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Joint Confidence Level Requirement: Policy and Issues

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Acronyms

CAD	Cost Analysis Division
CL	Confidence level
JCL	Joint Confidence Level
NAFCOM	NASA/Air Force cost model
NID	NASA Interim Directive
NPD	NASA Policy Directive
NPR	NASA Procedural Requirement

1. EXECUTIVE SUMMARY

NASA, through NASA Policy Directive (NPD) 1000.5, NASA Procedural Requirement (NPR) 7120.5D, and NASA Interim Directive (NID) 7120.81, is in the midst of implementing a Joint Confidence Level (JCL) requirement for all projects and programs. It extends the previous cost estimate confidence requirement by incorporating schedule confidence as well. At first glance, the JCL target level seemed reasonable in light of project management's general desire to closely monitor both cost and schedule. In practice, however, despite the many merits of this requirement, it introduces unintended consequences that establish potentially insurmountable challenges to most projects and programs.

In levying a cost confidence requirement on a program with many tightly coupled projects, a beneficial effect is provided by portfolio diversification because cost and budgets are *fungible*; program managers can transfer money from a project in surplus to another in shortage. This also means that projects can be budgeted at a lower cost confidence level (CL) than the program.

Extending the CL requirement to include schedule, as in JCL, however, reverses the benefits of portfolio effect. This is because, unlike money, time cannot be transferred from a project that completes work early to a project that is late. This is particularly true for a program that comprises many tightly coupled projects because it cannot be finished until *all* projects are done.

This paper will show, through analysis and examples, that the current JCL requirement demands budget and schedule reserves that are untenable for most projects and programs due to the current agency and government budgeting process and to historical uncertainties pertaining to NASA projects. Analyses have been conducted that show that, to meet the 65% JCL requirement, budget and schedule reserves of 30% to 50% are needed for a typical, tightly coupled human space flight program. It is doubtful that either the agency or the U.S. Congress would allow any program to maintain this level of reserves. This paper will argue that a more reasonable approach is to stipulate a cost confidence target only while enforcing an emphasis on schedule uncertainty as an inherent element within cost estimates.

The implications of a JCL target requirement notwithstanding, the analysis continues to provide invaluable, integrated insight into the health of programs and projects, serving as a vital portal into schedule, cost, and technical issues. The most significant contribution of JCL is its ability to provide information to program managers about the comprehensive impact of risks to schedule and cost, focusing on key risks that have the greatest effect on the plan. JCL has proven itself a valuable management tool that merges the stovepipes of risk, cost, and schedule, capturing the dynamics of the interrelationships.

This paper supports the JCL methodology, along with continued agency-wide implementation, because this methodology is fundamental to the success of programs and projects. For the Constellation program, the JCL process has generated new strategic dialogue and understanding among program and project stakeholders — and even within the project control teams

themselves. Analytical cooperation, as well as traceability, understandable methodology, identifiable input sources, and project-informed, analytically scrubbed results are all hallmarks of successful JCLs in action.

2. INTRODUCTION AND BACKGROUND

NASA NPD 1000.5 has levied the following requirement on the space flight program:

> *h. Base programs and projects involved in space flight and information technology per NPR 7120.5, NASA Space Flight Program and Project Management Requirements, and NPR 7120.7, NASA Information Technology and Institutional Infrastructure Program and Project Management Requirements, on the following:*
>
> *(1) For implementation of each major program segment (e.g., Constellation, full ISS capability, lunar exploration, etc.), programs and projects are to be baselined or rebaselined and budgeted based on a joint cost and schedule probabilistic analysis developed by the program or project in accordance with the following:*
>
> *(a) Programs are to be baselined or rebaselined and budgeted at a confidence level of 70 percent or the level approved by the decision authority of the responsible Agency-level management council. For a 70 percent confidence level, this is the point on the joint cost and schedule probability distribution where there is a 70 percent probability that the project will be completed at or lower than the estimated amount and at or before the projected schedule. The basis for a confidence level less than 70 percent is to be formally documented.*
>
> *(b) Projects are to be baselined or rebaselined and budgeted at a confidence level consistent with the program's confidence level.*
>
> *(2) As a minimum, projects are to be funded at a level that is equivalent to a confidence level of 50 percent or as approved by the decision authority of the responsible management council.*
>
> *(3) Joint cost and schedule confidence levels are to be developed and maintained for the life cycle cost and schedule associated with the initial lifecycle baselines (e.g., for space flight programs and projects baselines established at KDP-1 or KDP-C).*

This is a reasonable requirement if it is viewed without considering the larger context of the agency budgeting process, and the difficulties programs and projects will face when attempting to meet it. In this paper, we will present data and arguments signifying why this requirement may not be achievable under the present business practices of the agency. We will also provide recommendations on how it is possible for programs and projects to meet the intent of this requirement without satisfying an explicit JCL target. This paper is organized in the following manner:

- Section 3. provides an historical account of NASA cost confidence requirements and how they evolved into the current JCL interpretation. By tracing through the recent evolution

of cost estimate policy at NASA, the original intent of the JCL requirement may become more apparent.

- Section 4. describes how the portfolio effect benefits programs from a traditional cost confidence analysis perspective. In this section we will demonstrate, through examples, that a 70% program cost CL requires a mark that is less than 70% for each of the program's projects.
- Section 5. describes some idiosyncrasies regarding schedule confidence and some potentially counterintuitive findings with respect to programs with many tightly coupled projects. In this section we will demonstrate, through examples, how the portfolio effect's benefits reverse decidedly when applied to schedule confidence.
- Section 6. describes JCL and how its numerical representation is constrained by both cost and schedule confidence. In this section we will also demonstrate some of the implications on budget reserve and schedule float levels that are necessary to meet the requirement.
- Section 7. describes policy options the agency could pursue that meet the intent of the JCL requirement without levying both cost *and* schedule restrictions.

