[ANM02] Triage the Sub-Projects

Calculating and Applying Portfolio Contingency

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Triage the Sub-Projects

1. Introduction

Risk-adjusted cost estimates are necessary to understand the potential spread of actual costs through execution, and the resulting distributions are often used to quantify project contingencies by generating higher confidence levels above expected costs. In a portfolio of projects, allocating uncertainty at the project level will result in an equivalent higher confidence level draw at the portfolio level, and so it is unclear whether a portfolio should allocate and manage risk-informed contingency at the portfolio or project level. This topic will explore the cost and schedule impacts of allocating at different levels of a portfolio and provide an immature alternative approach to calculating contingency at the portfolio level. The introduced alternative approach will be refined in future iterations of this study based on further analysis and feedback on this initial paper.

1.1. Contingency

In the U.S. Department of Energy (DOE) Order 413.3B: Program and Project Management for the Acquisition of Capital Assets, contingency is defined as:

- Contingency: The portion of the project budget that is available for risk uncertainty within the project scope, but outside the scope of the contract. Contingency is budget that is not placed on the contract and is included in the TPC. Contingency is controlled by Federal personnel as delineated in the Program Execution Plan. [1]

Contingency is owned and managed by the government to account for risk and uncertainty that is outside the scope of the contract. DOE G 413.3-7A walks through how contingency should be calculated for capital asset acquisition projects by adding the risk informed and uncertainty informed Monte Carlo cost/schedule output at the desired confidence level. [2] Before providing an overview of how contingency in a portfolio of projects is calculated, the terms portfolio and project must be defined. A related term, management reserve, is a defined portion of cost for risk and uncertainties within the scope of the contract but outside the scope of the baseline estimate. [3] For DOE capital asset projects, management reserve is owned by the contractor, whereas contingency is owned by the government. It is important to note that in AACE RP 44R-08 and in the private sector the definitions of contingency and management reserve are reversed from the DOE definitions. [4] This paper will only utilize the DOE definition of contingency.

1.2. Definition of a Portfolio of Projects

In general terms, a portfolio is any defined grouping of individual items. These items, typically related in some manner, can be comprised of individual materials, and works, financial investments, business assets and services, or projects. For this study, a portfolio will be a group of individual projects:

- Project: A unique effort having defined start and end points undertaken to create a product, facility, or system. Built on interdependent activities planned to meet a common objective, a project focuses on attaining or completing a deliverable within a predetermined cost, schedule and technical scope baseline. [5]

- Portfolio: A group of individually managed projects which fall under a larger, centrally managed organization.

Portfolios may be established for DOE capital asset acquisitions to facilitate a single Critical Decision (CD) or Acquisition Strategy (AS) for a group of projects. [6] An example of a portfolio would be a large campus construction effort broken down into smaller construction efforts for individual buildings of the campus. These individual buildings could be managed as standalone projects and receive funding/additional oversight through the portfolio management organization. Figure 1 shows a generalized hierarchy of projects within a portfolio.

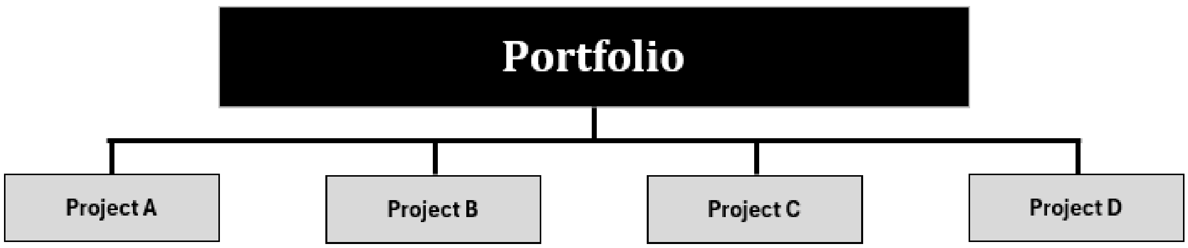

Figure 1: Hierarchy of a Portfolio of Projects

WBS Level	WBS #	WBS Element
1	**1**	**Portfolio**
2	1.1	Project A
2	1.2	Project B
2	1.3	Project C
2	1.4	Project D

Table 1: WBS of a Portfolio

A work breakdown structure (WBS) of a portfolio would have the portfolio be represented as the level 1 total of the WBS, with each project being represented as a subordinate level 2 element which is included in the sum of the total. Throughout this paper, WBS level 1 and level 2 elements will correspond to portfolios and projects, respectively. Table 1 is an example portfolio WBS corresponding to the hierarchy shown in Figure 1.

