assessment and flawed initial program planning.[4]

The GAO completed a detailed examination of NASA's cost estimating processes and methodologies for various programs. This report made numerous recommendations to establish a standard framework for developing Life Cycle Cost Estimates (LCCEs), which included conducting a cost-risk assessment that identifies the level of uncertainty inherent in the estimate.

Formal probabilistic estimating guidance was first mentioned in February 2006 in an e-mail from the NASA Administrator directing NASA's largest program at the time, Constellation, to budget to a 65-percent confidence level. Noted again a month later at a strategic management meeting in March 2006, "[the NASA Administrator] determined that NASA's standard practices will be to budget projects at a 70% confidence level based on the independent cost estimate…initiate a pattern of honest dealing between Program and Project Managers, HQ, the Congress, and the WH [White House], and to avoid the pattern of finger-pointing for cost overruns and schedule slips that have plagued the industry in the past." Guidance was clarified further in the spring of 2007.

Several issues arose from the initial guidance. First, the lack of formally documented policy guidance hindered effective implementation.[5] Second, by omitting schedule risk in the confidence statement, a vital programmatic variable was inconsistently being utilized. Last, the reconciliation process between projects and the Agency's non-advocate groups was tedious.[6]

In January 2009, NASA's cost estimating policy was updated to address the issues previously mentioned. Policy was inserted in the NASA governance structure[7] and was expanded to specify a JCL.

Though the tools, techniques, and methodologies were well understood and demonstrated in certain industries[8,9], much of the analysis traditionally had not been done in the aerospace industry on highly uncertain, complex developments. NASA is continually making strides to hone the associated best practices and understanding for JCL analysis.

J.1.3. Requirements

J.1.3.1. Intention of Policy

Currently, NASA is using a variety of cost analysis methodologies to formulate, plan, and implement projects. In the formulation stage, specifically for KDP-B, NASA is calling for programs and projects to provide probabilistic analysis on both their cost and schedule estimates. This analysis is then used to determine a high and a low estimate for cost and for schedule.

The community has identified two good candidate methodologies for producing the risk estimates and associated results: 1) complete parametric estimates of cost and schedule, or 2) complete a JCL

---

[3] Additional major causes of cost growth that were cited but are not addressed in this paper or directly with JCL policy include: acquisition workforce problems, "corporate-directed" actions, and competitive environment.

[4] Findings supported by a Booz Allen & Hamilton study for the U.S. Air Force Space and Missile Systems Center, 2002.

[5] Not captured in policy directives or procedural requirements (NASA governance structure).

[6] Project's estimates were typically done based on a project plan using detailed proposal data, grassroots estimates, and subject matter expert adjudications whereas the non-advocate probabilistic estimates were typically done parametrically using key measurable variables to "predict" cost. Reconciling the differences between these two methodologies and effectively informing the decision makers of the causality of the difference was time consuming and very difficult.

[7] Originally NPD 1000.5 and currently in NPR 7120.5E.

[8] For details on the methodology of convolving a probabilistic cost and probabilistic schedule estimate for a JCL, refer to Book, 2007, and Garvey, 2000.

[9] Construction, oil, and gas industries have been doing probabilistic resource analysis for some time.

consistent with policy. It is the viewpoint of the Office of Evaluation, and the majority opinion of the community,[10] that conducting a JCL at KDP-B should not be required. This is primarily because projects typically do not have detailed plans available to support an in-depth JCL analysis, and by design, the requirement at KDP-B is intended to "bound the problem." Conducting a parametric estimate of schedule and cost utilizes the historical data and performance of the Agency and provides a valuable estimate of the range of possibilities. Attempting a JCL at KDP-B, for these reasons, is therefore not required; however, if a JCL were conducted at KDP-B, it would fulfill the policy requirements of KDP-B because the JCL analysis is more stringent than the KDP-B requirement.

To calculate a JCL, the project should use a rigorous process that combines its cost, schedule, and risk into a single model that can generate a probabilistic assessment of the level of confidence of achieving a specific cost-schedule goal. The rationale for conducting JCL in support of KDP-C is to help ensure that: 1) The project's plan is well defined and risks are understood, and 2) The risk posture is acceptable for the timeframe and cost to which NASA is committing to external stakeholders. The Agency uses this assessment when considering its external commitment (the Agency Baseline Commitment [ABC] at KDP-C) as one means of ensuring the project has a robust plan with costs linked to schedule, where both are informed by risks.

Once a baseline is approved, NASA policy does not require a project to maintain the analysis models used to calculate the JCL. However, the Agency does utilize a variety of performance metrics to assess how well the project is performing against its plan. If these metrics show that a project's performance varies significantly from its plan, the project may need to replan, but Agency policy only requires a repeat calculation of the JCL in the event that the project requires a rebaseline. JCL analysis can provide valuable insights as a management tool; however, the only Agency requirement for JCL is at KDP-C.

J.1.3.2.   Policy Summary

In summary, NASA Procedural Requirements (NPR) 7120.5E (*http://nodis3.gsfc.nasa.gov/displayDir.cfm?t=NPR&c=7120&s=5E*) directs projects to generate a probabilistic cost-loaded schedule and produce a JCL for KDP-I/C[11] that is executable within the available annual resources. This JCL analysis will be evaluated by a non-advocacy body. The Decision Authority (DA) will determine the JCL (probability) for the associated development and life-cycle cost at which the Agency commits to deliver the program/project. It is recommended per policy that the JCL value be at 70 percent confidence for the ABC with a minimum value of 50 percent for the Management Agreement (MA), although the DA can adjust the confidence level with documented rationale.

J.1.3.3.   Policy Specifics

Specifically, the relevant language from NPR 7120.5E reads as follows[12]:

Tightly coupled and single-project programs (regardless of life-cycle cost) and projects with an estimated life-cycle cost greater than $250 million shall develop probabilistic analyses of cost and schedule estimates to obtain a quantitative measure of the likelihood that the estimate will be met in accordance with the following requirements.

At KDP I/KDP C, tightly coupled and single-project programs (regardless of life-cycle cost) and projects with an estimated life-cycle cost greater than $250 million shall develop a resource-loaded schedule and perform a risk-informed probabilistic analysis that produces a JCL. The JCL

---

[10] As discussed at the NASA Executive Cost Analysis Steering Group (August 2011).

[11] Key Decision Point I or Key Decision Point C. If it is a program, then KDP-I is appropriate, and if it is a project, KDP-C is appropriate.

[12] Language is taken directly out of NPR 7120.5E Section 2.4.

is the product of a probabilistic analysis of the coupled cost and schedule to measure the likelihood of completing all remaining work at or below the budgeted levels and on or before the planned completion of Phase D.

Mission Directorates shall plan and budget tightly coupled and single-project programs (regardless of life-cycle cost) and projects with an estimated life-cycle cost greater than $250 million based on a 70 percent joint cost and schedule confidence level, or as approved by the Decision Authority.

Any JCL approved by the Decision Authority at less than 70 percent shall be justified and documented.

Mission Directorates shall ensure funding for these projects is consistent with the Management Agreement and in no case less than the equivalent of a 50 percent JCL.

When a tightly coupled program, single-project program, or project with an estimated life-cycle cost greater than $250M is rebaselined, the JCL should be recalculated and approved as a part of the rebaselining approval process.

Loosely coupled and uncoupled programs are not required to develop program cost and schedule confidence levels. These programs shall provide analysis that provides a status of the program's risk posture that is presented to the governing PMC as each new project reaches KDP B and C or when a project's ABC is rebaselined.

J.1.3.4.   Policy Clarifications

There are several general areas of the policy that warrant additional clarification.

J.1.3.4.1.   Resource-Loaded Terminology

The policy clearly states that the projects are required to generate a *resource-loaded* schedule. This terminology can be confusing and deserves some attention. NASA's definition of resource loading is the process of recording resource requirements for a schedule task/activity[13] or a group of tasks/activities.[14] The use of *resource loading* implies, to many people, that the tasks need to be loaded with specific work or material unit resources. This is NOT the intent of the policy. In general, the terminology of *resource-loaded* schedule can be used interchangeably with *cost-loaded* schedule. The intent of the JCL policy is not to recreate the lower level management responsibilities of understanding and managing specific resources (labor, material, and facilities) but to instead model the macro tendencies and characteristics of the project. To do this, *cost loading* a schedule is sufficient and a resource-loaded schedule is not required.

> **Resource Loading vs. Cost Loading**
>
> If there were two individuals who were needed to perform a task (Person A and Person B), then to resource-load each person to that task we would identify how many hours each person would put on that task and their associated labor rate. However, with regards to cost loading, we are only interested in the total effort, measured in dollars, of the entire team (Persons A and B). For a JCL, cost loading a schedule is sufficient and a resource-loaded schedule is not required.

J.1.3.4.2.   Risk-Informed

---

[13] The terms "task" and "activity" are utilized interchangeably in this document.

[14] NASA Schedule Management Handbook, 2010.

The policy states that a project will need to perform a *risk-informed* probabilistic analysis to produce a JCL. NPR 7120.5E defines risk as "the potential for performance shortfalls, which may be realized in the future, with respect to achieving explicitly, established and stated performance requirements." Typically, from a risk-management perspective, discrete risks are identified and tracked, and mitigation plans are formulated. By *risk-informed*, the policy is stating that all appropriate discrete risks be modeled, but it is also the intent of the policy for *risk-informed* to also account for various uncertainties (that may not be discretely managed in the risk management system). Formal definitions within the context of JCL on what risk and uncertainty are will be discussed later and are summarized in the risk assessment section of this appendix.

J.1.3.4.3. Life-Cycle Costs and Schedule

It should be made clear that the scope of the JCL analysis typically includes content only through Phase D. This, by definition, is not the total life-cycle cost (as defined by NPR 7120.5E) or operational life of a project. The exact content of what is included in the costs and schedule to meet this Phase D requirement needs to be agreed upon between the project and the non-advocacy entity, as typically defined in the Terms of Reference (ToR) for the Non-Advocate Review.

J.1.3.4.4. Scope

International/Interagency Contributions and Inter-Project/Program Risks. With regards to International/interagency contributions and inter-project/program risks, the project is tasked to include the programmatic risk of cost and schedule impacts to the project stemming from those systems. The project should coordinate with the international, interagency, and inter-project/program entities when available, as well as coordinate with its mission directorate, to determine the adjudication and communication of the risks (ownership). Further work should be performed to determine how those risks will be incorporated and communicated in the range and JCL calculations. The non-advocacy review will have the responsibility to evaluate all aspects of the range and JCL analysis—including international/interagency and inter-project/program relationships.

Launch Vehicle Costs. Over the last few years of JCL policy implementation, there have been some misunderstandings on how to handle the risk associated with the launch vehicle (LV) costs in the JCL calculations. These misunderstandings dealt less with the mechanics of how to "add" the LV costs and the associated risks—as the LV costs and the risks are already captured in both the management and Agency cost commitments—but more with who should take ownership over the project life-cycle JCL analysis, which includes the LV. The issue of ownership over the project life-cycle JCL analysis (which includes LV) is discussed in the specific context of the Science Mission Directorate (SMD) missions; therefore, the following is not intended to add clarification on JCL calculations or life-cycle scope inclusion for programs/projects that fall under other NASA directorates.

In summary, the LV costs shall be included in range and JCL calculations. SMD, through its coordination with the Human Exploration and Operations (HEO) Mission Directorate and Kennedy Space Center (KSC) Launch Services Offices, will continue to be responsible for communicating the LV costs and risks to the project and for ensuring that they are integrated into the entire project scope (including LV) for the decisional PMC. The non-advocate review team shall evaluate all aspects of the JCL analysis, as well as the integrated analysis, in support of the KDP-C milestone.

J.1.4. Roles and Responsibilities

This section is to help the reader understand the core roles and responsibilities when implementing a JCL. This section is divided into three areas: Data to conduct the JCL, NASA Agency roles, and project-specific roles.

J.1.4.1.   Primary Roles in JCL Analysis

There are several stakeholders with direct impacts on the JCL process:

- Project managers:
    - The Project managers "own" the project advocate JCL analysis. This means that planning, developing, iterating, and presenting the results of the advocate JCL model is the project's responsibility.
- Mission Directorates:
    - Serve as co-owners of the KDP-C Decision Memorandum, where JCL results are documented in support of external commitments.
    - Monitor project JCL status and adjudicate UFE allocation.
    - Have the ability to provide external risks to the project in support of JCL analysis.
- Office of Evaluation (OoE):
    - Independent Program Assessment Office (IPAO) supporting the Standing Review Board (SRB):
        - Facilitates SRB evaluation of a project's JCL whenever a project is reviewed at KDP-C.
        - When requested, facilitates SRB evaluation of the project's JCL whenever there is a Special Review or Rebaselining.
        - Provides benchmark analysis for comparing the project's cost loading and schedule activity duration estimates.
    - Cost Analysis Division:
        - Agency JCL policy advocate.[15]
        - Coordinates and recommends Agency JCL policy, including derived requirements and implementation procedures.
        - Approval authority for JCL waiver requests.
        - Provides "jump start" advice and consulting support so programs and project may develop their JCLs.
        - Communicates requirements and orchestrates requisite education and training.
        - Provides access to Agency tools (e.g., Joint Analysis of Cost and Schedule [JACS] and POLARIS) and data (e.g., Cost Analysis Data Requirement [CADRe]).
- Office of the Chief Engineer (OCE):
    - Owner of NPR 7120.5E, where the JCL requirement resides.
    - Coordinates, with OoE/Cost Analysis Division (CAD), on JCL waiver requests.
    - Advises Baseline Performance Review (BPR) leadership on project performance that may lead to a rebaseline and require a new JCL per NPR 7120.5E.
- Office of Chief Financial Officer (OCFO):
    - Serves as co-owner of the KDP-C Decision Memorandum, where JCL results are documented in support of external commitments.
    - Serves as owner of the Major Program Annual Report (MPAR), which contains JCL results and performance status, and is provided to the external stakeholder (e.g., Congress, OMB).
    - Advises CAD on waiver requests.
    - Advises BPR leadership on project performance that may lead to a rebaseline and require a new JCL per NPR 7120.5E.

---

[15] NPR 7120.5E is available at *http://nodis3.gsfc.nasa.gov/lib_docs.cfm?range=1*.

J.1.4.2. Project-Specific Roles and Responsibilities

There are several key functions to be performed within the project; they are defined below.[16] Identifying roles and responsibilities early is very important to a successful JCL.

- <u>JCL Leader</u>: The JCL leader is the one individual responsible for coordination and integration of the JCL. This person should have a good understanding of the project plan including cost, schedule, and risk.

- <u>Scheduler</u>: This function is one of the most important functions in the JCL effort. This person must have intimate familiarity with the current project schedules. This person should have the expertise to construct a JCL schedule, if needed, and should be able to reach back to the technical experts.

- <u>Estimator or Resource Analyst</u>: This individual must be familiar with project current budget structure; cost estimates, including Basis of Estimates (BOEs); and resource plan(s).

- <u>Risk Manager</u>: The Risk Manager must be familiar with the current project risk management system. This person must be able to provide details supporting the risk register and should be able to reach back to the risk "owners" when needed.

Regardless how the functions get parceled out, it is important that the following fundamental questions get answered when initiating a JCL:

- Who is in charge of the JCL effort?

- Who will ultimately be responsible for the development of the model and analysis (who will run the model)?

- Who will build the analysis schedule?

- Who has access to the detailed cost data?

- Who can link the cost data to schedule tasks on the analysis schedule?

- Who can provide the risk information?

- Who can solicit and develop uncertainty data?

J.1.5. Data to Conduct JCL at KDP-C

The following section describes core informational products that will be needed to perform JCL analysis.

J.1.5.1. Schedule

Schedules should be sufficiently detailed to allow for an accurate and complete understanding of the entire task/project. Schedules perform best when they are integration focused and suitable for risk analysis. Detailed Integrated Master Schedules (IMSs) should be utilized, and they should be linked to any integration/analysis/summary[17] level schedule that is used to perform a JCL at KDP-C. For example, an IMS may inform an analysis level schedule, which forms the basis of the JCL model. In general, it can be difficult to perform a JCL on an IMS, and it is often recommended that schedules are appropriately

---

[16] These roles are listed by responsibility. Though it is very important to have each function represented, the people-to-function ratio does not have to be 1 for 1.