3. THE EVOLUTION OF CONFIDENCE LEVEL: FROM COST TO JOINT CONFIDENCE

The current NASA JCL policy derives from deliberations and formal mandates that reimagine the agency's cost estimating tradition, which changed significantly with the advent of cost risk practices. Signs of the agency's transition from exclusively deterministic cost analysis to the incorporation of uncertainty and risk first appeared in several places, primary among them the 2004 NASA Cost Estimating Handbook, written and promulgated by the Cost Analysis Division (CAD) at the NASA Headquarters Office of Program Analysis and Evaluation. At the time the handbook was published, regular consideration of uncertainty within the framework of cost estimating and assessment was not widely prevalent, as reflected in the *Cost Estimating at NASA* section: "Traditionally, NASA cost estimating focused on deterministic estimates…" Traces of the nascent cost risk paradigm were present, as expressed in then-CAD director Joe Hammaker's stated operating goal of "working a number of initiatives to further improve agency cost estimating," among which was "using cost risk analysis ('S-curves')… to communicate uncertainty and variability in cost estimates."

Within the handbook's *Confidence Levels and Budgeting* section appears a suggested guideline regarding CL within the context of a portfolio of programs:

> *As a general rule, cost estimates at NASA should be presented at the 70% confidence level. As an entire portfolio of Projects, the budget should be presented at the 80% confidence level.*

Note that the 70% and 80% figures here are represented as "general rules" and not hard agency mandates. Within the same section, Tim Anderson of the Aerospace Corporation provides rational for these specific values:

> *…[a decision maker)… needs to determine that percentile for each individual project, which when summed over all programs, is equivalent to the 80th percentile of the cost of the portfolio. This percentile tends to be substantially lower — near the 70th percentile — depending on the number of projects in the portfolio…*
>
> *So, assuming 10 to 20 major projects in the NASA portfolio… and assuming the ability to take money from healthy programs and give it to programs that are in trouble, then budgeting each program at the 70th percentile is roughly equivalent to budgeting the entire portfolio at the 80th percentile.*

Publication of the 2004 NASA Cost Estimating Handbook introduced to many the concept of budgeting projects and programs at high CLs. With the support of cost estimating experts and leaders, the idea of CL began to gain popularity at NASA Headquarters and around the agency as a potential reporting measurement of program and project health. However, due to the analytical complexity of CL budgeting, lack of widespread familiarity with its unique set of dynamics, and

absence of formal executive endorsement, neither program management requirements nor acquisition policy specified a CL value, though NPR 7120.5C (ratified March 22, 2005) addresses cost risk and confidence briefly:

> *The project [Life Cycle Cost] estimate shall include reserves, along with the level of confidence provided by the reserves.*
>
> *NPR 7120.5C requires projects to take cost risk into account when performing cost estimates. The costs reported…shall be risk-adjusted costs consistent with the… process as described in the NASA Cost Estimating Handbook.*

It was not until agency executives began to publically champion CL budgeting that the concept began to gain widespread appeal and acceptance as a project reporting mechanism. Former NASA Administrator Mike Griffin is credited as a catalyst for this new budgeting approach, often having expressed his concern over historical cost and schedule growth tendencies of NASA projects and a desire for the agency to master a method of forecast and control. In a February 2006 email to Exploration System Mission Directorate and agency management, he expounded on the new direction:

> *Yes, we are definitely making a change in how we do project budgeting in the Agency…Confidence-level budgeting is an attempt to use statistical methods together with cost-modeling techniques…to produce, for a given level of program content, a budget and associated schedule that carries with it some statistical level of confidence — "belief" if you will — that the project will achieve its goals. The confidence level is selectable by managers; we've chosen 70% for Agency projects in general, and I personally adjusted that to 65% for [Constellation].*

This email also marks one of NASA management's first references to the concept of schedule confidence being closely coupled with budget confidence. Thereafter, in agency management circles, "confidence level" gradually began to take on a more general meaning beyond affordability alone as a measure of program success.

More formal statements addressing cost confidence followed the email later that year, setting the stage for significant policy modification. Griffin, in commentary during the Senior Management Council on March 17, 2006, endorsed a specific cost confidence target:

> *NASA's standard practice will be to budget projects at a 70% confidence level based on the independent cost estimate. Any proposed deviations from this standard must be brought forward for consideration to the appropriate management council.*

In the wake of this wave of discussion at high levels of NASA, stipulations regarding CL budgeting were being sharpened for incorporation into agency law; but by March 2007, the "D" update to NPR 7120.5 contained only slightly expanded confidence content, including the following language:

> *… [For a project in Phase B]... the baseline life-cycle cost estimate includes reserves, along with the level of confidence estimate provided by the reserves based on a cost-risk analysis.*

Major modification to authoritative agency requirements would have to wait for another analytical paradigm: joint cost *and* schedule confidence.

Cost confidence estimating and resultant project reserve level determination does not constitute a comprehensive budget management solution. It is well known that the largest driver of cost uncertainty in many cases is not necessarily the intrinsic attributes of technical factors such as hardware mass but, rather, the uncertainty in the *duration* of work associated with the development effort, which is not often comprehensively or explicitly captured in cost models. Further, for any large-scale human space flight program whose deterministic schedule does not fall in line with the expected duration-to-complete, as affected by probable risk events and baseline duration uncertainties, cost estimates calibrated to the program's plan schedule will be significantly understated in variance and magnitude.

One of the many advertised benefits of cost estimating is its efficacy in exposing cost drivers: design complexity, hardware heritage, and so on. However, the details of a program's logically linked schedule structure have not been traditionally included in a direct manner within the framework of cost estimating technique; thus, insight into key schedule-related drivers has been largely absent.

This phenomenon was apparent within the Constellation program, which in late 2008 developed a Griffin-ordered proof-of-concept JCL model that explicitly addressed schedule as a major cost driver. The demonstrated capability of the Constellation JCL methodology, its solid endorsement from Griffin, increasing Congressional pressure on NASA to curb cost and schedule overruns, and the continuing CL campaign at high levels of the agency constituted the right mix of converging forces to successfully advance policy modification. On January 15, 2009, the acquisition policy document NPD 1000.5, containing greatly expanded CL language, was approved.[1]

Within the NPD is again the 70% mark, this time represented as a JCL target. The direct inheritance of this figure from previous cost CL discourse and candidate policy notions introduces several issues. The primary concern regards the policy's implied similarity between cost and joint confidence targets' degrees of achievability. A 70% probability mandate now applies not just to cost but to schedule as well, levying an additional layer of difficulty on programs in meeting confidence requirements. This paper discusses elsewhere the feasibility of a program overcoming this challenge.