1.3. Contingency in a Portfolio of Projects

Within DOE G 413-7A, contingency calculations are based on the probabilistic joint cost/schedule/risk model at the project level. [7] Contingency is commonly calculated using the difference between the base cost (the mean or 50% confidence level) and the 80% confidence level output. It is typical to define contingency at the project level, instead of the portfolio since each project will manage their own contingency through execution. However, this approach introduces a consideration given that contingency is calculated through Monte Carlo simulations on a probabilistic model: the sum of confidence level draws of a level 2 elements (projects) at a given probability level will generally not equal the sum of confidence level draws for the level 1 total element (portfolio), except under certain conditions which are atypical in cost estimation. [8]

The sum of higher probability level draws for level 2 elements are commonly observed to be greater than the corresponding probability level draw for the level 1 element. So, in the case of contingency in a portfolio, the sum of project contingency values calculated at the 80% confidence level would likely fall at a higher confidence level on the portfolio distribution. The interpretation of this result is that defining contingency at the project level may be overestimating overall portfolio contingency. Federal portfolios and projects compete with one another during funding requests, and a portfolio manager effectively operates under funding limitations of that environment. Not every project can get the entirety of their funding request. These funding limitations in a portfolio cause prioritization of individual projects which may result in a longer duration schedule for the portfolio, or a lower rate of capabilities being fielded per unit time. It has been recognized that using the budgeting to the desired percentile of the portfolio and allocating down to the corresponding percentiles at the project level may be a better alternative than budgeting each program in a portfolio to the 80th percentile. [9] A similar approach may be implemented for contingency calculations. Overestimating portfolio level contingency will exacerbate these funding limitation impacts, so the goal of this study is to identify a novel approach that optimizes portfolio contingency and effectively decrease portfolio schedule duration or increase the rate of fielded capabilities.

2. Joint Probability Distributions

Why does the sum of confidence level results at the project level not generally align to the confidence level results at the portfolio level? Section 2.1 outlines a formal, mathematical proof of this behavior, but it is worthwhile to explain this behavior intuitively first.

The 80% confidence level output of a *project* identifies the cost value that gives an 80% chance that actual *project* costs will be less than or equal to that cost value. The 80% confidence level output of the joint distribution at the *portfolio* level provides the cost values that gives an 80% chance that actual *portfolio* costs will be less than or equal to that value. Through execution, projects under a portfolio will realize different actual costs; some projects will use more of their contingency than others. The likelihood that something goes drastically wrong across all projects in a portfolio uniformly is lower than the likelihood that something goes drastically wrong in a single project.

Analogies outside of the scope of project management illustrate this concept further:

- Automotive insurance companies will provide policyholders with financial payouts in the event of a car accident in exchange for premiums paid by the policyholders. The premiums and limits on financial compensation are based on probability calculations on the level of risk that the insurance company assumes. In a given year, only a portion of policyholders will experience a car accident requiring a payout. The operating expenses, the financial payouts to policyholders in an accident, and the profit of insurance companies all come from the premiums paid for by all policyholders. These insurance companies can run without losing money because their premiums are based on the likelihood that only a certain percentage of policyholders will be in an accident and require a payout. While the likelihood that an individual policyholder gets into an accident is relatively high, the joint likelihood that a substantial number of policyholders get into an accident is much lower.

- Commercial airlines will commonly overbook a single flight by selling more tickets than available space on the plane. A typical sight at an airport gate is the gate attendant for the airline offering money in exchange for a different flight because the current flight is overbooked. Airlines employ this practice, despite offering compensation at the gate, because the joint likelihood that every single ticket holder is checked in for the flight on-time is low even though it is unlikely for a single passenger to miss the flight. Among all the ticketed passengers of the flight, some could arrive late, be delayed due to airport security, oversleep, navigate tight connecting flight windows, and a plethora of other reasons and will miss that flight without reimbursement from the airline.

In section 2.1, it will be explained mathematically why the sum of level 2 output at a certain probability level has a higher value than the level 1 output at the same probability level.

2.1. Mathematical Explanation

Definitions: For a continuously random variable X, the cumulative distribution function (CDF) F_x defines the probability p that $X \leq x$.

$$F_X(x) := P(X \leq x) = p \qquad \textit{(Def.1)}$$

The quantile function of a random variable X, also known as the inverse CDF, takes in the probability value p and returns the value of a random variable x such that $F_X(x) = p$.

$$F_X^{-1}(p) := x \qquad \textit{(Def.2)}$$

For normally distributed random variable X with mean μ and standard deviation σ, the quantile function is:

$$F_X^{-1}(p) = \mu + \sigma\sqrt{2}\, erf^{-1}(2p - 1) \qquad \textit{(1)}$$

Where erf^{-1} in (1) is the inverse error function, which is defined by its Maclaurin series as:

$$erf^{-1}(z) = \sum_{k=0}^{\infty} \frac{c_k}{2k+1}\left(\frac{\sqrt{\pi}}{2} z\right)^{2k+1}$$

$$c_k = \sum_{m=0}^{k-1} \frac{c_m c_{k-1-m}}{(m+1)(2m+1)};\ c_0 = 1 \qquad \textit{(Def.3)}$$

Note that the coefficients, c_k, of the inverse error function series are all greater than or equal to 1 and increasing $c_{k+1} \geq c_k \ \ \forall k \geq 0$ (*Result 1*).