[17] The terms "integration," "analysis," and "summary level schedules" are used in the context of the JCL analysis interchangeably; however, the term "analysis schedule" is typically used to circumvent confusion. Succinctly, an analysis schedule is a logically linked schedule that is informed by the logic of the IMS; however, the detail of the schedule is rolled up to a higher level. For example, an IMS may have several activities that describe the many aspects associated with a thermal vacuum test, whereas an analysis schedule may show the test as one summarized activity.

summarized into an analysis schedule with the emphasis on the ability to conduct a schedule risk analysis (see the detailed discussion in J.2.1.1.). It is important to understand where discrete risks may occur in the plan and how historical uncertainty in task durations affects the plan.

J.1.5.2. Cost

The general approach to estimating costs should be consistent with Section 2 of the Cost Estimating Handbook. Some general key characteristics that must be adhered to in a JCL analysis are as follows (for more information, please see section J.1.6.3.):

- The cost estimate will need to be linked to the schedule (e.g., cost-loaded). As a note, by loading the cost estimate to the schedule, a phasing profile will be a resulting output.

- Allocated costs in the schedule will need to be characterized as time independent or time dependent (see section J.1.6.3.).

- Careful consideration needs to be made on what level of risk and uncertainty is inherently in the cost estimate (see section J.1.6.4. and J.1.6.5.).

J.1.5.3. Discrete Risk List and Uncertainty Data

The project should have a risk management system that is identifying and quantifying the known risks associated with the plan. It is important to note that the project must account for and is responsible for risks that may not be the direct responsibility of the project (e.g., the risk of an international contribution not coming in at the scheduled date). The risk list should be robust and capture as much risk as possible. Oftentimes, projects may capture only the top *x* number of risks; however, for a successful and informative JCL analysis, this is not desirable. Risk should be individually identified and quantified (likelihood of occurrence, cost, and schedule impact) and be mapped to an activity within the JCL schedule. CAD resources such as historical CADRe data capture historical project risks that can be helpful in ensuring a more complete risk list.
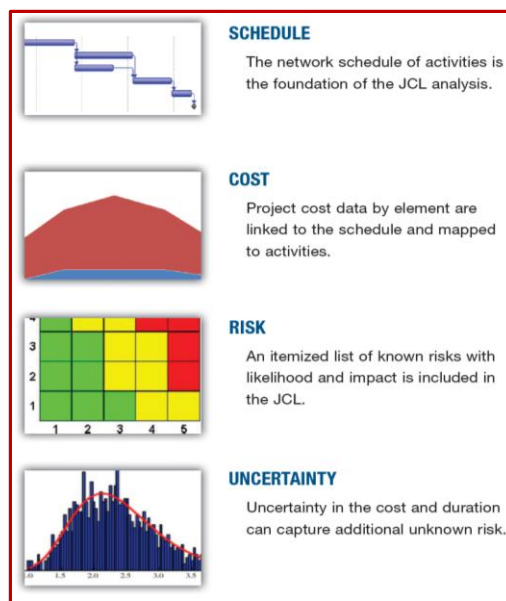
Schedule task durations and costs associated with those tasks should include uncertainty to the baseline plan. Examples of inputs to such uncertainty factors can be historical data, Subject Matter Expert (SME) opinion, or past performance data—see section J.4.2. for more details.

J.1.6. JCL Process Flow

This section mirrors the pattern of Section 3 of the Cost Estimating Handbook, but with more depth, as required by an actual cost estimator or analyst. The steps below are each amplified in sections J.2. through J.5.

In general, there are five fundamental steps in building a JCL with one prerequisite step.

- Step Zero: Identify goals for the JCL

- Step One: Build a JCL schedule/logic network (a summary analysis schedule)

- Step Two: Load cost onto the schedule activities

- Step Three: Incorporate risk list

- Step Four: Conduct uncertainty analysis

- Step Five: Calculate and view results, and iterate as required

SCHEDULE
The network schedule of activities is the foundation of the JCL analysis.

COST
Project cost data by element are linked to the schedule and mapped to activities.

RISK
An itemized list of known risks with likelihood and impact is included in the JCL.

UNCERTAINTY
Uncertainty in the cost and duration can capture additional unknown risk.

J.1.6.1. Step Zero: Identify goals of JCL

As stated previously, JCL is a policy requirement, but it can also be a very valuable management tool. There are certain quality standards that must be met to satisfy policy. However, depending on goals and expectations of the JCL analysis, you may want to set up the JCL analysis to assist and be synergistic with other products and processes. When setting up the JCL process, especially the schedule, it is important to think about what questions you want the JCL to answer, who will be the primary users and beneficiaries, and what fundamental insight you want to see.

J.1.6.2. Step One: Schedule Network/Logic Network

The backbone to the entire JCL analysis is the schedule. Having a quality schedule with logic networking is key to a successful JCL. For more information on developing a schedule, please refer to the NASA Schedule Management Handbook.[18] For purposes of this illustrative example, it is assumed that your project has set up a very simple schedule.[19] Figure J-2 shows a simple schedule with two parallel activity streams, one with three tasks and one with two tasks, converging on a single integration task. Once that integration task is complete, the project is complete.

As you will notice, the schedule is logically linked, meaning that you can see the predecessors and successors for every task. You may also notice that the project's milestone, in this case Project End, is linked in the schedule network too. This will allow you, as you progress through the JCL steps, to understand how that milestone may ebb and flow to the left and right.

---

[18] *http://www.nasa.gov/pdf/420297main_NASA-SP-2010-3403.pdf*

[19] Note that this example analysis schedule is extremely simplified—a high-level schedule of a typical spacecraft system will have much more detail than this.
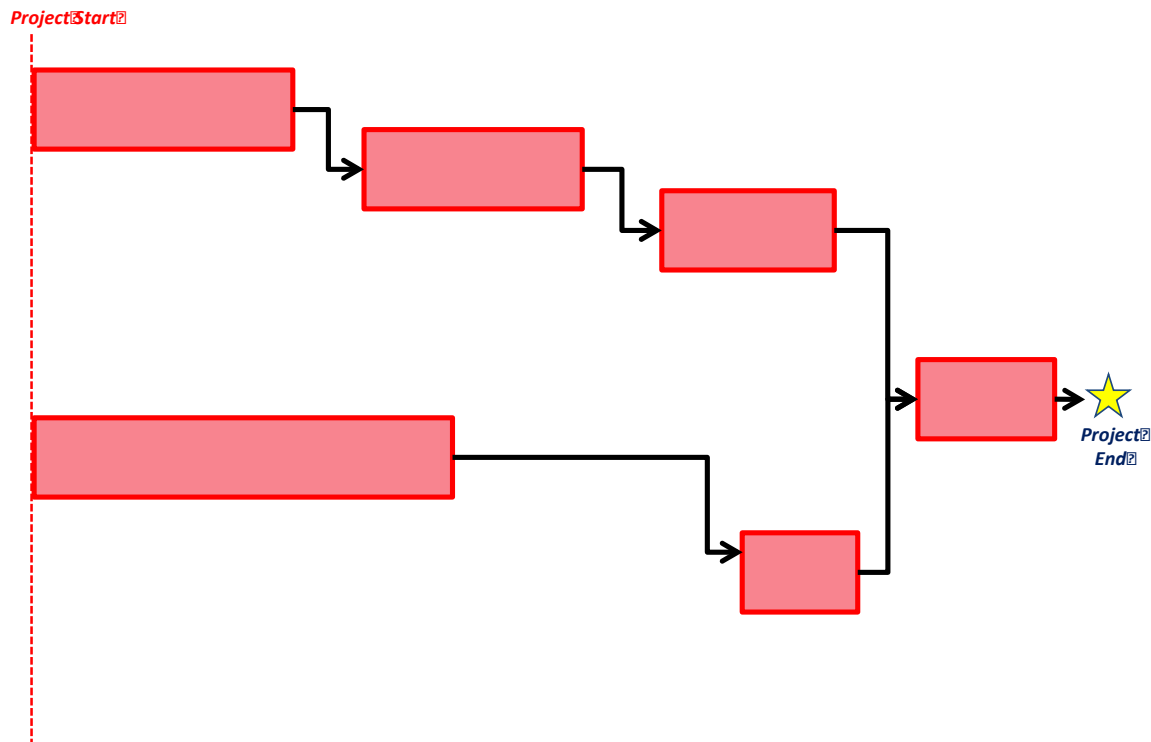
Figure J-2. Summary Schedule

J.1.6.3.   Step Two: Cost Loading the Schedule

Once a robust schedule that accurately portrays project work flow is established, the next step is to cost-load the schedule. Cost loading is accomplished by mapping cost to schedule. You want to load the cost effort for each task by how that cost (or effort) interacts with the schedule activity.

To do this, distinguish cost into two characteristics: time dependent (TD) and time independent (TI) costs.

TD costs are defined as those costs associated with effort that is based on the duration of a task. TD costs are periodic (daily, monthly, quarterly, annual) values that result in total cost as a function of total duration multiplied by the appropriate periodic value (burn-rate). Many tasks on a program/project display this behavior. Common examples are rent, utilities, facility maintenance, sustaining operations, program management, system engineering, quality assurance, other periodic fixed expenses, and other tasks which display a Level of Effort (LOE) nature.

TI costs are defined as those that are associated with the total effort to be conducted for a task irrespective of overall duration. The overall duration of TI costs are primarily a factor of three variables: 1) scope of work to be conducted; 2) productivity of the staff performing the work; and 3) achievable staffing level based on resource and fund availability. The overall duration of the task is thus determined by the effort required for its completion, and the costs are not a function of time but rather scope; while for TD elements, cost is a direct function of duration. Many tasks on a program/project display this behavior. Common examples of TI costs are materials, tests, and one-time expenses.

Figure J-3 illustrates how time dependent costs can spread over separate tasks.
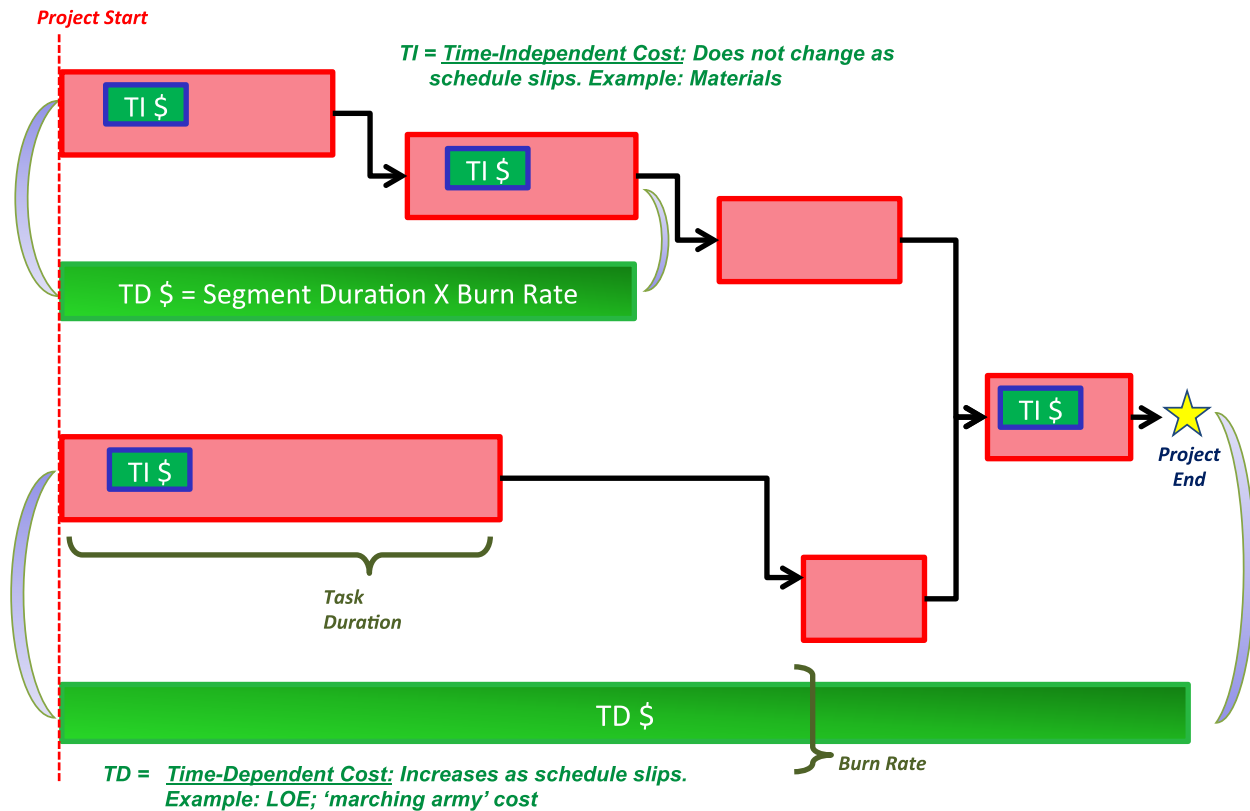
Figure J-3. Cost-Loaded Schedule

This example shows two sets of TD costs. One set expands across the entire project. This implies that there is a "standing army" of personnel that will follow the project regardless of where it is in the life cycle (i.e., project management). Another observation is that there are two tasks that do not have TI costs. This is not to imply that there are no costs associated with these tasks—in fact there are TD costs—it does show that these tasks are LOE tasks that are executed only by the TD resources or costs.

J.1.6.4.   Step Three: Incorporate Risk List

So far, the schedule represents the baseline plan for the project (cost and schedule). All durations and cost assumptions may have risk mitigation (for costs and schedule) embedded in the plan, but risk realization from the risk management system has not been incorporated. Traditionally, NASA programs will utilize their risk management system to help populate these risk tasks; however, a JCL analysis does not have to be limited by what is currently being managed in the risk management system. For example, there may be a programmatic risk that does not "make it" in the risk management system but still is of concern to the project manager. The JCL analysis allows the project to model the programmatic consequences and expected value of these risks.