[1] A portion of this language can be found in Section 2 of this paper.

Further introduction of CL policy followed the NPD. In September 2009, after months of crafting by top NASA officials, NID 7120.81, an interim update to NPR 7120.5D, was issued. This document increased the reach of CL direction by imbedding it within the definitions of core programmatic terminology and identifying the primary consumers of CL products:

> *A **Commitment Baseline** establishes and documents an integrated set of project requirements, cost, schedule, technical content, and an agreed-to Joint Cost and Schedule Confidence Level (JCL) that forms the basis for NASA's commitment to OMB and Congress.*

Other statues within the policy read almost identically to those found in 1000.5, supplemented with more specific instruction for project-specific confidence:

> *Projects are baselined or rebaselined and budgeted at a confidence level consistent with the program's confidence level... As a minimum, projects are funded at a level that is equivalent to a confidence level of 50 percent or as approved by the decision authority.*

Evident here are echoes of Tim Anderson's original recommendation that projects should be funded at a sufficiently high cost CL to achieve a satisfactory overall portfolio confidence. However, the policy institutes a minimum 50% *joint* confidence target for projects. JCL models representing large crewed programs, whose methodology best-practices encourage the inclusion of a logically linked schedule, behave in fundamentally different ways than cost-only confidence tools due to the interplay among many parallel development tasks. This distinction is critical; the following sections discuss the intricacies of the portfolio-related aspects of schedule and joint confidence.

4. COST CONFIDENCE AND THE MERIT OF PORTFOLIO EFFECT

The term "confidence" connotes a lack of certainty regarding the outcome of a future event. This is especially true of space program development of new hardware and software. Therefore, it is necessary to provide an uncertainty range around deterministic cost estimates to account for unforeseen events and other development risks. In a program with many sub-projects, the integrated cost estimate represents the sum total of the portfolio of its risk-adjusted components.[2]

To generate the integrated cost estimate for an entire program, analysts use three basic approaches:

a) *Parametric models based on historical data*
Several cost models, based on historical data, have been developed by the aerospace industry to generate parametric cost estimates and variance. A prominent example is NAFCOM [NASA/Air Force cost model], a joint NASA/U.S. Air Force-developed cost model that has been widely used to create project cost estimates. This method can produce quick and accurate estimates if the user is proficient with the tool. However, parametric-based estimates suffer from the fact that the uncertainty is bounded by historical data, clouding the traceability of underlying drivers.

b) *Cost estimates based on analogies to previous programs*
In this approach, cost estimates are based on similar past programs and adjusted for program specifics via expert judgment. This is a relatively crude "most likely" type of point estimate. This can be a quick and relatively accurate method of estimating costs if good comparisons are available. However, new technology and other factors may render historical comparison inapplicable.

c) *Ground-up (or "bottom-up") estimates*
In this approach, detailed technical information and requirements are used to derive the cost estimate. Strictly speaking, detailed task breakdowns are developed based on a work breakdown structure, and the costs of each of these tasks are estimated. Specific cost risk drivers are then identified and quantified to derive the total cost estimate and distribution. Since less guesswork is involved, this can be an accurate method if requirements and specific tasks are well defined.

Most parametric cost models are based on the totality of previous projects' experience. Significant drivers of costs are extracted as parameters and fit with a regression equation. The standard errors are converted to a standard deviation, forming the basis of an uncertainty distribution. One can argue that aside from the general lack of transparency into historical risk representation within the cost uncertainty sources, the distribution should capture all of the discrete risk events that have affected past programs. This line of argumentation is sound, but

[2] Here, the program management and program integration functions are treated as projects.

only to a certain extent. One obvious rebuttal is the fact that schedule rarely appears as a parameter within cost models, thereby excluding what could be a potentially significant cost penalty associated with schedules that are likely to slip. This is one of the primary reasons why cost-only estimates are not comprehensive.

Once projects produce their individual cost estimates and render a CL, the cost estimates and CL are reported to the program, after which a program CL can be calculated. The well-known "portfolio effect" comes into play during the integration of these project estimates. This term is borrowed from the financial industry, which uses this statistical phenomenon to reduce the risk exposure of a portfolio of assets through diversification. Within the context of cost estimate CL calculation, the effect implies that the uncertainty level of the aggregated program will be less than each project's, as shown in Figure 1.

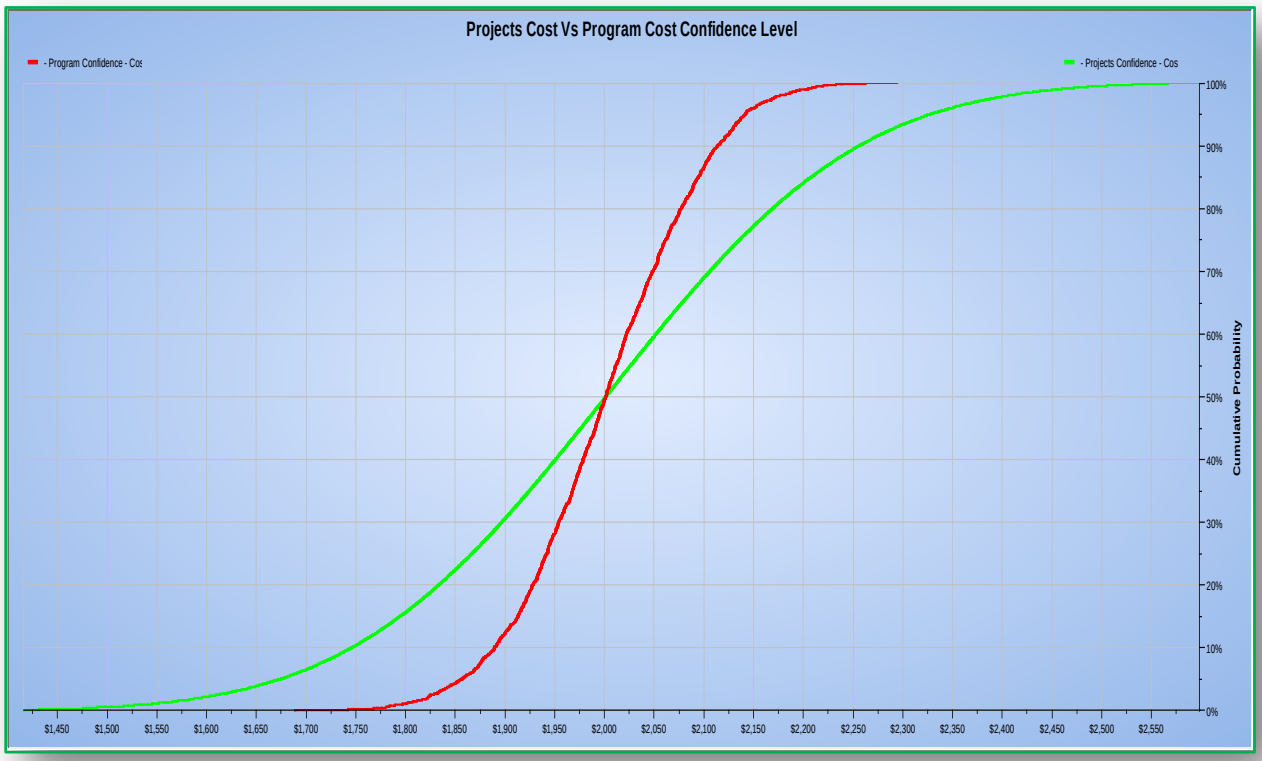


Figure 1: Uncertainty levels.

X-axis: Cost / Y-axis: Confidence Level

A more pertinent view of this portfolio effect is depicted in Figure 2. When projects are budgeted at a 60% cost CL, the program enjoys a higher CL of 70%. Similarly, if projects are budgeted at a 40% CL, the program will suffer a lower CL of 30%. The mean of the estimate (or the *expected*

value) is the demarcation point above which the effect is beneficial and below which it is detrimental. In this way, the portfolio effect acts as a two-edged sword.[3]

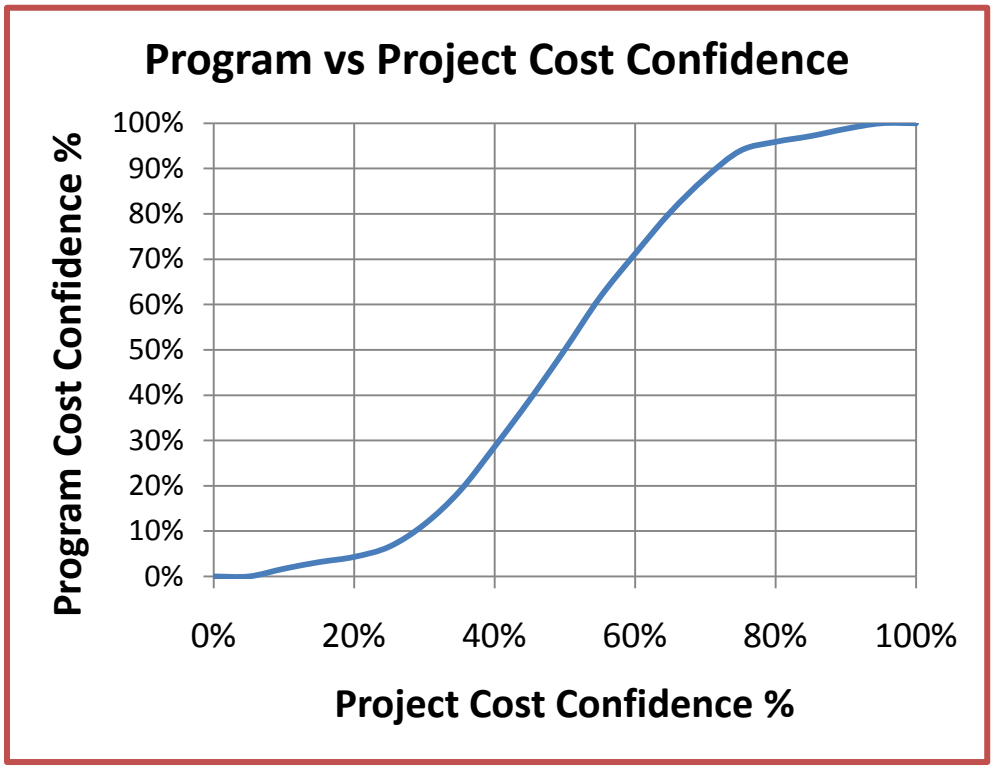
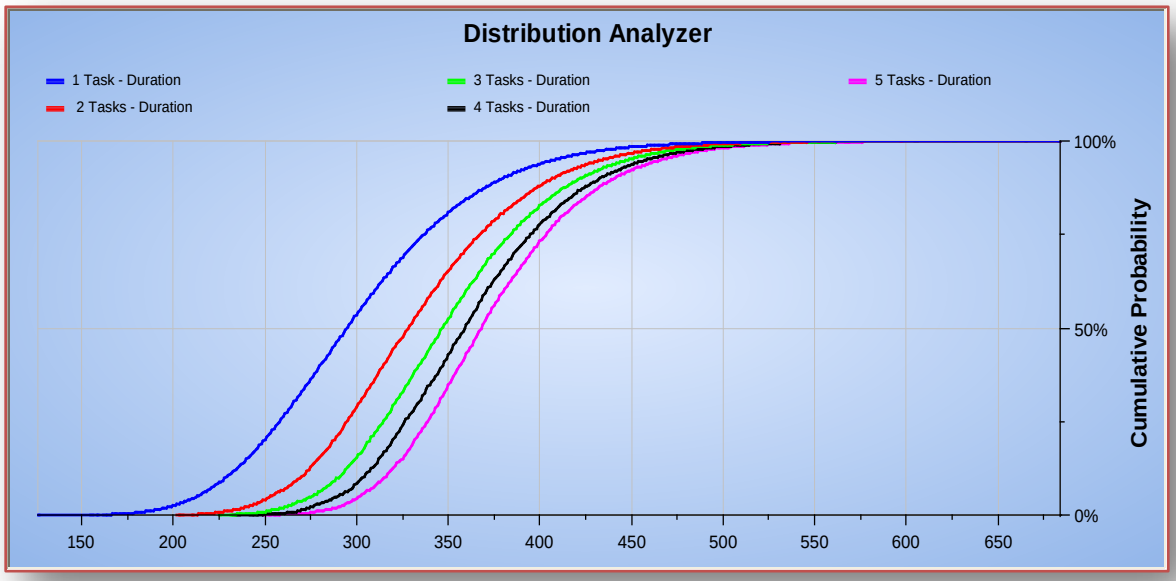


Figure 2: Program vs. project cost confidence.