Figure J-4 demonstrates how to incorporate discrete risks into the system. From a schedule perspective, a risk event is treated the same way as a task; however, in the schedule, the risk event task only occurs *x* percent of the time as specified by the discrete risk's probability of occurrence. Capturing risks and adding them into the schedule is introducing the first probabilistic aspect of JCL. From a static viewpoint, it looks like the risk is just a task, but when you start to run simulations, the risk event will only occur *x* percent of the time. When the risk event does not occur, the task and associated dollars will essentially default to zero; however, when the risk does occur, the task takes on the defined duration and dollar impact. The duration impact when the risk occurs can be considered the duration consequence of that

risk. You may notice that there are only TI associated costs with the risk. These costs would be the direct cost impact of the risk occurring. The duration impact of the risk affects the start date of the successor task. This impact could cause the timeframe of the TD costs on the bottom to expand. This potential expansion captures the indirect risk dollars associated with the discrete risk. When a project identifies risks for a JCL analysis, it is important that it identifies the activities the risk affects, the probability of occurrence of the risk, and the consequence (in both direct cost and direct schedule) of the risk happening.
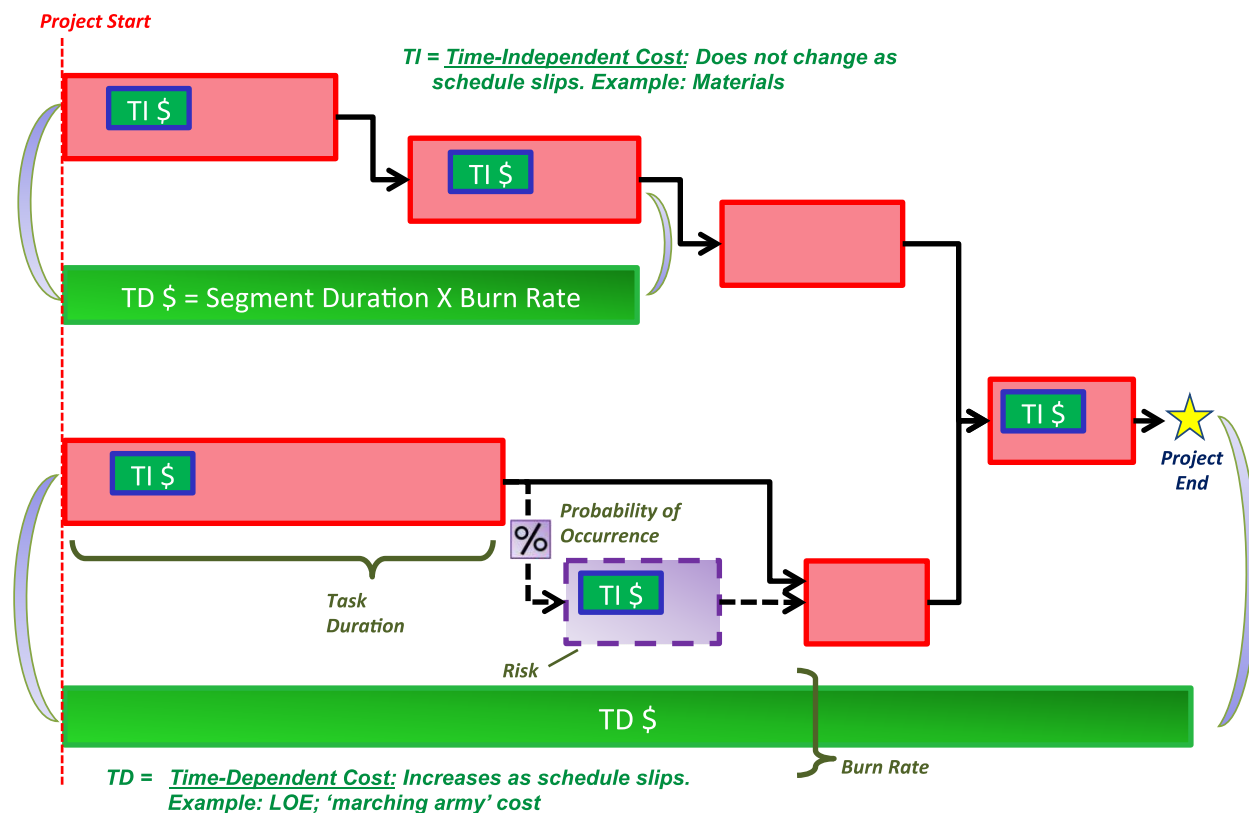

Figure J-4. Schedule with a Discrete Risk

J.1.6.5.   Step Four: Conduct Uncertainty Analysis

Step 4 to performing a JCL is identifying and implementing the uncertainty. To this point in the JCL process, the primary driver of the JCL results is the quantitative risk assessment and the effect it has on the risk-adjusted cost and schedule. While the risk assessment provides a snapshot in time of potential future events that may cause the project to overrun, it does not account for two key facets that have the ability to drive cost and schedule.

> **Tip:**
> History and experience have shown that the variance in a typical JCL model is driven significantly more by the uncertainty inputs than the discrete risks. With this said, it is essential to consider uncertainty when conducting a JCL analysis.

- Incomplete Risk Register: Although NASA's Continuous Risk Management (CRM) process aims to create as comprehensive a risk register as possible, it is unrealistic to predict all events with the possibility to increase cost or schedule.

- • Uncertainty in the Baseline Estimate: Disregarding risks altogether, it is impossible to predict the time or budget required to complete various segments of space-vehicle research, development, and production.

In recognition of these two facets, you or you in collaboration with your designated JCL analysts must account for uncertainty in their baseline cost and schedule plans. For the purposes of JCL, it is important to further distinguish between risk and uncertainty as they are distinct inputs to the JCL model.

For JCL analysis, risk and uncertainty are defined as the following:

Risk is an event not in the project's baseline plan that is an undesirable[20] outcome (discrete risk). This definition is similar to what is seen in a risk matrix. The event is characterized by a probability of occurring and an expected impact if the event did occur.

Uncertainty is the indefiniteness about a project's baseline plan. It represents our fundamental inability to perfectly predict the outcome of a future event.

For a seasoned cost or schedule risk analyst, it is clear that there is an overlap between these two terms. The indefiniteness of a project's baseline plan is partially caused by risks to the project. In traditional, inputs-based cost-risk analysis, discrete risks are not included as inputs, as they would likely cause double-counting when uncertainties in the technical inputs and cost outputs are accounted for. In JCL, analysis risks from the project's risk register are modeled alongside uncertainties applied to the baseline plan. This is done to increase the usefulness of JCL analysis to a project manager; being able to discern the effect each risk has on a project's cost and schedule allows for the development of risk mitigation plans.

To avoid double counting, special care must be taken to segregate uncertainty caused by risks already being modeled in the JCL simulation from the underlying uncertainty of the project's plan once these risks have been discounted. Although it is surely the case that this segregation can never account for all aspects of double counting, the benefit to project managers of getting to see risks outweighs the potential for slight errors in the analysis.

Typically, uncertainty is modeled using a three-point estimate. The low value represents the low extreme of uncertainty, the middle value represents the "most likely" value of the cost or duration, and the high value represents the high extreme of uncertainty. Please note, the baseline plan may not be any one of these numbers (low, middle, high) but should be within the range of low and high. Please refer to Figure J-5 for a visual representation.

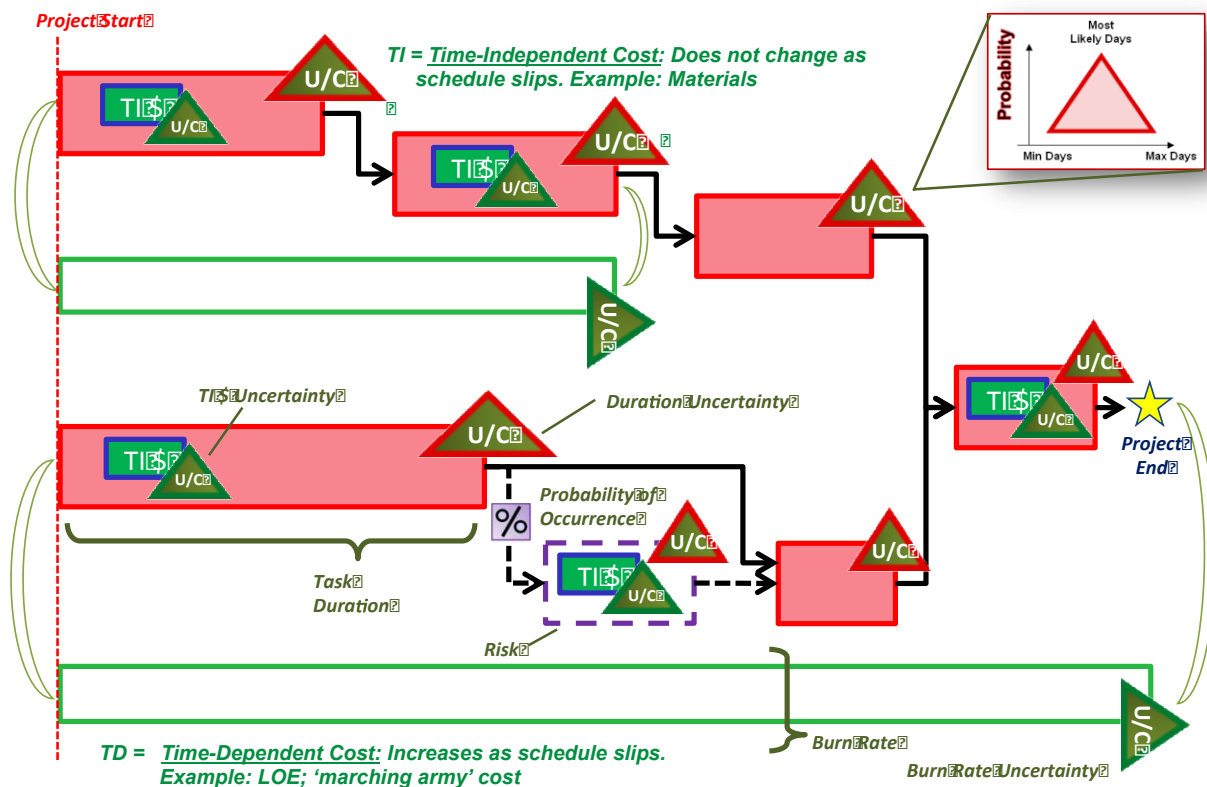[20] Risks can also be opportunities if the outcome of the event is a positive outcome.

Figure J-5. Schedule with Uncertainty

J.1.6.6. Step 5: Calculate and View Results, and Iterate as Required

The process shown above should be considered iterative. However, at any point in the JCL iteration process, the final and key step is interpreting the results of the analysis. A more exhaustive list of possible output reports are shown in section J.5. With that said, it is important to explain briefly the most commonly used JCL chart, the scatterplot. A JCL calculation result, commonly referred to as a scatterplot, is graphically depicted as follows in Figure J-6.

As shown in Figure J-6, the x-axis represents the final completion date, and the y-axis represents the final cost through that completion date. The scatterplot shows the simulated outcomes of the cost and schedule risk analysis. Each dot in the scatterplot represents a specific result, or scenario, from the simulation calculation (cost and schedule). In this example, the blue lines (the crosshair) intercept at the project's baseline plan, or point estimate (PE). To the bottom left, the green dots represent all the scenarios that are at or below the baseline cost and schedule. For this specific example shown in Figure J-6, if you take the green dots and divide them by the total amount of dots, you would get 19.6 percent of the dots being within cost and schedule—or put another way, 19.6 percent JCL.
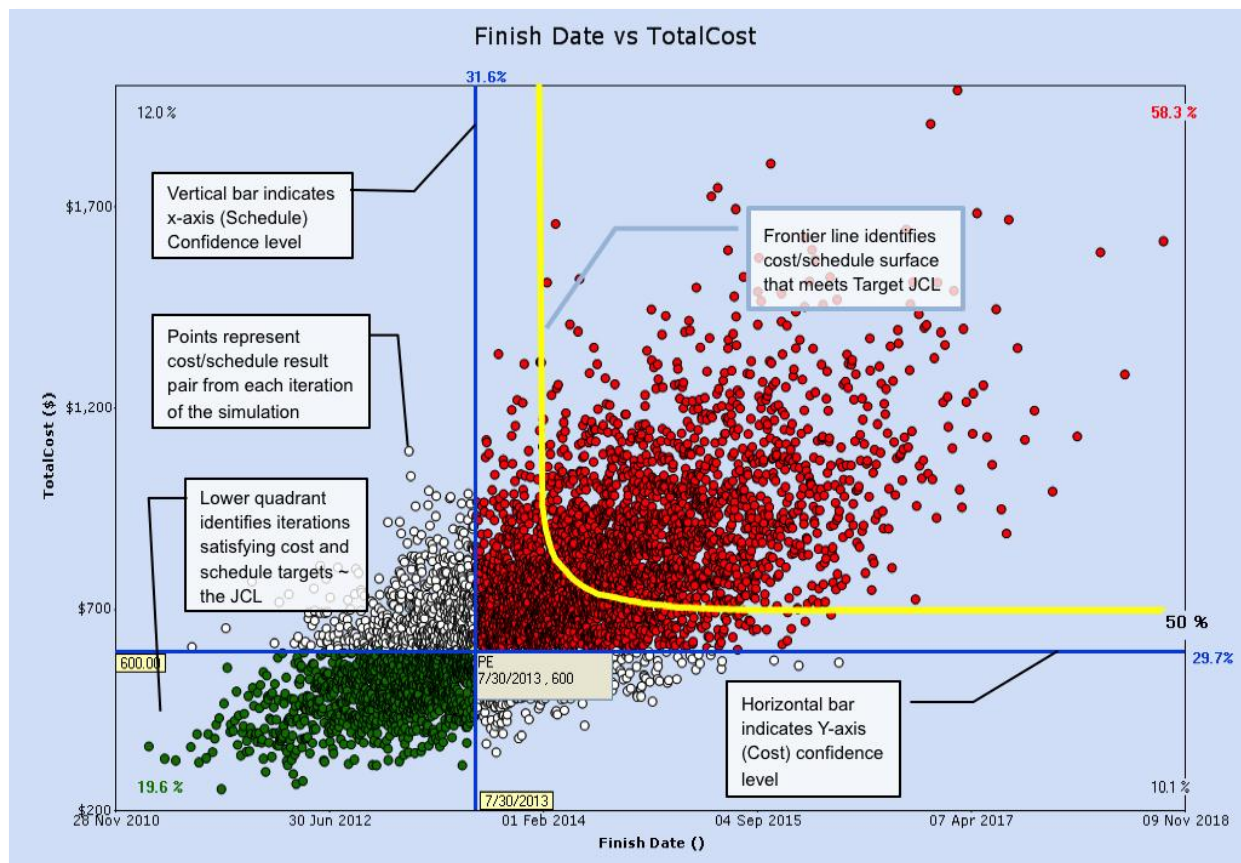
Figure J-6. Scatterplot

The crosshair can be moved to a date and cost to obtain their joint confidence. The horizontal bar of the crosshair indicates the cost confidence level whereas the vertical bar of the crosshair indicates the schedule confidence level.

The yellow line represented in this pictorial above represents the "frontier curve," or indifference curve, that specifies all the cost/schedule combinations that will meet a targeted JCL. In this example, the frontier curve represents the 50‑percent JCL frontier curve. Note that the asymptotic tails shown are purely academic; it is recommended to be as close to the center of the cluster for that given frontier curve.

> **One Last Note:**
> The scatterplot is *only* valid for the current plan and should be considered a snapshot in time. If the project changes its baseline plan, due to factors such as a funding or schedule increase or technical challenge, this will fundamentally change the project's risk posture, and you will need to rerun the JCL. The scatterplot only illustrates protection scenarios—it does not provide guidance and should only be used as a starting point to trade off cost against schedule.

J.1.7. *JCL Methodology and Tool Section*

J.1.7.1. JCL Calculation Methodology

JCL is a broad term, and there are two broad approaches to completing a JCL: 1) bivariate independent cost and schedule distributions[21], and 2) probabilistic cost-loaded schedule (PCLS) [22]. Both methodologies will produce a JCL; however, to fulfill the intent of the NASA JCL policy requirement, it is intended for a project or program to perform the PCLS. NASA is actively implementing PCLS to link NASA's commitment probabilistically to the project's specific plan. For a more detailed discussion on the attributes of both methodologies, please refer to Table J-1. The Agency uses the PCLS assessment method when considering its external commitment (KDP-C) as one means of ensuring that the project has a robust plan with costs linked to schedule, where both are informed by risks. With this said, the bivariate distribution method can be utilized as a cross-check to a project's PCLS analysis.

Note: There are several ways one could categorize the taxonomy of JCL methodologies and techniques. The authors chose, in this case, to focus on the two overarching methodologies and do not address the pros and cons of various techniques within the methodologies.

J.1.7.2. Tool Suites

There are multiple tools that can be utilized to perform a JCL analysis. The Cost Analysis Division—that oversees the JCL policy implementation for NASA—recommends a set of tools to use; see Appendix E for more information. Most tools that perform probabilistic schedule risk analysis can be used to perform the basic functions needed to fulfill the JCL policy. It is important to note too that the capabilities of the industry are improving at a rapid pace.

Selection consideration should also be based on a firm understanding of current platforms. For example, what software is being used to build and maintain the schedules, or what software is being used by the cost/budget/resource analysts. Lastly, it is important to consider the familiarity of the tools at the project's Center (and of the project personnel), as well as the familiarity of the non-advocacy entity reviewing the JCL analysis.

Toolsets and Licenses:

NASA CAD currently has an Agency license agreement for two tools (ACEIT JACS and Polaris) and has provided training to Agency personnel. It is recommended that all JCL analysis be performed on one of these two tool platforms. If you are a project that wishes to utilize another toolset, please contact CAD at *hq-cad@mail.nasa.gov*. For details on how to obtain these tools or for more assistance on tool selection, please refer to
http://www.nasa.gov/offices/ooe/CAD/.

---

[21] See *Probability Methods for Cost Uncertainty Analysis* by Paul Garvey for more details.

[22] Methodology encompasses schedule-loaded cost estimating tool.