[3] Appendix A describes the mathematical framework behind the portfolio effect.

5. IDIOSYNCRASIES OF SCHEDULE CONFIDENCE

The aforementioned portfolio effect does not apply to schedule confidence in the same way, however. Schedule estimates are fundamentally different than cost because they are based on the internal schedule structure of the project. Also, unlike cost, where a budget surplus in one project can be used to fund projects that are insolvent, a project's schedule float cannot be used to remedy other projects that are late completing critical work. In the case of a program with many parallel project development efforts, all of the efforts must be finished before a program can declare success. When the uncertainty of schedules is added to the analysis, as in the case of schedule risk, a portfolio of project schedules acts like a maximum function, as shown in Figure 3.



	Deterministic Value	Deterministic Probability	Mean	Standard Deviation
1 Task - Duration	300	54%	300	60
2 Tasks - Duration	300	30%	334	56
3 Tasks - Duration	300	16%	352	53
4 Tasks - Duration	300	9%	364	52
5 Tasks - Duration	300	5%	374	51

Figure 3: Portfolio of project schedule.

This simple illustration shows that, for a generic program consisting of sub-projects, each with schedule uncertainty (characterized here by a standard deviation of 20%), there is a progressive shift of the schedule confidence distribution to the right as the number of projects in the portfolio increases. It also shows that the CL for the program is lower if more projects are present. For instance, if each project has a schedule confidence of 54%, a program comprising five projects

has a schedule confidence of 5%. This directly contrasts with the portfolio benefits a program enjoys when only cost is considered.

6. JOINT CONFIDENCE LEVEL REQUIREMENT AND IMPLICATIONS

JCL seeks to unite cost and schedule confidence into one measure and answer the following question: What is the probability that the program will finish on or before a certain date *and* on or less than budget? At first glance, levying a requirement on a composite of both cost and schedule figure seems to be a reasonable idea. However, extending the 70% cost confidence target to joint confidence merits further consideration of certain mathematical implications.

The impact of including schedule within JCL analysis has been detailed in the previous sections. Examining this issue from a different perspective, we turn our investigation toward what is necessary, in terms of both budget reserve and schedule float, to satisfy the 65% JCL mark. We have already shown the results of a simple analysis that constructed a generic program with five sub-projects, in part to show the schedule impact of parallel tasks on risk analysis but also to highlight the marginal impact of adding sub-projects beyond a total of five, as indicated in Figure 3. A similar analysis can be performed with respect to JCL that involves a similar five-project assumption. Figure 4 shows a program's JCL level vs. that of a project to further demonstrate the negative impact of combining schedule confidence with cost confidence. In this analysis, it is apparent that substantially higher project JCLs (87%, for example) are required to achieve a 50% program JCL.

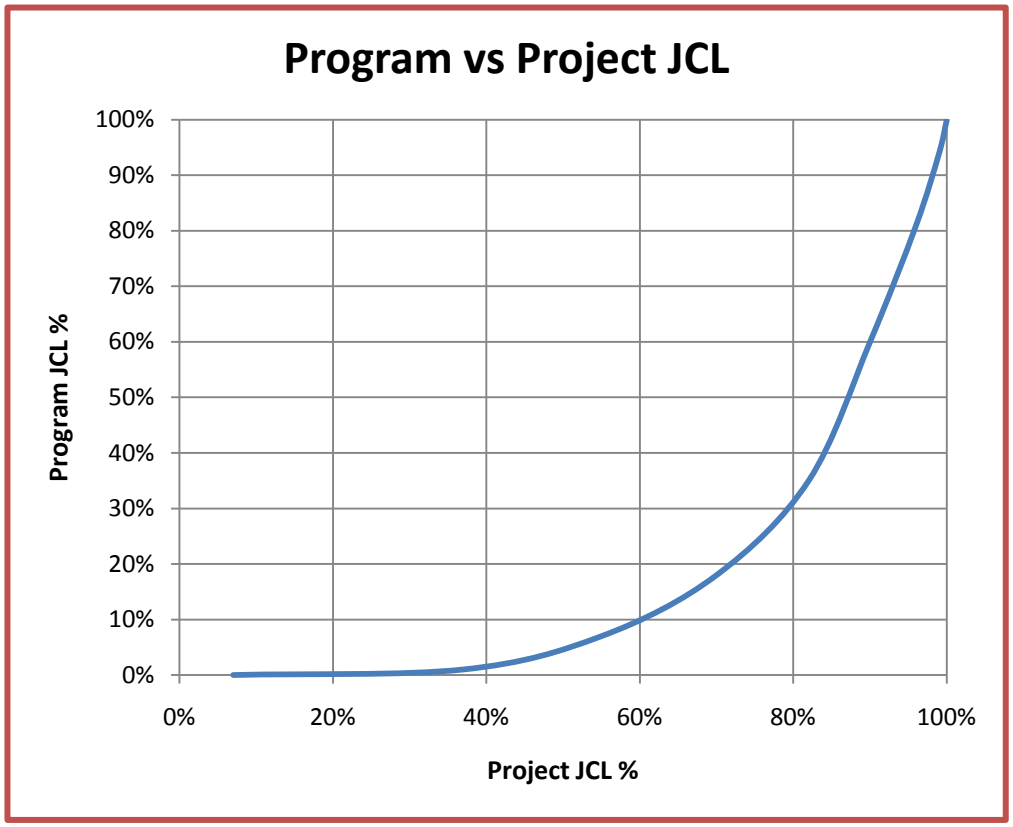


Figure 4: Program JCL level vs. project level.

In any risk analysis, the results are mainly driven by the uncertainty bound assumptions. In this particular instance, we choose to use a parametric approach so that results from various uncertainty bound assumptions can be compared. Figure 5 depicts JCL s-curves as a function of normalized budget and schedule reserves, which are calculated as a percentage of the original planned value. For example, if the planned duration and budget of a program is 4 years and $1 billion, then 40% normalized reserve translates to 1.6 years of schedule reserve and $400 million of budget reserve.

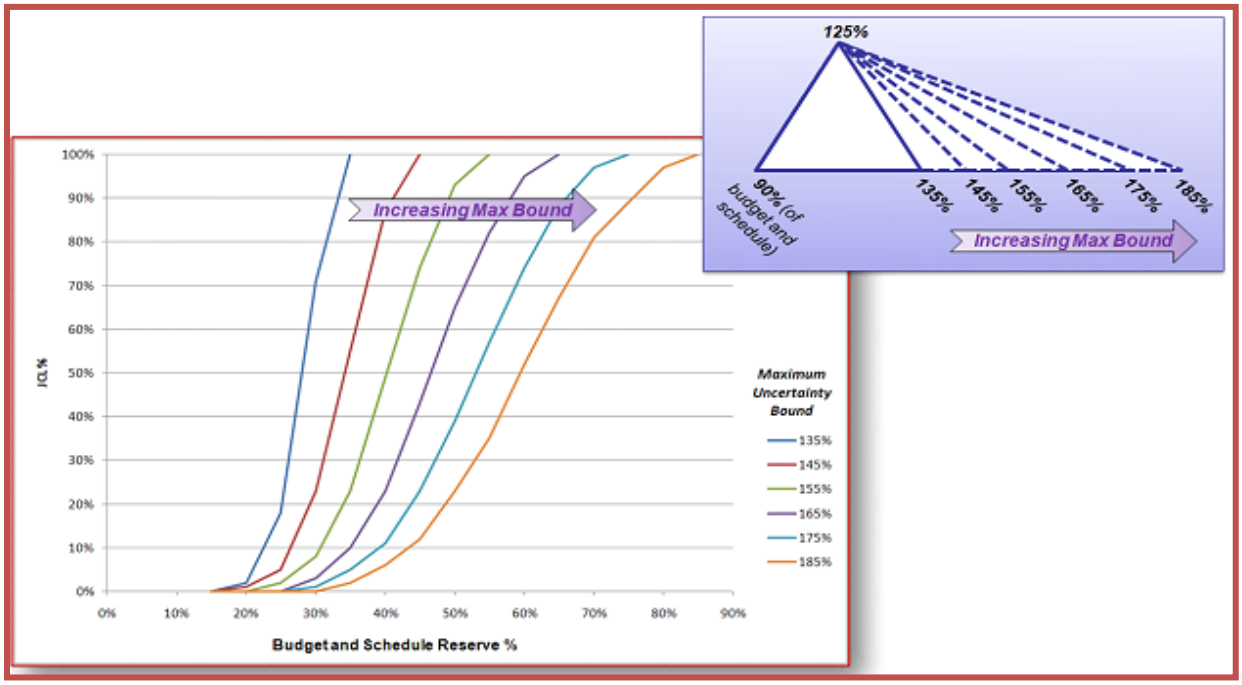


Figure 5: JCL s-curves at 90% and 125%.

In this analysis, it is assumed that uncertainty can be described by a triangular distribution, with the optimistic and the most likely fixed at 90% and 125% of the planned duration and the pessimistic duration varies as shown.

Figure 6 shows the results of the same analysis, assuming instead a most likely value of 115% for the cost and schedule triangular distributions. We believe that these two uncertainty assumptions (115% and 125%) should capture both optimistic and pessimistic bounds from an historical perspective.

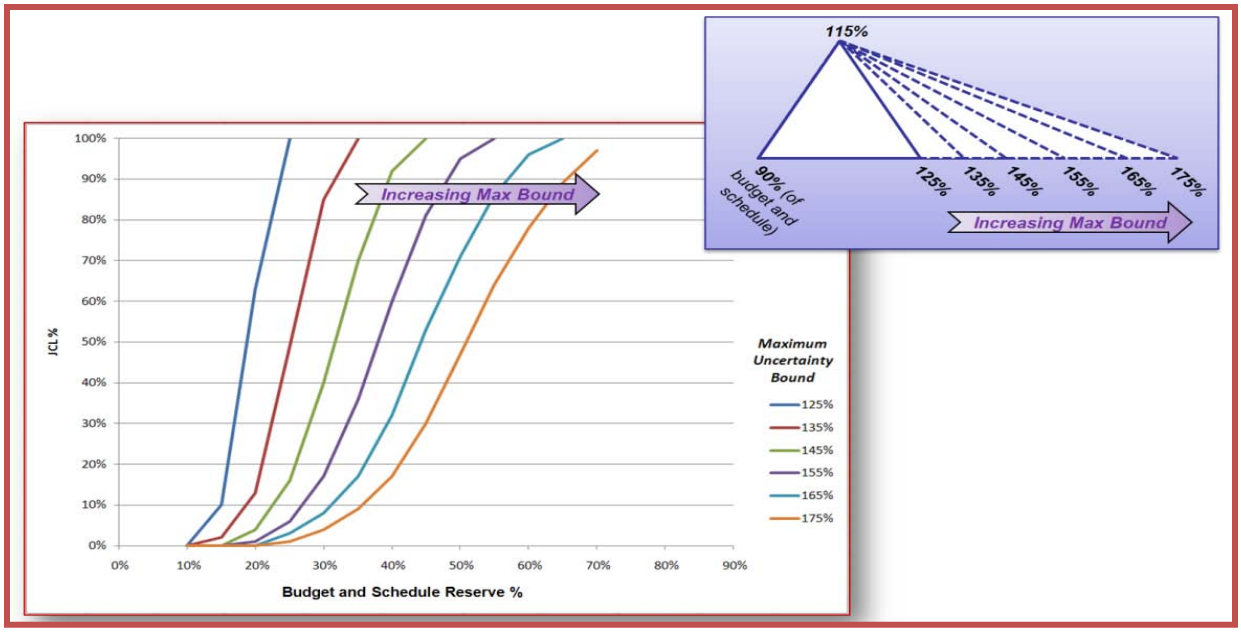


Figure 6: JCL s-curves at 90% and 115%.