Table J-1. Methodology Summary

	Bivariate Independent Cost & Schedule Distributions	Probabilistic Cost-Loaded Schedule
Description	JCL developed by independently producing a probabilistic cost and schedule distribution. The distributions are combined using classical bivariate joint probability methods.	JCL developed by directly linking cost and schedule logic based on project's specific schedule and cost plans.
Detail level	Typically, less detailed.	Typically, more detailed.
Cost Methodologies	Typically, parametric but can be with analogy, SME-based, or grassroots methodologies.	Typically, detailed costs built from SME, grassroots, or proposal data.
Schedule Methodologies	Typically, parametric but can be done analogy, SME-based, or grassroots methodologies.	Typically, detailed costs built from SME, grassroots, or proposal data.
Risk/ Uncertainty Methods	Risk and uncertainty inherent in parametric and analogy based data. If done by SME or grassroots methods, the risks and uncertainty would be informed by SMEs.	Risks are informed by risk management, and uncertainty is typically SME based.[25]
Types of Tools - Cost[26]	NAFCOM, PRICE, SEER, NICM, PCEC, etc.	Typically, detailed grassroots or proposal cost data stored[27] in either MS Excel or ACEIT.
Types of Tools - Schedule[28]	Schedule Estimating Relationship Risk Analysis (SERRA) Model or other user-created models if BOE is parametric, otherwise Polaris, JACS, MS Project with @RISK, or Primavera Risk Analysis Tool,.	Polaris, ACEIT, JACS, Oracle Primavera Risk Analysis Tool.
Integration Platform	Distributions can be convolved using analytical- or simulation-based tools (e.g., MS Excel, @RISK, Crystal Ball, ACEIT, MATLAB).	Scheduling tool (see above).
Life Cycle Implementation	During formulation.	Implementation at completion of formulation.
Skill Sets	Typically, cost estimating community.	Risk management, schedule, and cost/resources communities.
Data Sources	Typically, historical data from actuals and observations.	Detailed project plans, historical and SME input for risk/uncertainty.
Effort Level	Typically, low level of concentrated effort with faster turnarounds.	Typically, high level of concentrated effort from staff members with slower turnarounds.
Strengths	• Grounded in historical data and past performance • Less labor intensive and faster turnarounds • Community of practice well established	• Forces integration of PP&C silos and data products • JCL analysis can be used to improve project plan • Facilitates better understanding and communication of project phasing and reserve levels • Enforces scheduling best practices • Enforces quantification of risk realization
Challenges/ Issues	• Difficultly linking JCL to project plan • Potential to double-count cost and schedule risk • Difficult to implement after formulation • Phasing techniques have to be implemented externally • Parametric scheduling tools/methodologies immature	• Schedule and cost BOE • Mapping cost to schedule • Identifying uncertainty levels • Identifying cost behavior types (TI/TD)
Recommend Uses	• Cross-check for PCLS analysis. • Early assessments during formulation.	• Rigorous analysis in preparation for KDP-C.

---

[25] Best practices would encourage all uncertainty parameters to be based on historical data.

[26] Lists are not exhaustive.

[27] Can be stored in scheduling tool.

[28] Lists are not exhaustive. See Appendix E for a list of available tools.

J.2. Integrated Schedule

This section provides insight and recommendations for developing program schedules specifically for performing a JCL schedule analysis. The intent of this section is to provide guidance on JCL schedule analysis; it is not intended to provide guidance for developing an IMS. For more detail on programmatic IMS development, please reference the NASA Scheduling Handbook (NASA, 2010).

J.2.1.   Developing a JCL Schedule

Prior to developing a schedule for JCL analysis, careful consideration should be given to several important factors that will impact its purpose and analysis validity. Key factors to be considered include, but are not limited to, the following:

- The levels of schedule insight and analysis capability that are desired throughout project implementation;

- The magnitude and complexity of schedule data to be maintained and processed;

- The schedule management tools that potentially will be used; and

- The potential for accurately loading TD and TI costs to schedule tasks.

Project management should understand that the level of project insight and analysis that can be achieved is strongly dependent on the level of detail contained in the schedule. It should also be understood that detailed critical path identification and analysis, as well as detailed insight into program issues, cannot be done without properly defining

> **Analysis Schedule Tip:**
> Key characteristics of an analysis schedule are that it:
> 1) Displays major work flows,
> 2) Identifies work required to support major deliverables (areas that are actively being tracked),
> 3) Identifies major cross dependencies with, or across, management responsibility boundaries, and
> 4) Has traceability and transparency to a more detailed IMS or lower level schedules.

analysis level tasks and applying appropriate schedule logic. Therefore, the level of schedule detail contained in the JCL schedule is important to gain adequate insight into the potential risk impacts. Oftentimes, there are numerous management tool sets available that do not allow for easy and/or accurate transfer and integration of schedule and performance data. It is crucial for achieving successful program management that tool sets that provide efficient and accurate transfer and integration of data be chosen and, where possible, mandated for all project participants.

The following options are offered as recommendations[29] for JCL schedule development:

- Analysis Schedule: For complex projects, it is recommended that projects use an analysis schedule for JCL purposes. An analysis schedule is a high-level overview of an entire program/project, where a subset of task durations is captured in a single task, similar to when viewing various details in MS Project[30]. Analysis schedules provide a good modeling framework

---

[29] As a third approach, schedule development uses milestone sets to reflect the major events in accomplishing all program effort. Sets of meaningful event milestones reflecting each project's scheduled effort would be used in place of detailed- or summary-level tasks. Milestone interdependencies are much more difficult to reflect accurately when using this technique. This difficulty is due to the method in which the planner/scheduler (P/S) has to account for the effort being carried out in between the milestones. In order for the analysis schedule to keep the proper time-phasing for the numerous project milestones, the P/S must either incorporate appropriate schedule lag values between each milestone or assign date constraints to each milestone included in the schedule. These practices are not conducive to sound schedule analysis. This method is not recommended and is not considered best practices but can be useful in early JCL analysis.

[30] It should be noted that a summary of schedule is not the same as an analysis schedule. An analysis schedule has schedule logic that "pushes" and "pulls" the summarized schedule logic.

to identify general areas and time period of critical activity sets. Analysis schedules should have traceability and transparency to the more-detailed IMS. They should display major work flows, identify work required to support major deliverables (areas that are actively being tracked), identify linkages of budgeted work to schedule scope, and provide insight into major cross dependencies with or across management responsibility boundaries.

- Detailed IMS: Another approach is to have the JCL schedule be the "same" as the detailed schedule—commonly referred to as IMS. This strategy provides the overall capability for integrated insight and oversight of all project work, including detailed critical path and program issue information. It should be understood; however, that while this strategy is enticing, it may not be a practical approach for the analysis schedule for JCL purposes.

While both types of schedules result in different levels of detail fidelity, if properly constructed, they both can serve as a credible foundation to the JCL analysis. Further conversation is needed when discussing the attributes of an analysis schedule versus an IMS. As with any programmatic procedures and requirements, there are many development tools to support the management and tracking of various program functions.

J.2.1.1.   IMS versus Analysis Schedule

To avoid the creation and maintenance of multiple artifacts, a project's IMS can be used as-is for performing JCL analysis. In addition to not requiring additional artifacts, using the project's IMS as the basis for the JCL model ensures risks are applied accurately to the lowest affected tasks. Another advantage to using a detailed IMS schedule is that all details of program tasks and required work are intact; hence, when performing any JCL analysis, the schedule aspects are performed at a granular level. Risks and uncertainties can be tied directly to the respective tasks, and impacts are captured within the logic of the task in the truest fashion. Table J-2 outlines a comparison of schedules.

Table J-2. Schedule Comparison

	Integrated Master Schedule	Analysis Schedule
Description	• Requires risk, uncertainty, cost, schedule, slack, and margin applied to lowest affected tasks.	• High-level overview of an entire program/project • Subsets of tasks are captured as a single task
Detail level	• Can be cumbersome and large; can range to the tens of thousands of activities.	• Confined to a size that is manageable, leading to a greater overall perspective.
Sources of data	• Often contains contractor schedules with inappropriate constraints.	• Rollup of master schedule • Can lead to missed data lost in rollup
Risk/Uncertainty	• Data-driven uncertainty assigned to the lowest level, usually the task level, can be difficult • Uncertainty level may require the use of subjective distributional assumption since historical data may not be available	• Uncertainty is rolled up to a level that it can be reasonably assessed • Impact of risk may be overstated as schedule/slack/margin is rolled up.
Simulation	• May require level of granularity or magnitude of data handling that is not available in a commercial-off-the-shelf (COTS) tool.	• Simple to run on a COTS schedule risk analysis tool due to decreased complexity.

Using a detailed schedule for a JCL analysis does have some drawbacks: 1) A detailed program/project schedule can be cumbersome and large. For space systems, these schedules can range to the tens of thousands of activities. Managing and maintaining JCL analysis for all of these activities can be

burdensome.[31] Oftentimes, an IMS is a continually updated project artifact coming from several other elements (i.e., subcontractors). This can make maintaining a lower-level schedule for JCL analysis purposes arduous. Also, contractor schedules tend to be "delivery oriented" and often include constraints on key delivery dates, tasks, or resources that can hide the true impact of risks when the schedule is run through a simulation. Performing schedule health checks on the IMS—already a best practice for scheduling—can mitigate some of these errors, but it is not possible to determine if the model is error-free until the simulation is run and results are monitored to ensure they are consistent with the inputs. 2) Assigning data-driven uncertainty at the lowest level of an IMS can be difficult. When creating an analysis schedule, the IMS is rolled up to a level at which uncertainty can be reasonably assessed (i.e., component or subsystem level). When using the full IMS, the most common methodology is to apply uncertainty at the task level. It is often necessary to use subjective distributional assumptions when applying uncertainty using the bottom-up method because historical schedule data are rarely, if ever, available at this level.

An advantage to using an analysis schedule as the artifact is that it is typically easier to gain an overall perspective of a project in a single glimpse with fewer schedule line items. Also, applying uncertainty and cost to analysis schedules is fairly simple given the limited number of tasks when compared to the project's IMS. Simulations are also simple to run using any COTS schedule risk analysis tool due to the decreased complexity and size of the schedules.

A drawback to using an analysis schedule is that there could be a loss of schedule logic by rolling up multiple tasks into a single task. If analysis schedules are "rolled" up to too high of a level, then that can adversely affect the confidence in the JCL output results. The impact of risks will likely be overstated as schedule slack and margin, existing at the lowest level of the IMS, will be forsaken when the schedule is rolled up. Additionally, the creation of an analysis schedule for JCL means the project will have to maintain one more additional artifact throughout its life cycle if the JCL analysis is to be updated.

Regardless of approach, the goal of the schedule that supports JCL analysis is to understand how a schedule will react to risk impacts and uncertainty. Logic and constraints can have significant, adverse effects to a JCL analysis. The following sections address specific types of logic and constraints that may not affect a deterministic project schedule, but can have significant effects on the JCL analysis results. When addressing these potential pitfalls, the goal is not to change schedule logic or constraints to garner desired or positive results, but to ensure that the JCL analysis will accurately capture positive and negative changes in the schedule due to schedule logic and flow.

For the purposes of this handbook and appendix, an analysis schedule will be the default method that is primarily referred to when addressing JCL schedules.

---

[31] It should be noted that when running JCL simulations, a large IMS can bog down the analysis simulation times, especially if there is a high degree of constraints and improper logic. This simulation performance may or may not be an issue when conducting a JCL as it is very dependent on tool platform.

J.2.2. Schedule Assessment

Schedule assessment is the process of determining schedule validity and performance at a given point in time. A thorough schedule assessment using many of the techniques described in the following paragraphs should always be performed prior to establishing the IMS baseline and is essential in ensuring a quality JCL analysis. Periodic assessment is also necessary to gain assurance that the schedule continues to generate valid data and support the project's objectives throughout the

> **Tip:**
> Schedule health-check tools will provide metrics on the health of a project's schedule. It is important for a project to confer with the non-advocacy reviewer on the criteria or expectations.

project life cycle. A reliable schedule assessment checklist is an important aid that can benefit a project team or outside review team in determining schedule validity. For more information on schedules and assessments, see Appendix K and the NASA Schedule Management Handbook.

Schedule assessment and analysis principles are the same during and after schedule development, with the exception of progress evaluation which occurs after development is complete. The following processes should be continued routinely throughout the project life cycle. As a note, a schedule health check or assessment is usually the first thing a non-advocate review team will do to a project schedule— so be prepared!

There are many tools that can be used to help a project perform a schedule assessment, including one sponsored by NASA called STAT.[32]

J.2.2.1. Schedule Logic

The logic[33] of a schedule should be reviewed to ensure that it is complete, accurate, and realistic. Within the schedule, there should be a minimal number of tasks with no successors or predecessors identified. When these occasions do arise, valid rationale should be documented.

A thorough effort should be made to identify the tasks that may be worked in parallel with other tasks, tasks that must be worked in series with other tasks, and tasks that may be worked once another task has progressed beyond a given point. Each of these situations can be reflected with the proper use of logic relationships and lag or lead values.

A schedule logic review by project team members should focus on three specific areas. Firstly, within each logical grouping of work, the sequence of tasks/milestones should be verified. This may involve team members from different organizations, multiple project personnel from the same organization, or both. Secondly, each interface, or "hand-off," between different work groups should be verified. And finally, the overall project phasing sequence should be validated.

> **Schedule Logic Review Steps:**
> 1) Verify each sequence of tasks/milestones within each logical grouping of work.
> 2) Verify each interface or "hand-off" between different work groups.
> 3) Validate the overall project phasing sequence.

It is recommended to verify that the duration for each task/activity entered is accurate and realistic based on the information provided for that task/activity. The method of verification is dependent upon the credibility of the source of the original duration information. All assumptions made in determining task/activity durations should be

---

[32] For more information on STAT, or to acquire STAT, please refer to *http://evm.nasa.gov/handbooks.html*.

[33] The term "logic" is meant to represent the sequence and relationships of tasks within the schedule.

recorded. This can be an especially important consideration when later assigning resources to scheduled tasks/activities. Knowing the basis for task durations may also aid in setting risk parameters when conducting schedule risk assessments.

With each schedule task now relatively well defined, the duration for each should be verified with the task owner. All changes have to be evaluated for the impact on other related or logically tied tasks/milestones. All specific assumptions that are part of the basis for determining the duration of a task should be recorded. This should include the impact on the duration due to the experience or skill level of the resources to be assigned to each task.

J.2.2.2.　　Constraints

A constraint is a fixed date assigned to control when a task starts or finishes. Caution should be exercised when using constraints because they are a significant factor in how float (slack) is calculated throughout the project schedule. While it is certainly true that there are various scheduling situations that require the use of constraints, careful thought should be given so that they are used appropriately—because their impact to the JCL analysis can prove detrimental.

Forced or fixed dates (constraints) should only be used when network logic cannot accurately depict the true sequence of work because of some external influence or an influence beyond the control of project team members. The constraint types should be reviewed carefully for accuracy and desired effect. "As Late As Possible" constraints should generally not be used in a JCL schedule. Improper and/or invalid use of constraints should be minimized due to the potential for creating misleading schedule and JCL results.

Constraints used in general schedule management, while at times may be necessary, have a drastic effect when performing a JCL. Oftentimes, constraints are placed into an IMS for management purposes. As a project progresses toward that date, the constraints are often removed or adjusted to reflect progress. In many cases, the logic is adjusted based on the progress of preceding tasks or changed to reflect newly allocated funding to allow a task to begin. Constraints may also be used to reflect milestone or project reviews slated for a specific time.

For a JCL schedule, it is best to remove as many constraints as possible so that the logic of the schedule will flow more naturally during a simulation. Again, the JCL is aimed at capturing the total bandwidth of a project's life cycle or phase at a single point in time. JCL tools are incapable of making "human-like" decisions when they come across a hard constraint date. JCL tools cannot look at a constraint during a simulation and factor in whether or not the task can start earlier or end sooner than it is currently slated. Therefore, when completing a JCL on a schedule with several or significant constraints, the results will be skewed based on the type of constraint used. Understanding how a schedule ebbs and flows naturally as risks materialize or mitigate gives a higher fidelity of insight to all areas of a project; however, by having constraints, those insights are altered in an unrealistic way.