The results of these two analyses can be safely summarized thus: <u>To meet the 65% JCL requirement, budget and schedule reserves of 30% to 50% are needed for a typical, tightly coupled human space flight program. It is doubtful that either the agency or Congress would allow any program to maintain this level of reserve.</u>

7. RECOMMENDATIONS AND CONCLUSION

While the thrust of this paper contains a critical examination of the JCL requirement through the lens of mathematics, the inherent value of this analytical framework and process cannot be overshadowed. JCL, in the beginning stages of implementation around the agency, is already effecting change at program and project control levels. Due to the unique integration properties of the analysis, specialized program data regarding cost, schedule, and risk are being scrutinized outside of their separate programmatic corners. This cross-checking mechanism is facilitating new cooperation among data owners and leading to a deeper understanding of program and project issues. Chief among these are risks that are being much more comprehensively examined and dissected than before.

Despite our solid endorsement of JCL methodology and process, and of the many benefits associated with both, the confidence target as a program requirement nevertheless dictates large amounts of both budget reserves and schedule float that may be practically unsustainable if not unachievable. In examining an alternative to the JCL target requirement, we first must understand its original intent. As described in Section 2., confidence analysis evolved from a primary focus on cost, the aim of which was to remedy the deficiency in prior estimating methodology that did not explicitly consider the cost impact of schedule delays. This is particularly true in the case of parametric cost models, whereby content was estimated but not spread systematically over a schedule with interdependent tasks. An additional deficiency of many cost models is that they do not distinguish between time-dependent and time-independent costs. In many NASA projects, the time-dependent portion of the overall costs (the portion that increases as schedule slips) can be substantial; therefore, there is a strong correlation between schedule growth and cost growth. For a cost model to be comprehensive, it must take schedule into consideration.

A JCL model produces both marginal cost and marginal schedule distributions,[4] the former of which already captures schedule impact on cost. As an alternative, requiring that only cost confidence be extracted from a JCL model relaxes the additional, explicit constraint on schedule and improves confidence. Figure 7 shows the marginal cost s-curve compared to the JCL curve as a function of reserve requirement.

[4] See Appendix B for a mathematical description of a marginal distribution.

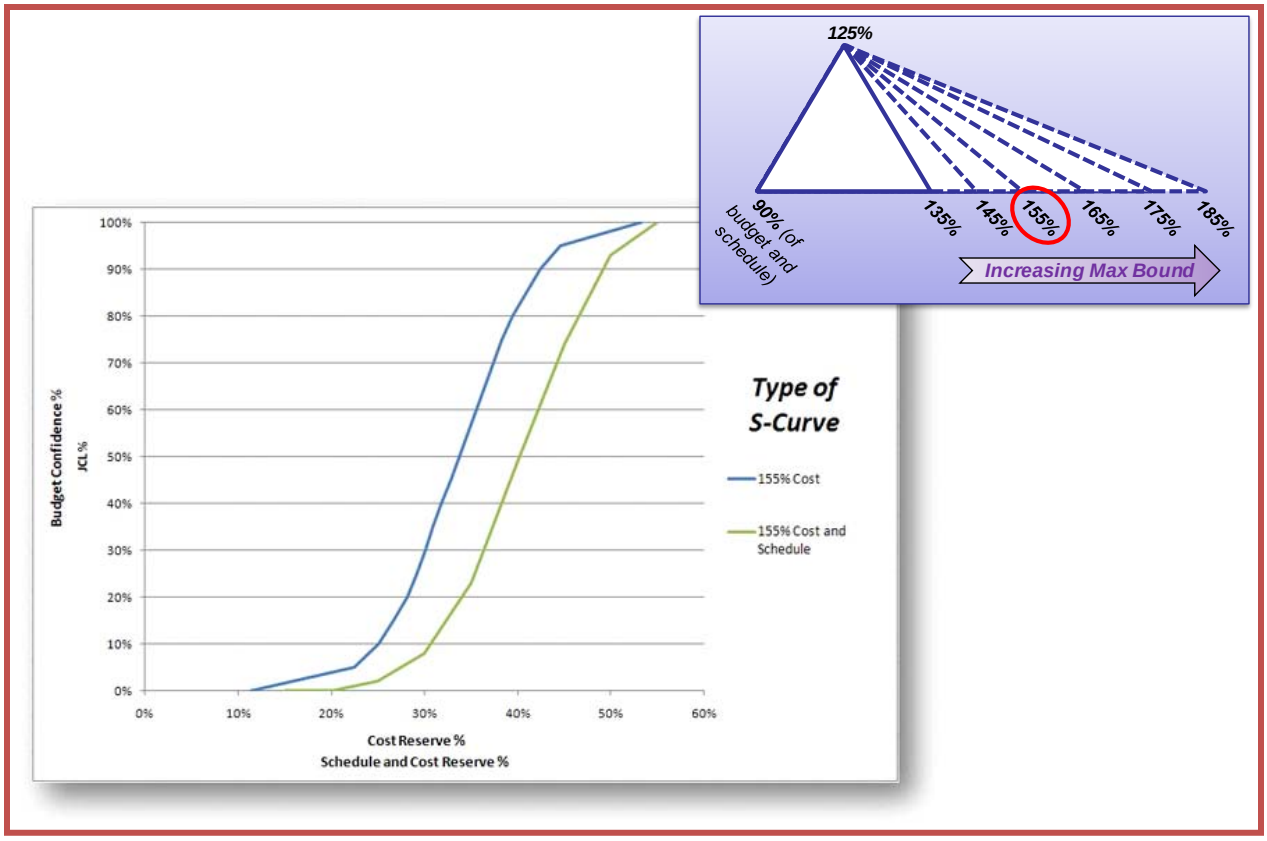


Figure 7: Marginal cost s-curve compared to the JCL curve.

There are several advantages to using cost-only CL as a requirement instead of joint confidence:

a. It is a simpler, more intuitively obvious metric than joint confidence.
b. The agency can continue to use a portfolio approach to manage programs that otherwise would not be valid if joint confidence metrics are employed.
c. Funding is fungible, whereas schedule is not, making cost confidence a more management-friendly measurement.
d. It is a requirement that programs and projects have a reasonable chance of meeting.
e. It allows project managers to manage cost by using schedule as a lever.