For example, say there is a constraint of "Start No Earlier Than" on Task B of October 10, 2015; its predecessor Task A is planned for completion on October 1, 2011, but Task B can start as soon as Task A is completed. When a JCL iteration is run, every single iteration performed will start Task B on October 10, 2015, no matter when its predecessor finishes. This becomes especially problematic if Task A finishes after October 10, 2015, on the given iteration, because due to the constraint, Task B will still begin on the October 10. It should be noted that from a programmatic standpoint, there may be a reason why Task B cannot start until October 10 due to Task B being out in the distant future (e.g., funds availability, resource availability, etc.).

Another example of constraints unnaturally impacting a JCL analysis is a "Finish No Later Than" constraint. During the JCL calculations, no matter how the logic flow of the schedule is developed, a task

with this type of constraint will always finish on that particular date. An example of how this could negatively impact a JCL analysis is illustrated as follows. Consider a project that has a risk tied to a task with this type of constraint, with the risk impact being a 30-day delay. In the JCL analysis, this task will always show a finish date no later than indicated in the schedule, even if in logic the risk should push the tasks completion date out 30 days from its original completion date. This will skew the overall picture of the analysis to possibly reflect a project completion date to be earlier than what it should if the risk impact was reflected as modeled.

Common constraint types that can be imposed on a task include, but are not limited to, the following:

- As Soon As Possible—A task or milestone will finish as early as possible based on its assigned logical relationships and duration. This condition can also be described as the absence of any constraint and is deemed an acceptable constraint for JCL schedules.

- As Late As Possible*—A task or milestone will finish as late as possible without affecting the scheduled end date. This constraint uses total float to calculate its early finish date instead of free float. This can cause the project end date to slip.

- Start No Earlier Than or Start On or After—A task or milestone will start no earlier than the assigned start date. However, it can start as late as necessary.

- Start No Later Than* or Start On or Before—A task or milestone will start no later than the assigned start date. However, it can start as early as necessary.

- Finish No Earlier Than or Finish On or After—A task or milestone will finish no earlier than the assigned finish date. However, it can finish as late as necessary.

- Finish No Later Than* or Finish On or Before—A task or milestone will finish no later than the assigned finish date. However, it can finish as early as necessary. This is a useful constraint to use for a contract deliverable milestone or project completion milestone.

- Must Start On* or Start On or Mandatory Start—A task or milestone will start on the assigned date. Use of this constraint overrides schedule date calculations driven by logic, possibly resulting in a date that is physically impossible to achieve.

- Must Finish On* or Finish On or Mandatory Finish—A task or milestone will finish on the assigned date. Use of this constraint overrides schedule date calculations driven by logic, possibly resulting in a date that is physically impossible to achieve.

- Deadline*—While not listed as a constraint type, a deadline date assignment on the schedule for any task or milestone has the same results as assigning a "Finish No Later Than" or "Must Finish On." Float (slack) calculations are from the deadline date assignments.

*These types of constraints act as completion points in the schedule, from which the total float value is calculated.

Ideally, *minimal* **use of constraints, other than As Soon As Possible, is strongly encouraged**. Remember that constraints override task interdependency relationships. An example of where a constraint may generally have a valid purpose would be assigning a "Start No Earlier Than" on a scheduled receivable from an external source.

"Constraints" may also refer to limitations or conditions that affect the schedule. Typical examples of these situations may include test facility downtime or unavailability of specialized computer

time/equipment. These situations can be modeled through the use of calendars/assignments within the automated scheduling tool.[34]

J.2.2.3.   Embedded Schedule Margin

When planning out a program schedule, "margin" is added to task duration to account for future unplanned events, uncertainty, and potential risks. This schedule margin, also referred to as "reserve," can create a negatively skewed view of a program when a JCL is completed.

> **Tip:**
> When conducting a JCL analysis, identify any schedule margin that may be included in a task duration and either remove it or designate it separate from the task.

One misconception to clear up is that margin is not the same as "float" or "slack"; both are calculated values based on network logic between a target start date and the earliest as possible date. Also, margin does not mean the same as lag time, which is the period of time applied to a relationship between two tasks that delays the defined relationship execution. For example, a task logically tied to another task with a finish-to-start relationship and a 5-day lag time will result in the successor task's start being delayed until 5 days after the completion of the predecessor.

Margin is an identified and planned duration that is managed. Normally its value is a result of a schedule risk assessment or past experience/history. Margin is analogous to schedule reserve and should be managed like budget reserve. In essence, the addition of margin is done to increase the confidence of the completion date in the schedule. But when margin is left in tasks during a JCL analysis, it will reflect completion dates that are not indicative of the duration or LOE of said planned activity.

Since margin is added to duration to capture future uncertainties, it can be removed from the task duration and then modeled as uncertainty prior to running the simulation. Uncertainty can be specifically applied to task duration and is a recommended method for capturing schedule margin. By applying uncertainty rates to the task, instead of adding margin, it allows for the durations to fluctuate in a more realistic manner during a simulation, as opposed to a set margin or uncertainty value. Also, by removing schedule margin from a task's duration, it avoids applying uncertainty twice to a task that in turn would make the task appear to have a longer duration than actually planned.

J.3.   Cost Estimating

This section will provide insight and recommendations for cost estimating as it pertains specifically to JCL. This section will only address JCL-specific topics that may not be covered under the previously mentioned best practices. So, for example, discussion on cost estimating methodologies, documentation, and general risk analysis will not be provided.

J.3.1.   Cost Loading

For the purposes of the JCL model, cost loading is the process of mapping cost estimates to elements in the schedule. Almost without exception, this is not a straightforward one-to-one function. In practice, the detail contained in the cost file can match, exceed, or be less than the detail of the schedule.

A key principle of mapping cost to a schedule is defining the characteristics of those costs as they relate to the schedule task(s). This characterization is expressed as TI costs and TD costs.[35]

---

[34] Note that different software tools may have different constraints or even different terminology to describe constraints.

[35] For further examination of determining TI from TD, see David Hulett (2011), *Integrated Cost-Schedule Risk Analysis*, Ashgate.

J.3.1.1. Time Independent (TI) Costs

TI costs are defined as those that are associated with the total effort to be conducted for a task irrespective of overall duration. The overall duration of TI costs are primarily a factor of three variables: 1) the scope of work to be conducted; 2) the productivity of the staff performing the work; and 3) the achievable staffing level based on resource and fund availability. The overall duration of the task is determined by the effort required for its completion, and the costs are not a function of time but rather scope, while for TD elements, cost is a direct function of duration. Many tasks on a program/project display this behavior. Common examples of TI costs are materials, tests, and one-time expenses.

J.3.1.2. Time Dependent (TD) Costs

TD costs are defined as those costs associated with effort that is based on the duration of a task. TD costs are costs that are periodic (daily, monthly, quarterly, yearly) values that result in total cost as a function of total duration multiplied by the appropriate periodic value (burn rate). Many tasks on a program/project display this behavior. Common examples are rent, utilities, facility maintenance, sustaining operations, program management, system engineering, quality assurance, other periodic fixed expenses, and other tasks which display an LOE nature.

In assessing total TD costs, an analyst must estimate two attributes: 1) the duration of the task and 2) the periodic effort required. Normally, the periodic effort is quantified in terms of a burn-rate (daily, monthly, quarterly, yearly).

Experience has shown that a majority of a project's cost will be TD rather than TI; however, the breakout of TD/TI is very dependent on the nature and acquisition strategy of the project.

J.3.1.3. Hammock Task

Because a typical cost estimate Work Breakdown Structure (WBS) will not map one-for-one to a schedule WBS, a concept of creating a "hammock" task is often applied to the schedule.

Hammock tasks are created within JCL models when costs are to be mapped to a schedule, but the latter is significantly more detailed than the available costs. The concept is to focus on a logical section of the schedule that contains a series of tasks that are all sequentially linked via finish-to-start relationships. As illustrated in Figure J-7, the hammock task is a new task construct that is linked to the start date of the first task in this sequence and to the end date of the last task—the name comes from this anchoring to the first and last tasks, which is analogous to two trees that anchor a hammock.[36]
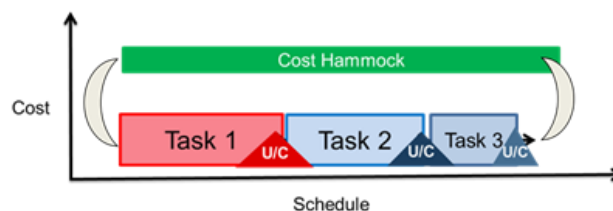

Figure J-7. Hammock Task

Consequently, when the simulation runs, this task dynamically expands or contracts depending on the behavior of the tasks under it. Hammock tasks are typically used to capture LOE segments of the schedule (e.g., project management).

---

[36] In this figure, the hammock is called a "cost hammock." Both terms mean the same thing.

J.4.   Risk Assessment

This section provides insight and recommendations for how to handle the probabilistic aspect of the JCL analysis. The probabilistic portion of JCL relies on a project's risk management system to help inform the JCL; however, this section only addresses JCL-specific topics that may not be covered under risk management best practices, as well as how to apply the identified risk management discrete risks to a JCL analysis.[37]

This section covers two broad topics: discrete risks and uncertainties. From a modeling aspect, a JCL is calculated by incorporating discrete risks and uncertainties. For example, if a project JCL duration and cost estimates were performed using strictly parametric (Schedule Estimating Relationship [SER] and Cost Estimating Relationship [CER]) techniques—and if it was deemed that all the types of discrete risks that could fall on the project were captured in those parametrics—then the entire JCL could be calculated using solely uncertainty techniques. On the other hand, if a project had a clear and omniscient view of all the discrete risks (and quantified general uncertainty as "risks that could occur"), then the entire JCL could be calculated using solely discrete risk techniques. In general, projects lean on using their risk management system (which is not omniscient) to capture discrete risks that are currently being watched and managed while using uncertainty to capture unknown-unknowns and scope uncertainty in the baseline plan.

J.4.1.   Risk Management System

Projects tend to include only a subset of their project-level risks or only near-term risks; however, **a robust JCL should include all of the project-level risks over the entire development phase** in order to maintain risk traceability throughout both the project risk management system and JCL model. The JCL analysis does not have to be limited by what is currently being managed in the risk management system. For example, there may be a programmatic risk that does not "make it" in the risk management system but may be of concern to the project manager.

The JCL analysis allows the project to model the programmatic consequences and expected value of such a risk. When a project identifies risks for a JCL analysis, it is important that it identifies:

•   The task(s) or activities the risk will impact;

•   The type of impact (e.g., a delayed start or a delayed completion); and

•   The probability of occurrence of the risk and the consequence (in both direct cost and direct schedule) of the risk happening (e.g., the schedule duration impact of the risk and the costs that will be incurred if the risk occurs).

J.4.1.1.   Identify Links to Schedule Tasks[38] and Types of Impacts

From a schedule perspective, a risk event is treated the same way as a task; however, in the schedule, the risk event task only occurs a certain amount of time (corresponding to that discrete risk's probability of occurrence). Capturing risks and adding them into the schedule is introducing the first probabilistic aspect of JCL. From a static viewpoint, it looks like the risk is just a task, but when simulations are run, the risk event will only occur *x* percent of the time. When the risk event does not occur, the task and associated dollars will essentially default to zero; however, when the risk does occur, the task takes on a duration and dollar impact.

---

[37] An excellent reference for overall risk analysis is the "Joint Cost and Schedule Risk and Uncertainty Handbook" at *https://www.ncca.navy.mil/tools/csruh/index.cfm*.

[38] Activities and task are interchangeable.

There are two general ways to identify *what* task a risk affects and *how* the risk is affecting that task. As shown in Figure J-8, the first category is risk events that cause a delay in the completion of the impacted task. These are modeled as successors to the impacted task, and the impacted task's successors are moved to the risk task as its successors. In this way, the risk task is added as an intermediate task between the impact task and its successors. For delayed completion risks, link the risk task to the task affected as a successor and ensure that the risk impacts have the same successors as the affected task.
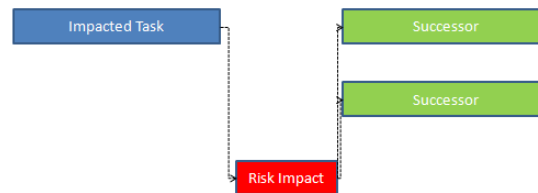
Delayed Completion Risk Item

Figure J-8. Risk Event Delays to the Completion of an Impacted Task

As shown in Figure J-9, the second category is risk events that cause a delay in the start of the impacted task. These are basically risks that create a new effort to be conducted before the impacted task can begin. These are modeled as predecessors to the impacted task, and the impacted task's predecessors are moved to the risk task as its predecessors. In this way, the risk task is added as an intermediate task between the impact task and its predecessors. For delayed start risk, link the risk task to the task that is delayed as a predecessor, and link to the same predecessor as the affected task.
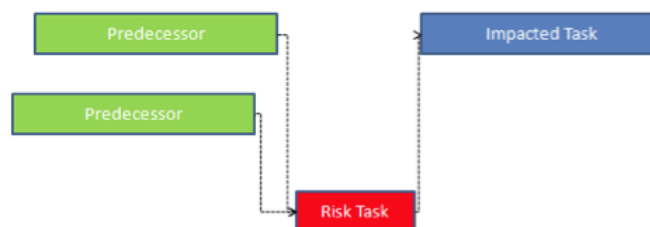
Delayed Start Risk Event

Figure J-9. Risk Event Delays to the Start of an Impacted Task

In the process of implementing risk tasks, a project may identify that a risk event can impact several tasks within the schedule. Additionally, a project may identify that many risk events impact a specific schedule task. Each of these categories required a slight variation in the approach for implementing the risk impact. The following items identify the two categories of grouping (serial, parallel) for multiple risk impacts to a schedule task.

- **Serial Impacts:** These are risk impacts that can occur independently and have a cumulative impact to the schedule task. These risk tasks are linked in serial to each other. Figure J-10 shows how having two serial impacts affecting a schedule task would be modeled in the analysis. The original successors of the impacted task are linked to the last risk impact item.
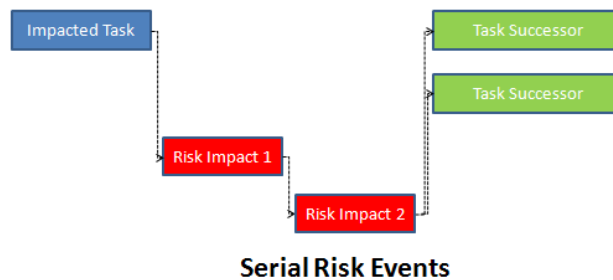
Serial Risk Events

Figure J-10. Serial Impact

- **Parallel Impacts:** These are risk impacts that occur independently and can be worked for resolution in parallel due to workforce and impact area. These risk tasks are implemented as parallel events. Figure J-11 shows how having two parallel impacts affecting a schedule task would be modeled in the analysis. The impacted task is linked to both risk events, and the original successors of the impacted task are linked to both risk events. In this manner when the risk events occur, the cost and schedule impact of each will be modeled in the schedule. If both risk events occur at the same time, then the schedule impact is the greater of the two, but the cost impact is cumulative.
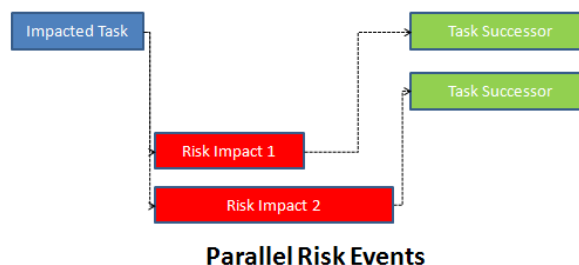

Parallel Risk Events

Figure J-11. Parallel Impact

J.4.1.2. Quantify Likelihood and Impacts

The likelihood of occurrence is typically expressed in percent likelihood of occurrence (0–100 percent)—or put simply, from a JCL modeling perspective, the percent amount of time the risk task will be "turned" on and affect the schedule. This input to a risk identified in a risk management system is commonplace, should already be part of the risks management products, and should be fairly straightforward. Most JCL tools will only support a specific value for the percent likelihood input.