In sum, the Constellation program recommends that the agency require a program or project to be budgeted according to a cost confidence target only, and to derive the target from a joint confidence model based on a logically linked schedule.

8. APPENDICES

8.1 APPENDIX A: CORRELATION AND PORTFOLIO EFFECT

Given a portfolio of cost estimates, the portfolio standard deviation can be expressed as:

$$\sigma_p = \sqrt{\sigma C \sigma'}$$

where

$\sigma = [\sigma_1, \sigma_2, ...\sigma_n]$ is a row vector of each individual standard deviation, and σ' is the column vector (a transpose of the row vector). *C* is the correlation matrix.

Since the portfolio standard deviation $\sigma_p \geq 0$, *C* must be positive semi-definite (with all eigenvalues of *C* being greater or equal to zero). This requirement is also necessary for generating correlated random variables for a Monte-Carlo simulation.

The same principal can be extended to calculate a closed-form value for portfolio CL cost estimates:

$$\delta_{p.70\%} = \sqrt{\Delta_{70\%} C \Delta'_{70\%}}$$

where:

$\Delta_{70\%} = [\delta_{1,70\%}, \delta_{2,70\%}, \delta_{3,70\%}, ...\delta_{n,70\%}]$

$\Delta'_{70\%}$ = transpose of $\Delta_{70\%}$, a column vector

$\delta_{1,70\%}$ = value at 70% ($v_{1,70\%}$) – mean value (μ_1), for project 1

$\delta_{p.70\%}$ = portfolio value at 70%($v_{p,70\%}$) - portfolio mean(μ_p)

Therefore,

$$v_{p,70\%} = \delta_{p.70\%} + \mu_p$$

These equations tell us that given the correlation matrix *C*, the portfolio value at 70% confidence can be calculated from the individual $\delta_{i,70\%}$. These equations also demonstrate that by directly summing each project's 70% confidence number results in a portfolio CL in excess of the 70%. Similarly, summing the 30% confidence number of the individual projects results in a portfolio CL that is less than 30%. The precise portfolio CL depends on the correlation matrix *C*. In summary, the portfolio effect is beneficial if the confidence for individual project is greater than the expected value, and the effect is detrimental if the confidence for each project is less than the expected value.

8.2 APPENDIX B: JOINT CONFIDENCE DISTRIBUTION AND STATISTICS[5]

The joint distribution $F_{x,y}(x,y)$of two random variables *x* and *y* is the probability of the event

$$F(x,y) = P\{x \le x1, y \le y1\} = \int_{-\infty}^{x1} \int_{-\infty}^{y1} f(\alpha,\beta)d\alpha d\beta$$

where $f(x,y)$ is the joint density function.

In the study of several random variables, the statistics of each are called *marginal*. Therefore, $F_x(x)$ is the marginal distribution and $f_x(x)$ is the marginal density. Some simple properties of joint statistics are:

$$F_x(x) = F(x,\infty) \qquad F_y(y) = F(\infty,y)$$

$$f_x(x) = \int_{-\infty}^{\infty} f(x,y)dy \qquad f_y(y) = \int_{-\infty}^{\infty} f(x,y)dx$$

An important concept in probability and statistics is the idea of independence and dependence. One way to measure the linear dependence of two distributions is correlation. For example, a simple joint distribution is the joint normal density function

$$f(x,y) = \frac{1}{2\pi\sigma_1\sigma_2\sqrt{1-r^2}} exp\left\{-\frac{1}{2(1-r^2)}\left[\frac{(x-\mu_1)^2}{\sigma_1^2} - 2r\frac{(x-\mu_1)(y-\mu_2)}{\sigma_1\sigma_2} + \frac{(y-\mu_2)^2}{\sigma_2^2}\right]\right\}$$

The two marginal density functions for normal distributions are:

$$f_x(x) = \frac{1}{\sigma_1\sqrt{2\pi}} \exp\{-\frac{(x-\mu_1)^2}{2\sigma_1^2}\}$$

and

$$f_y(y) = \frac{1}{\sigma_2\sqrt{2\pi}} \exp\left\{-\frac{(y-\mu_2)^2}{2\sigma_2^2}\right\}.$$

It is easy to see that the correlation coefficient *r* combines the two marginal density functions into a joint density function. When these two distributions are independent, the correlation is 0, so the joint density reduces to the product of their marginal densities.

[5] Athanasios Papoulis, "Probability, Random Variables, and Stochastic Processes" McGraw-Hill, 1984

One important piece of information derived from these equations is, for positive correlation coefficient r

$$\|F(x)\|\|F(y)\| \leq \|F(x,y)\| \leq \|F(x)\|$$

or

$$\|F(x)\|\|F(y)\| \leq \|F(x,y)\| \leq \|F(y)\|.$$

Therefore, the joint confidence number is bounded by the product of its constituent marginal confidence numbers but does not exceed either of them. This means that, for example, if schedule confidence is 40% and cost confidence is 60%, the joint confidence is bounded by

$$0.24 \ \leq joint\ confidence \ \leq 0.4$$

The lower bound assumes that cost growth and schedule growth are independent, and the upper bound assumes that they are 100% correlated. The exact value depends on the correlation between the two.

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13. ABSTRACT *(Maximum 200 words)*

NASA, through NPD 1000.5, NPR 7120.5D, and NID 7120.81, is in the midst of implementing a Joint Confidence Level (JCL) requirement for all projects and programs that extends the previous cost estimate confidence requirement by incorporating schedule confidence as well. At first glance, the JCL target level seemed reasonable in light of project management's general desire to closely monitor both cost and schedule. In practice, however, despite the many merits of this requirement, it introduces unintended consequences that establish potentially insurmountable challenges to most projects and programs. Yet these challenges are outweighed by the fact that the most significant contribution of JCL is its ability to provide information to program managers about the comprehensive impact of risks to schedule and cost, focusing on key risks that most greatly affect the plan. Indeed JCL has proven itself a valuable management tool that merges the stovepipes of risk, cost, and schedule, capturing the dynamics of the interrelationships. This paper supports the JCL methodology, along with continued agency-wide implementation, because this methodology is fundamental to the success of programs and projects. Analytical cooperation and traceability, understandable methodology, identifiable input sources, and project-informed, analytically scrubbed results are all hallmarks of successful JCLs in action.

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