The duration impact when the risk occurs can be considered the duration consequence of that risk. Typically, if there is a duration impact, this is submitted with a three-point estimate (a low value, a "most likely" value, and a high value). Along with identifying a duration impact, the project will have to also identify a "direct" cost impact for that risk. This direct cost impact could take the form of added TI costs (e.g., remanufacturing a faulty part), TD costs (e.g., risk occurs and forces overtime work), or a combination of both. These impacts are also typically captured as three-point estimates. Regardless of whether the impact is captured as TI, TD, or a combination—it should be noted that the project should only identify the direct costs associated with the risk. For example, if a risk occurs that causes a delay in the start of an integration task—hence, causing a "standing army", or in TD costs, to accumulate—then the model, through the schedule structure, will account for the indirect costs of that risk occurring.

J.4.1.3. Premitigation Versus Postmitigation

Properly capturing risk mitigation within a JCL model is a two-step process. First is to ensure that cost and timelines associated with the mitigation effort are captured and clearly identified within the cost estimates and Integrated Master Schedule. Since most JCL models are constructed utilizing a summary analysis schedule, it is recommended to capture all mitigation task activities into a single task activity that spans the total timeframe of the mitigation effort. The cost associated with the effort should be captured within the mitigation task accordingly in a TD and TI costing. Mitigation tasks will have uncertainty; therefore, a range estimate in terms of Min/Most Likely/Max values should be established for both cost and duration of a mitigation activity. One may also go so far as to say that a higher level of uncertainty would be applied to mitigation than other activities within the same WBS element, as mitigation of risk contains high degrees of uncertainty of success.

The second step is to capture postmitigated risk within the model. As with the current JCL model development process of capturing the likelihood of occurrence and the consequence of impact, capturing postmitigated risk is no different. The only difference is that the values for postmitigated risk are based on successful mitigation efforts and not on the likelihood and consequence of risks in their current state.

J.4.2. Schedule/Cost Uncertainty

To this point in the JCL process, the primary driver of the JCL results is the quantitative risk assessment and the effect it has on the risk-adjusted cost and schedule. Should an analyst run a JCL simulation with just these risks, there would be a striking characteristic of the results: the coefficient of variation of both the cost and schedule risk distributions is small.

The reason for this disparity between the previously mentioned JCL model results and historical data is the omission of cost and schedule uncertainty from the JCL model. While the risk assessment provides a snapshot in time of potential future events that may cause the project to overrun, it does not account for two key facets that have the ability to drive cost and schedule.

- Incomplete Risk Register: Although NASA's Continuous Risk Management process aims to create as comprehensive a risk register as possible, it is unrealistic to predict all events with the possibility to increase cost or schedule.
- Uncertainty in the Baseline Estimate: Disregarding risks altogether, it is impossible to predict the time or budget required to complete various segments of space-vehicle research, development, and production.

In recognition of these two facets, JCL analysts must account for what is not included in the discrete risk list relative to baseline cost and schedule plans.

This section provides a working definition for uncertainty versus risk and then discusses various methods for selecting and applying cost and schedule uncertainty distributions to the JCL model, including these methods' advantages and shortcomings.

It is recognized that the taxonomy and definitions of "Risk" and "Uncertainty" have been defined by several sources, including Knight, 1921, pp. 19–20; Fuguitt and Wilcox, 1999, pp. 140–141; Garvey, 2000, p. 27; and Hubbard, 2010, pp. 49–50. Most notably, the GAO's Cost Estimating and Assessment Guide differentiates risk and uncertainty using the following definitions (General Accountability Office, 2009):

- **Risk** is the chance of loss or injury. In a situation that includes favorable and unfavorable events, risk is the probability that an unfavorable event will occur.
- **Uncertainty** is the indefiniteness about the outcome of a situation. It is assessed in cost estimate models to estimate the risk (or probability) that a specific funding level will be exceeded.

In keeping with the spirit of the sources cited above, and for the purposes of this handbook and appendix, and NASA JCL implementation, risk and uncertainty are defined as follows[39]:

- **Risk** is an event not in the projects baseline plan that is an undesirable[40] outcome (discrete risk). This definition is similar to one that one would see in a risk matrix. The event is characterized by a probability of occurring and an expected impact if the event did occur.
- **Uncertainty** is the indefiniteness about a projects baseline plan. It represents our fundamental inability to perfectly predict the outcome of a future event. Uncertainty is characterized by a probability distribution, which is based on a combination of the prior experience of the assessor and historical data.

In order to avoid double counting, JCL analysts must take special care to segregate uncertainty caused by risks already being modeled in the JCL simulation from the underlying uncertainty of the project's plan once these risks have been discounted.

Typically, uncertainty is modeled using a three-point estimate shown in Figure J-12. The low value represents the low extreme of uncertainty, the middle value represents the "most likely" value of the cost or duration, and the high value represents the high extreme of uncertainty. Please note that the baseline plan may not be any one of these numbers (low, middle, high) but should be within the range of low and high.
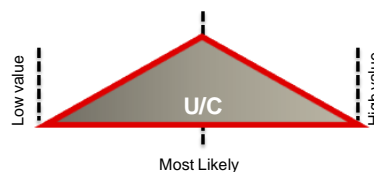

Figure J-12. Uncertainty

Uncertainty can be modeled, in most platforms, by percentage- or duration-based value as shown in the two examples below:

- Percentage based example: Low is 95 percent the value of the baseline plan, most likely IS the baseline plan value, and high is 200 percent the value of the baseline plan
- Duration based example: Low is based on the analogy X and is x months duration, most likely is based on average of several analogies and is x+3 month duration, and high is based on the analogy Y and is x+10 months duration

The examples above all assume a triangular distribution, but uncertainty can be modeled using other distributions including, but not limited to, normal, lognormal, Weibull, Rayleigh, PERT, or uniform. Parametric analysis can also be used to derive uncertainty distribution.

There are several factors that influence these two critical uncertainty components discussed earlier (incomplete risk lists and uncertainty in the baseline estimate):

- The complexity of the work can affect uncertainty. In general, the higher the complexity, the more uncertain the outcome becomes.

---

[39] It is important to note that "risk" and "uncertainty" are modeling constructs for JCL analysis. Within a JCL model, uncertainties *can* be modeled as risks (100 percent probability with variable impact) and risks *can* be modeled as uncertainties. As an example, risk factors approach, discussed below, can be utilized to capture both discrete risks and uncertainties.

[40] Risks can also be opportunities if the outcome of the event is a positive outcome.

- Underlying slack assumptions can drive uncertainty ratings. For example, if a project's tasks have a lot of "built-in" reserve to the durations, then there are more opportunity risks associated with the tasks than negative risks. Also, if a task is an analysis schedule task, then the slack assumptions at the lower level may influence the decision on how much uncertainty there is (and how to skew the uncertainty).

- The confidence level of meeting the planned task should factor into the analysis. In this case, uncertainty would be counteracting any preconceived optimistic or pessimistic bias.

It is critical that analysts invest time and thought in developing credible and appropriate schedule uncertainty distributions. At a macro level, there are three methods for selecting schedule uncertainty distributions: data-driven, SME-driven, and performance-based approaches.

J.4.2.1. Data-Driven Methods

The most defensible method for selecting uncertainty distributions is through the analysis of historical data. This analysis can be accomplished by utilizing historical analogy (either by direct comparison or by bounding possible outputs with analogies) or though utilizing parametric (cost/schedule as a function of some driving factor) data. Either approach is highly defendable but oftentimes hard to use due to a lack of data at the appropriate level. Cost and Schedule data (both raw and normalized datasets) can be accessed in ONCE.[41,42]

Things to consider when utilizing parametrics or historical data:

- **Were the data normalized? How?** If the data were not normalized, some simple normalization may be warranted (e.g., inflation). For normalized data, oftentimes "outlier" events will be "normalized" out. Understanding what the data constitute is very important.
- **At what level are the data, and are the data compatible with my JCL model?** As discussed, above, uncertainty metrics (whether done in absolute or relative terms) are not easily transferable from one level of fidelity to another.
- **Are the data relevant to what is being estimated?** As with all statistically driven analysis, special care must be taken so that the data are homogeneous to what is being estimated.
- **Are there enough data to support the analysis?** Sample size matters**.** Small samples introduce statistical bias in the estimate of population range parameters. This bias should be considered and accounted for Jarvis & Oleson, 2012.

J.4.2.2. Performance-Based Methods

In some cases, it is possible to use performance data to extrapolate uncertainty distributions for use in JCL models. Performance-based methods are really an offshoot of Data Driven Methods. There are countless methods by which this can be done based on the type of performance data available and the level at which the data have been captured. For example, it is sometimes easy to compare a project's most up-to-date IMS to earlier versions. This comparison provides the JCL analyst with a view for how the project's duration estimates have compared to their actuals. In this case, the distribution that best fits the growth patterns of completed tasks can be used to model uncertainty of to-go tasks. Performance-based (e.g., EVM) methods allow an analyst to develop low-level uncertainty distributions with the rigor of data-based approaches. This method is one of the best ways that data can be used to justify uncertainty

---

[41] See the paper "One NASA Cost Engineering (ONCE) Database" (Johnson, Plumer, Blandford, & McAfee, 2014), and Appendix A.

[42] Additional data, relating uncertainty to project's complexity, are available (Elliott & Hunt, 2014).

factors for JCL analyses. Some references on how to use performance data for uncertainty analysis include Kuo, Cyr, & Majerowicz, 2014; and Cyr & Kuo, 2012.

Things to consider when utilizing performance based inputs:

- **Past Performance:** Just like in mutual funds, past performance may not be a good indicator of the future. This is especially the case when moving from one "type" of activities to another.
- **Level of Data:** As stated previously, one needs to make sure that the level of performance-based metrics collected is the same general fidelity as the JCL model.

J.4.2.3.   SME-Based Methods

Unfortunately, it is rarely the case that data exist to justify all the uncertainty distributions required for JCL analysis. This is particularly true when a bottom-up analysis is performed on either an analysis schedule or the project's IMS, as even the highest-level analysis schedules tend to have tasks at a lower level (component or below) than schedule data that are available. Under these circumstances, it is necessary to obtain subject matter expert judgment (SME) in order to develop schedule uncertainty metrics. This section will outline the most common method for obtaining SME inputs and converting them into triangular uncertainty distributions for use in JCL simulations. Following a discussion of several issues associated with this methodology, other approaches for using SME guidance to develop uncertainty distributions will be discussed.

Although SME guidance is generally not considered a best-practice "estimating methodology," there are actions that can be taken to ensure that the analysis is as accurate as possible. The first step in developing SME-based distributions is identifying the experts who will provide input to the analysis. Experts should be chosen based on their familiarity with the tasks for which they are providing input. Additionally, the JCL analyst should take care to document the name, position, and contact information for each SME. This approach ensures that the analysis is traceable should any questions arise later on.

Once an expert or group of experts has been identified, the next step is to extract their inputs for the uncertainty distributions. This identification is traditionally done through the evocation of three potential durations for the task in question: The minimum duration required to complete the task, the most likely duration required to complete the task and the maximum duration required to complete the task. These durations are then modeled in the JCL analysis as a triangular distribution.

There are two issues with this method that must be accounted for in the selection of distributions: one due to the unique nature of JCL analysis, the other inherent to all SME-based judgments. Since JCL analysis models a project's risk register, if proper care is not taken in the selection of uncertainty distributions, risk can be double counted. This occurs when a SME's judgment regarding the events likely to increase or decrease the time required to complete a task contains risks that are already being accounted for in the model of the risk register. Although there is no fool-proof way to be 100% sure that no double counting is taking place, there are actions a JCL analyst can take to minimize this risk. When evoking uncertainty distributions, the JCL analyst should walk through the risk register with the SME. The SME should be asked if, in the other projects they have worked, these risks have ever been experienced. If they have, it is likely that the uncertainty distribution includes these risks. At this point, the analyst has two choices: either remove the risk from the JCL model or lower the uncertainty distribution to avoid double counting.

One risk whenever SME judgment is used to develop uncertainty distributions is the tendency for SMEs to underestimate the true uncertainty. It has been demonstrated that SMEs tend to only capture a portion of the true uncertainty in their estimate of the range of potential outcomes of an event (Hubbard, 2010). Thus, it is important that the JCL analyst compensate for this underestimation through the expansion of the distributional bounds.

One final approach for making SME-driven uncertainty estimates as accurate as possible is through obtaining multiple inputs from which a distribution can be developed. For further references, please refer to Greenberg, 2014, and Butts, 2012.

Things to consider when utilizing SME inputs:

- **Right Expertise:** It's important to get the right expert solicitation for cost and schedule uncertainties. For example, a person may be quite the expert in a technical field but may not have a good handle on the cost and schedule uncertainties of that field; whereas a recent project manager, or Center cost estimator, may not be as competent in the technical area but have a better feel for cost and schedule impacts.
- **Confirmation Bias:** Tendency to search for or interpret information in a way that confirms one's beliefs or hypotheses. For example, an SME on a given project may underestimate the negative uncertainty because they "want" the project to succeed.
- **Framing Bias:** Using a too-narrow approach and description of the situation or issue.
- **Hindsight Bias:** Inclination to see past events as being predictable.

J.4.3. Risk Factors

Another method for applying risks and uncertainties in a JCL analysis is to apply risk factors to activities. These risk factors can be thought of as global risk, or uncertainties, that may apply to a large subset of the tasks. This method can be used if you feel that there are common risks to the project or uncertainties that are affecting multiple tasks. For example, performance risk or uncertainties could be applied to multiple tasks' duration and cost due to known past performance issues.

J.4.4. Correlation

Correlation is essentially the degree to which two or more attributes or measurements show a tendency to vary together. The schedule logic of the JCL analysis handles functional or structural correlation; however, there are other areas in which to consider correlation.

As best practices, consider correlation for duration uncertainty distributions, the TD distributions, and the TI distributions. Adding correlation between risk can be modeled in most platforms and may be deemed to be appropriate. As guidance, there is research[43] indicating that a .3 correlation factor for task uncertainty distributions is appropriate and that a .6 correlation factor between cost items is an appropriate starting assumption. These guidelines are merely that; the schedule's detail and topography can affect what the true correlation is as well as a number of other factors. Remember, assuming a correlation factor of zero is still a correlation assumption.

For the latest in correlation guidance and research, please contact *hq-cad@mail.nasa.gov*.

J.5. Reporting

JCL reporting can assist the project as well as facilitate communication and reconciliation with the Agency's non-advocacy entities. This section briefly describes several common JCL outputs and displays.[44]

---

[43] Christian Smart (2013), *Robust Default Correlation for Cost Risk Analysis,* ICEAA conference, https://www.iceaaonline.org/awards/papers/2013_Risk2_paper.pdf.

[44] Recommended Reference: J.K. Johnson, D.M. Elliott (2013), *Understanding The Results Of An Integrated Cost-Schedule Risk Analysis*, presented at the American Institute of Aeronautics and Astronautics (AIAA) SPACE 2013 Conference & Exposition.

J.5.1.   Cumulative Statistical Results

The cumulative statistical results from an integrated cost-schedule risk analysis are most often used to calculate a desired statistical confidence level. Similar to the traditional cost s-curve, the integrated cost-schedule scatterplot represents a cumulative distribution—of cost and schedule pair values (see Figure J-13). Cumulative results displayed as scatterplots can be provided at any element level in the integrated cost-schedule risk analysis. The standard display for the cumulative statistical result is the scatterplot in most major software applications such as Joint Analysis of Cost and Schedule (JACS), Polaris, Oracle Primavera Risk Analysis (OPRA), and Deltek Acumen.
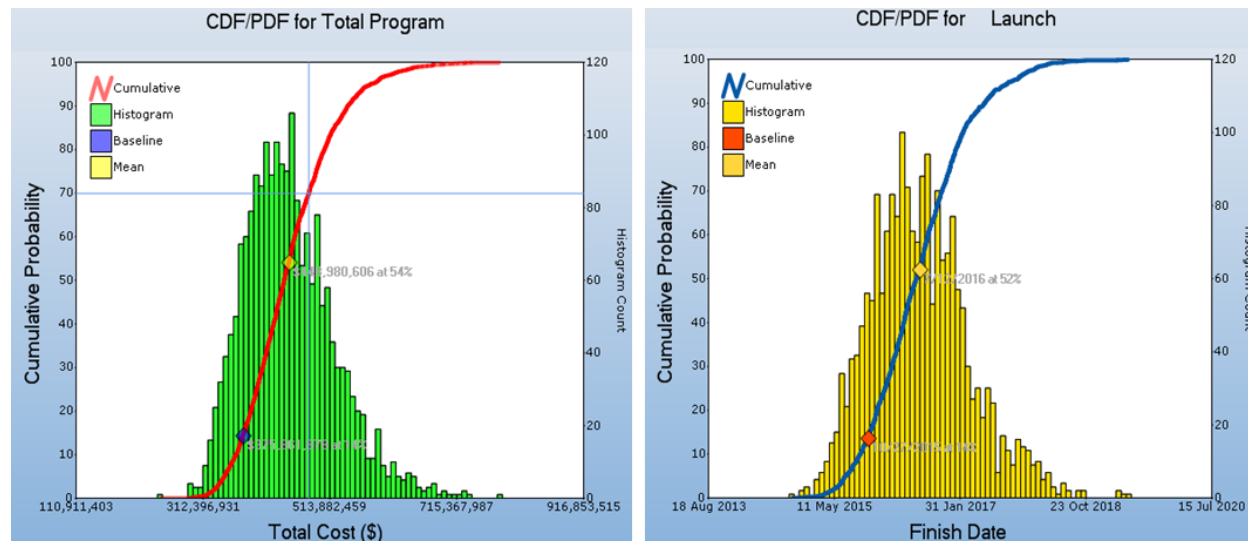

Figure J-13. Traditional Cost & Schedule S-Curves (Cumulative Distribution Function [CDF]) with Histogram (Probability Density Function [PDF])

J.5.2.   Scatterplot

A more sophisticated JCL scatterplot than was shown in the introduction to JCL in Figure J-6, is shown in Figure J-14.

The scatter plot in Figure J-14 shows iterations of cost and schedule risk analysis. Each scatterplot dot represents a specific result, or scenario, from the simulation calculation (cost and schedule). In Figure J-10, the x-axis represents the final completion date and the y-axis represents the final cost through that completion date. The scatterplot shows the simulated outcomes of the cost and schedule risk analysis. Each dot in the scatterplot represents a specific result, or scenario, from the simulation calculation (cost and schedule). The horizontal bar of the blue crosshair indicates the (Cost) confidence level, whereas the vertical bar of the blue crosshair indicates the (Schedule) confidence level. The blue-line crosshair itself reflects the project's point estimate (baseline plan) where the $600 million project cost is at a 29.7 percent confidence level (CL) and the 7/30/2013 completion date is at a 31.6 percent CL.

Note that the CL to be at or below the point estimate's cost AND schedule is 19.6 percent, which is an estimation of a joint probability of cost and schedule. One way to visualize this joint probability is to refer to the green dots in the lower left of Figure 10. These dots represent all the scenarios that are at or below the baseline cost and schedule. In this example, if you take the green dots and divide them by the total amount of dots, you would get 19.6 percent of the dots being within cost and schedule—or put another way, 19.6 percent JCL.
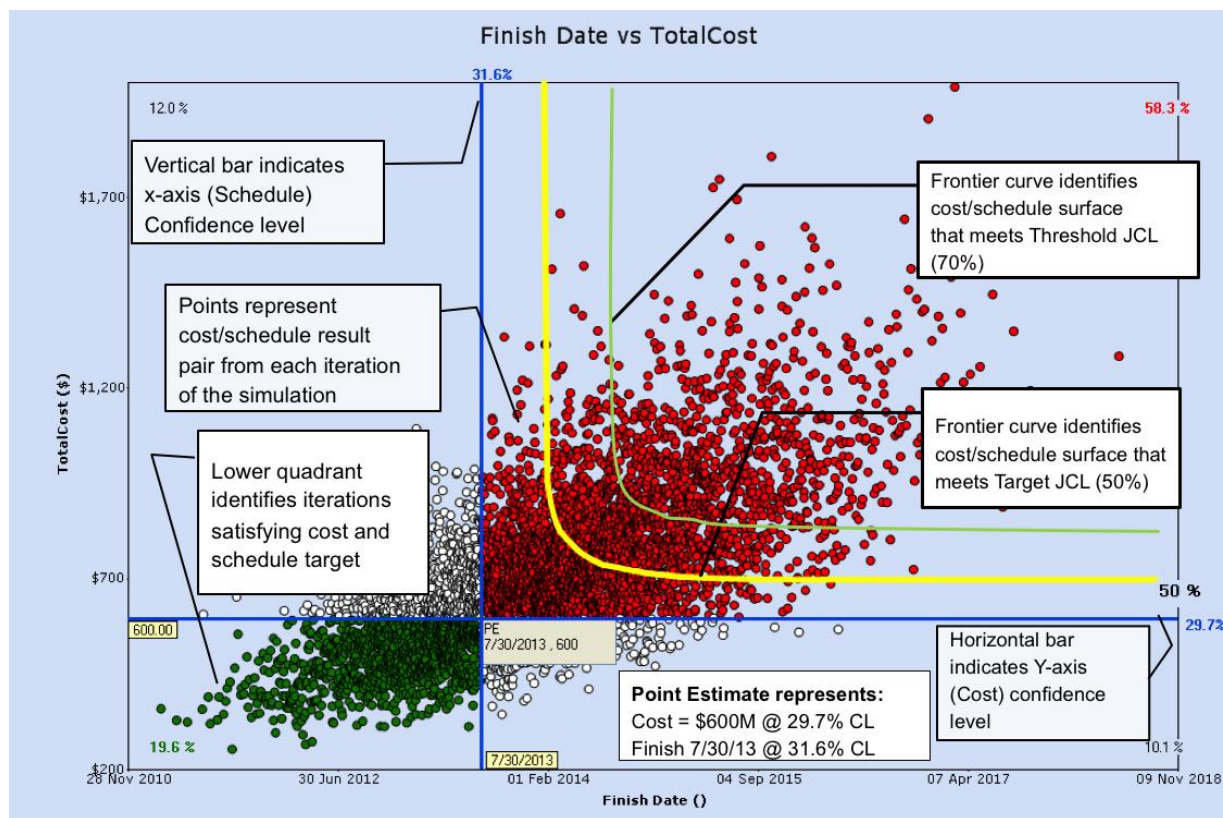
Figure J-14: JCL Scatterplot

The yellow and green lines in the upper-right quadrant of Figure J-10 represent indifference curves, or "frontier curves," that specify all the cost/schedule combinations that will meet a specific joint confidence of cost and schedule. In this example, the yellow line represents the 50-percent JCL frontier curve while the green line represents the 70-percent JCL frontier curve. Note that the asymptotic tails on each frontier curve are purely academic—it is recommended to be as close as possible to the center of the cluster for that given frontier curve.

The frontier curves shown in Figure 10 (i.e., 50 percent and 70 percent JCL) are important references for those NASA projects/programs that need to satisfy KDP-C requirements per NPR 7120.5E. If Figure J-10 came from such a project or program, it would likely move the blue crosshair to a date and cost to obtain the Target JCL of 50 percent.

The scatterplot is ONLY valid for the current plan and should be considered a snapshot in time. If the project changes its baseline plan due to factors such as a funding or schedule increase or technical challenge, the project's risk posture will fundamentally change, and you will need to rerun the JCL. The scatterplot only illustrates protection scenarios—it does not prove guidance and should only be used as a starting point to trade off cost against schedule.

J.5.3. *Sensitivity Reports*

In addition to cumulative statistical results, the results of an integrated cost-schedule risk analysis can be expressed by illustrating the probabilistic sensitivity of elements or inputs present in the model (see Figure J-15). This is commonly done in cost-risk analysis using Tornado or Variance charts that express the relative contribution of the elements by an established metric (correlation, standard deviation, total variance, etc.).[45] These types of rank ordered charts are often referred to as "pareto" charts.[46]
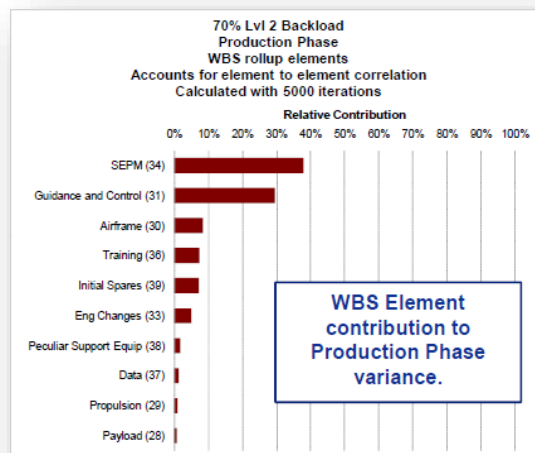

Figure J-15. Variance Analysis Charts to Determine Uncertainty Drivers (Smith, 2011)

There are a wide range of probabilistic sensitivity reports available to the analyst. Many commercial software products that can complete an integrated cost-schedule risk analysis provide multiple types of probabilistic sensitivity results, including the following:

- Duration Sensitivity: The correlation between a task's duration and the total program duration

- Cost Sensitivity: The correlation between a task's cost and the total cost of the project

- Duration-to-Cost Sensitivity: The correlation between a task's duration and the total cost of the program

- Criticality Index: The percentage of time a task spent on the critical path during the probabilistic analysis

- Discrete Risk Criticality: The probability that a risk register event will be on the critical path if it occurs

In the above sensitivity results, the critical path is defined as the path of least duration through the sequence of activities in the schedule with zero float or slack. Both the Criticality Index and the Discrete Risk Criticality can provide valuable insight into the key drivers of the probabilistic integrated cost-schedule risk analysis.

---

[45] A. Smith (2011), *Relating Tornado and Variance Analysis with Allocated Risk Dollars*, ACEIT User Workshop.

[46] Pareto charts are named for Vilfredo Pareto and are generally charts that contain both bars and a line graph where individual values are represented in descending order by bars, and the cumulative total is represented by the line.

J.5.3.1. Criticality Index

Figure J-16 shows that the Criticality Index identifies tasks in the integrated cost-schedule risk analyses that are impacting the probabilistic schedule results (i.e., finish date or total duration). The Criticality Index is based on the measuring of the stochastic critical path in the integrated cost-schedule risk analysis. The stochastic critical path provides the individual task's frequency expressed as a percent time where total float, or total start float, is less than or equal to 0. This means that elements on the stochastic critical path are directly influencing the finish date or total duration of a project.

In Figure J-16, the elements are rank-ordered by the percentage of simulation iterations for which a task was on the critical path during the analysis. The key contributors to project duration and finish date are those tasks with a 100-percent Criticality Index. These tasks, regardless of how the task durations varied during the probabilistic analysis, were always on the critical path. These tasks are therefore likely to be critical to ensuring project completion on time.
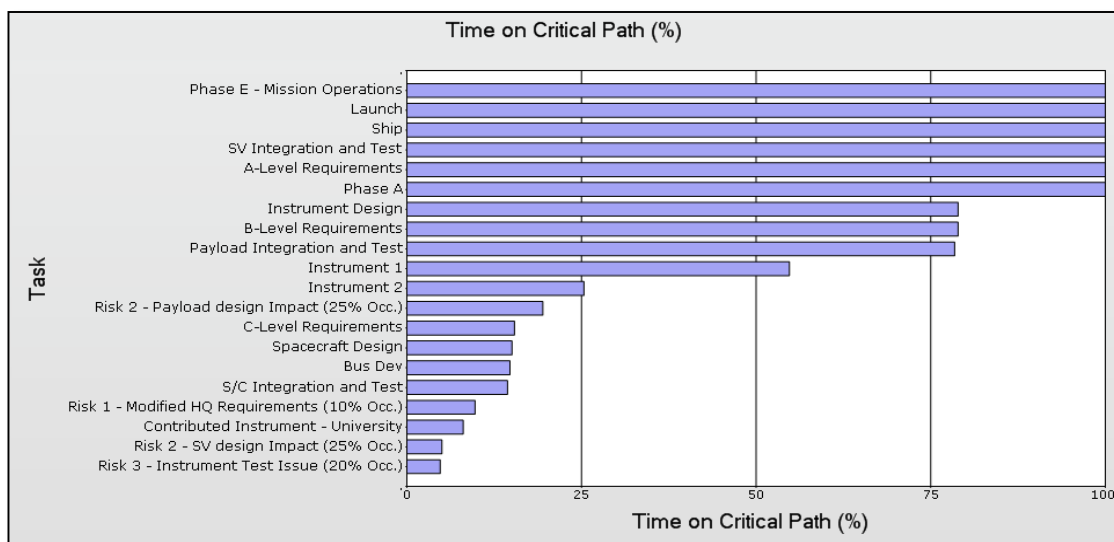

Figure J-16. Criticality Index Example Displays the Percentage of Time a Task Spent on the Critical Path

J.5.3.2. Discrete Risk Criticality

The Discrete Risk Criticality report is an extension of the Criticality Index and an excellent way to calculate and visualize the key discrete risk events that contribute most to the results of the integrated cost-schedule risk analysis. Discrete risk criticality is calculated as the frequency that a discrete risk appears on the critical path when it is active. Since an integrated cost-schedule risk analysis can contain a multitude of discrete risks, each with their own likelihood of occurrence and impact, it is important to analyze those discrete risks that, when active, contribute significantly to the probabilistic results. This is most directly accomplished by measuring the risks' frequency of occurrence on the critical path (see Figure J-17).
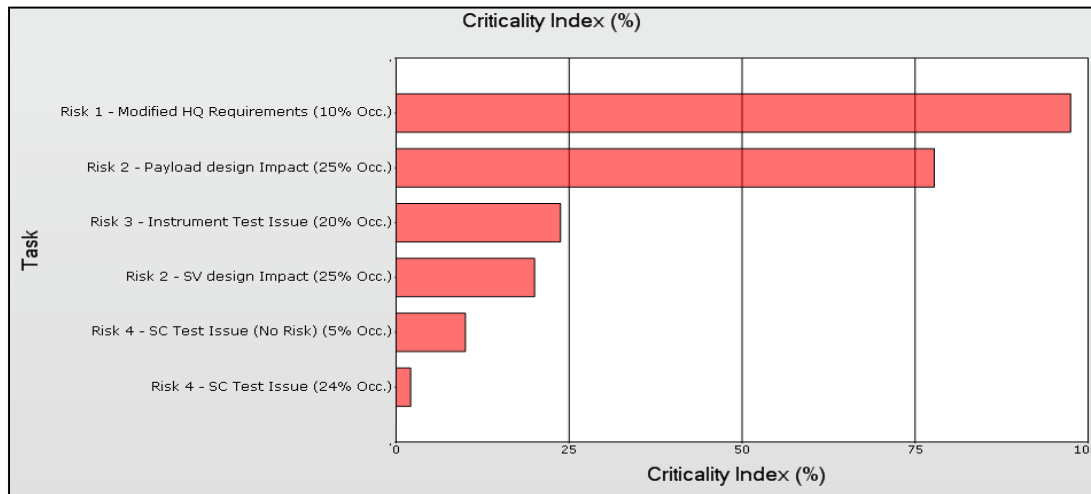
Figure J-17. Discrete Risk Criticality Index Example Shows Risk Events Frequency on the Critical Path

In Figure J-17, the elements are rank-ordered by a Criticality Index percent. This metric has a range from 0 to 100 percent, with elements that contribute the most and have a higher number approaching 100 percent. The calculation of the Criticality Index for any discrete risk event in the model is expressed as follows:

$$Criticality\ Index\ percent = \frac{Number\ of\ Iterations\ where\ Total\ Float \leq 0}{Total\ Number\ of\ Iterations}$$

The integrated cost-schedule risk analysis can provide valuable insight for project managers and others with meaningful probabilistic sensitivity results such as the Critical Index and the Discrete Risk Criticality. All too often, projects focus on a deterministic critical path and do not consider the effects of risks or uncertainty not directly linked to the deterministic critical path. By analyzing and illustrating the stochastic critical path, and by expressing all key elements with frequency values, additional drivers can often be highlighted that have not been previously considered.

J.5.4. Advanced Results

Advanced results from the integrated cost-schedule risk analysis can provide enhanced insight into more than just the cumulative results or key drivers. A key advantage of the integrated cost-schedule risk analysis is the ability to generate statistical results over time. By developing a functional relationship between cost, schedule, and risk, the integrated cost-schedule risk analysis offers the ability to view and analyze results in a time-phased manner. In particular, an integrated cost-schedule risk analysis that uses either a cost- or resource-loaded schedule as its foundation can offer significant advantages for understanding the risk results over time.[47]

The Milestone Overlay and Annual Cost Uncertainty results are both advanced results that display the probabilistic results from an integrated cost-schedule risk analysis in a temporal context. Both the Milestone Overlay and Annual Cost Uncertainty are unique and advanced in that they are not readily available from all commercial software applications that perform integrated cost-schedule risk analysis.[48]

---

[47] Hulett, *Integrated Cost-Schedule Risk Analysis.*

[48] Joint Analysis of Cost and Schedule (JACS), by Tecolote Research, and Polaris, by Booz Allen Hamilton, both offer these outputs standard for analysts.

J.5.4.1.   Milestone Overlay

The Milestone Overlay is an advanced result that can display multiple XY scatter plot results for any number of predetermined milestones or key tasks. This result is essentially a combination of multiple cumulative scatterplots for selected milestones or key tasks in the integrated cost-schedule risk analysis. The flexibility of an integrated cost-schedule risk analysis easily supports this implementation by calculating and displaying the cost/schedule pair values for multiple elements or tasks on the same scatterplot.

Figure J-18 shows a Milestone Overlay result for an example project. In this example, multiple scatterplots are shown and color-coded. Scatterplots for Preliminary Design Review (PDR), Critical Design Review (CDR), and Launch are identified and plotted together against an X-axis of Finish Date and a Y-axis of Total Cost. The integrated cost-schedule risk analysis is able to produce scatterplots of any identified or preselected milestone or task. The Milestone Overlay can combine these together to produce a result that shows the risk to each milestone or task over time.
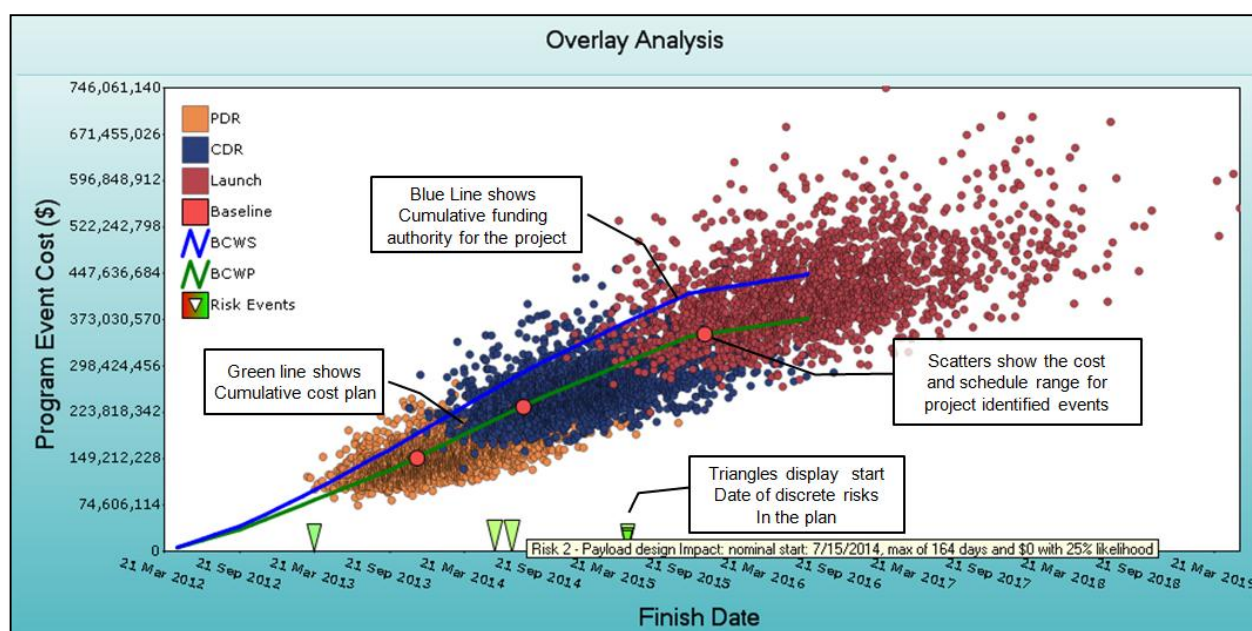

Figure J-18. Milestone Overlay Advanced Result Example Displays the Scatter Plots for Milestones (PDR, CDR, and Launch) Over Time

The baseline dates and costs for PDR, CDR, and Launch are shown as red circles in Figure J-18. These red circles mark projects' planned dates and costs for these important milestones. In each case, the red dot can be measured and contrasted against its corresponding scatter plot. Budget lines are also present, representing the Budgeted Cost of Work Scheduled (BCWS) and Budgeted Cost of Work Performed (BCWP) and providing further insight into the initial available resources over time.[49]

The Milestone Overlay also allows plotting of the discrete risk events and their occurrences over time. Individual risks are highlighted by triangles and annotated above in Figure J-18. By plotting multiple scatterplots over time in comparison to planned milestones dates and costs, the Milestone Overlay can

---

[49] BCWS and BCWP are common in EVM analysis. BCWS is the sum of the performance budgets for all work scheduled to be accomplished within a given time period. BCWP is the value of completed work expressed as the value of the performance budget assigned to that work.

provide a time-phased view of the cumulative results for multiple events and tasks. Including additional data such as the available budget and discrete risk events further enhance a project's understanding of the integrated cost-schedule risk analysis results over time.

J.5.1.2. Annual Cost Uncertainty

The cost- (or resource-)loaded schedule approach to conducting an integrated cost-schedule risk analysis provides additional advancement to analysts that need to compare the annual cost risk to available resources. The Annual Cost Uncertainty results can display the probabilistic results for cost over time and allow for easy comparison to budget data. The key aspect of the Annual Cost Uncertainty result is that it can display the cost risk statistical results by a specified time period (e.g., fiscal year). Approaches have existed previously for calculating and displaying the cumulative cost uncertainty for the same budget comparison purpose.[50] By calculating and viewing the statistical results in an annual time-phased manner, analysts can identify particular time periods that may require reserve utilization and/or contain a significant amount of risk.

An integrated cost-schedule risk analysis that is developed using a cost- (or resource-)loaded schedule approach allows the analyst to produce Annual Cost Uncertainty results since the cost, and probabilistic risk results, will be phased over the project schedule. Understanding these results can provide insight for analysts that need to compare the time-phased risk results with available annual budgets. In Figure J-19, the time-phased probabilistic results of the integrated cost-schedule risk analysis are displayed from the 5th to 95th percentile for the years 2012 through 2020. The years 2015, 2016, 2017, and 2018 are annotated to highlight the likelihood of reserve utilization. In these years, the available annual resources, denoted by the orange line, are significantly less than the mean statistical result from the analysis, denoted by the blue line.
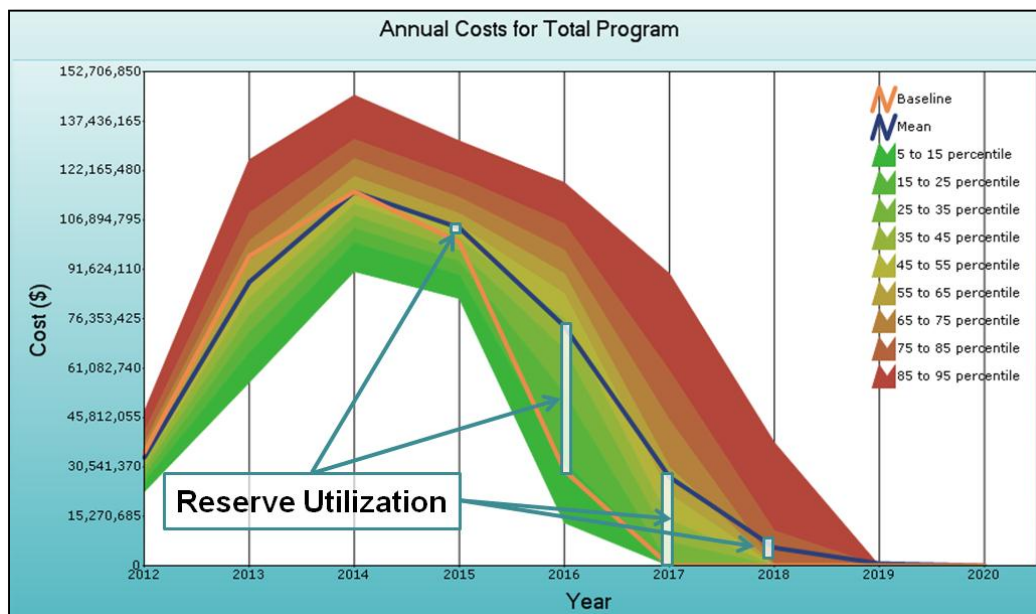

Figure J-19. Annual Cost Uncertainty Result Example Displays Cost Risk Statistics Over Time in Comparison to Available Annual Resources

---

[50] K. Cyr (2007), "The Constellation Confidence Level Estimate," *NASA Cost Symposium*.

Figure J-20 shows another example of such a display. The multi-colored bars represent the dollars needed by year for various confidence levels. The blue represents a low confidence level whereas the red represents a very high confidence level. The black lines represent the budget for each year. So, for example, the first year's (2011) budget is $120 million, and its associated confidence level is well below this project's objective of 80 percent confidence level. The Gantt chart on the bottom of the figure provides similar analysis but by duration confidence for various summary tasks. Analysis such as this is helpful to determine whether the project's funding profile is in harmony with the probabilistic results from the JCL model. In this example, it appears that the funding for 2016 is not adequate (~10 percentile) for this project's specific risk posture.
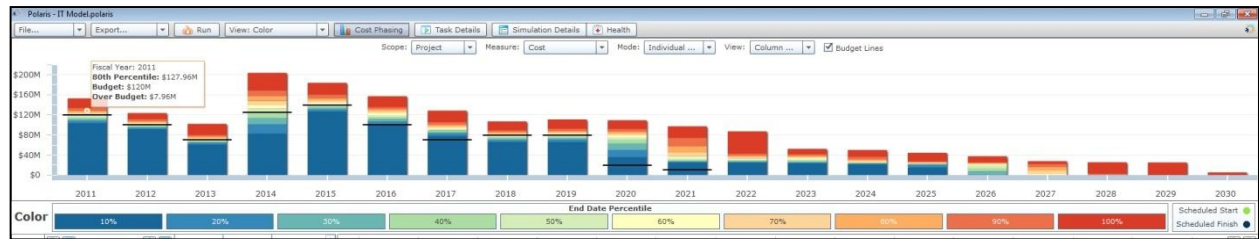

Figure J-20. Annual Phasing Example

The creation of advanced results such as the Milestone Overlay and Annual Cost Uncertainty offer unique insight into the statistical results over time. The Milestone Overlay illustrates schedule milestone drift and allows for analysis of milestone or key event completion. This is an advanced approach to understanding the cumulative results from a scatterplot and offers added insight with the inclusion of an annual budget and the timing of discrete risk events. The Annual Cost Uncertainty result also provides added insight into the results of the integrated cost-schedule risk analysis by displaying the statistical results from the 5th to 95th percentile for an identified time period, such as each fiscal year.

Works Cited

Book, S. (2007). Quantifying the Relationship Between Cost and Schedule. *The Measurable News* .

Butts, G. (2012). Psychology & It's Effects on Estimating. *NASA Cost Symposium.*

Cyr, K. (2007). The Constellation Confidence Level Estimate. *NASA Cost Symposium.*

Cyr, K., & Kou, F. (2012). An EVM Based Cost Estimate Methodology and Example. *NASA Cost Symposium.*

Elliott, D., & Hunt, C. (2014). Cost and Schedule Uncertainty: Analysis of Growth in Support of JCL. *NASA Cost Symposium.* http://www.nasa.gov/sites/default/files/files/10and11_NASA_Cost_Symposium_2014_CostSchedule Uncertainty_Final_TAGGED.pdf

Fuguitt, D., & Wilcox, S. J. (1999). *Cost-Benefit Analysis for Public Sector Decision Makers.* Westport: Quorum Books.

Garvey, P. (2000). *Probablity Methods for Cost Uncertainty Analysis.* New York: Marcel Dekker, Inc.

Garvey, P. R. (2000). *Probability Methods for Cost Uncertainty Analysis: A Systems Engineering Perspective.* New York: Marcel Dekker.

General Accountability Office. (2009). *GAO Cost Estimating and Assessment Guide.* GAO. www.gao.gov/products/GAO-09-3SP

Greenberg, M. (2014). Expert Elicitation of a Maximum Duration using Risk Scenarios. *NASA Cost Symposium.*
http://www.nasa.gov/sites/default/files/atoms/files/38_elicitation_of_max_using_risk_scenarios_final28jul2014_with_backups_tagged.pdf

Hamid Habib-Agahi, G. F. (2011). NASA Instrument Cost Model. *NASA Cost Symposium*, (p. 10).

Hubbard, D. W. (2010). *How to Measure Anything.* John Wiley & Sons, Inc.

Hulett, D. (2011). *Integrated Cost-Schedule Risk Analysis.* Ashgate Publishing.

Hulett, D. (2009). *Practical Schedule Risk Analysis.* Gower.

Jarvis, W., & Oleson, P. (2012). KDP-B Range Estimates: Unbiased Range Estimation. *NASA Cost Symposium.*

Johnson, J. K., Plumer, E., Blandford, M., & McAfee, J. (2014). ONCE 2.0. *NASA Cost Symposium.*
http://www.nasa.gov/sites/default/files/files/25_ONCE_2_0_Enhancements_2014_Cost_Symposium_Submit_TAGGED.pdf

Knight, F. (1921). *Uncertainty and Profit.* New York: Houghton Mifflin.

Kou, F., Cyr, K., & Majerowicz, W. (2014). Duration Uncertainty Based On Actual Performance Lessons Learned. *NASA Cost Symposium.*
http://www.nasa.gov/sites/default/files/atoms/files/41_duration_uncertainty_lessons_learned_final_09jul2014_tagged.pdf

NASA. (2012). *NASA Procedural Requirements 7120.5E: NASA Space Flight Program and Project Management Requirements .* NASA.

NASA. (2010). *NASA Schedule Management Handbook.* NASA.
www.nasa.gov/pdf/420297main_NASA-SP-2010-3403.pdf

NASA. (2014). *NASA Space Flight Program and Project Management Handbook.* NASA.

Pareto Chart. (n.d.). Retrieved August 2013, from Wikipedia:
http://en.wikipedia.org/wiki/Pareto_chart

Smith, A. (2011). Relating Tornado and Variance Analysis with Allocated Risk Dollars. *ACEIT User Workshop.*

United States Air Force Space and Missile Systems Center, Booz Allen & Hamilton . (2002). *Space Systems Development Growth Analysis.* United States Air Force and Missile Systems Center.

United States General Accounting Office. (2004). *Lack of Disciplined Cost-Estimating Processes Hinders Effective Program Management.* General Accounting Office. www.gao.gov/products/GAO-04-642

United States General Accounting Office. (2002). *Space Station: Actions Under Way to Manage Cost, but Significant Challenges Remain.*

Acknowledgments

JCL analysis is still relatively new to NASA. It would be impossible to thank everyone who has contributed to the NASA JCL efforts; however, CAD would like to thank a few key members of the community that directly or indirectly contributed a major portion of the JCL appendix.

- Charles Hunt—NASA Cost Analysis Division
- James Johnson—NASA Cost Analysis Division
- Tom Coonce—NASA retired
- Eric Druker—Booz Allen Hamilton
- Darren Elliott—Tecolote Research Incorporated
- Jo Gunderson—NASA retired
- Parameswaran Nair—Goddard Space Flight Center
- Steve Wilson—Johnson Space Center
- James Taylor—Smith and Associates
- The former Constellation Program Office Cost Analysis Group