Proof: Let $X_1, X_2, \ldots, X_n$ be independent normally distributed variables with mean values μ_i and standard deviations σ_i, with $n \geq 2$. Let random variable $Y = \sum_{i=1}^{n} X_i$. It follows that Y is also normally distributed with mean μ and standard deviation σ such that:

$$\mu = \sum_{i=1}^{n} \mu_i \qquad (2)$$

$$\sigma^2 = \sum_{i=1}^{n} \sigma_i^2 \tag{3}$$

In the context of uncertainty cost estimation, each X_i is a level 2 WBS element and Y is the level 1 total of the WBS. The purpose of this study is to explore variations between level 1 and level 2 contingency allocations that are derived from the CDFs of the model output, which correspond with the quantile function for random variable Y (level 1 allocation) and the sum of quantile functions for $X_1, X_2, \ldots, X_n$ (level 2 allocation).

Assume that $p > 0.5$. The quantile function for the level 1 allocation at probability level p using *(1)* is:

$$F_Y^{-1}(p) = \mu + \sigma\sqrt{2}\, erf^{-1}(2p-1) \tag{4}$$

Substituting equations *(2)* and *(3)* into equation *(4)* results in:

$$F_Y^{-1}(p) = \sum_{i=1}^{n} \mu_i + \sqrt{\sum_{i=1}^{n} \sigma_i^2}\, \sqrt{2}\, erf^{-1}(2p-1) \tag{5}$$

To establish the necessary inequalities to compare to the sum of quantile functions of the level 2 WBS elements, some intermediate relationships are required:

- Result 2: The inverse error function element in *(5)* is non-negative for $p > 0.5$. First, Result 1 shows that each coefficient c_k is non-negative. All the remaining constants of the inverse error function are non-negative. Additionally, since $p > 0.5 \rightarrow (2p-1)^{2k+1} > 0\ \forall k \geq 0$. Thus, $erf^{-1}(2p-1) > 0$ for $p > 0.5$.
- Result 3: The root sum of variances in equation *(5)* are less than or equal to the sum of standard deviations. By definition of variance for normal distributions and since $n \geq 2$:

$$\sqrt{\sum_{i=1}^{n} \sigma_i^2} < \sum_{i=1}^{n} \sqrt{\sigma_i^2} = \sum_{i=1}^{n} \sigma_i$$

Result 2 and result 3 applied to equation *(5)* yields:

$$F_Y^{-1}(p) = \sum_{i=1}^{n} \mu_i + \sqrt{\sum_{i=1}^{n} \sigma_i^2}\, \sqrt{2}\, erf^{-1}(2p-1) < \sum_{i=1}^{n} \mu_i + \sum_{i=1}^{n} \sigma_i \sqrt{2}\, erf^{-1}(2p-1)$$

Rearranging the terms above yields:

$$F_Y^{-1}(p) < \sum_{i=1}^{n} \mu_i + \sum_{i=1}^{n} \sigma_i \sqrt{2}\, erf^{-1}(2p-1) = \sum_{i=1}^{n} \mu_i + \sigma_i \sqrt{2} erf^{-1}(2p-1) = \sum_{i=1}^{n} F_{X_i}^{-1}(p)$$

$$F_Y^{-1}(p) < \sum_{i=1}^{n} F_{X_i}^{-1}(p) \tag{6}$$

Inequality *(6)* shows that for probability levels strictly greater than 50%, the level 1 allocation of risk is always less than the level 2 allocation of risk for independent, normally distributed variables. Similarly, for $p < 0.5$ and $p = 0.5$:

$$p < 0.5 \rightarrow F_Y^{-1}(p) > \sum_{i=1}^{n} F_{X_i}^{-1}(p) \quad (7)$$

$$p = 0.5 \rightarrow F_Y^{-1}(p) = \sum_{i=1}^{n} F_{X_i}^{-1}(p) \quad (8)$$

Let $C_j(p_1, p_2)$ be the contingency function, which defines the risk informed contingency value between p_1 and p_2 where $p_1 < p_2$ at WBS level $j = 1, 2$.

$$C_1(p_1, p_2) = F_Y^{-1}(p_2) - F_Y^{-1}(p_1) \quad (Def.4)$$

$$C_2(p_1, p_2) = \sum_{i=1}^{n} F_{X_i}^{-1}(p_2) - \sum_{i=1}^{n} F_{X_i}^{-1}(p_1) = \sum_{i=1}^{n} F_{X_i}^{-1}(p_2) - F_{X_i}^{-1}(p_1) \quad (Def.5)$$

Using the standard definition of risk-informed contingency with $p_2 = 0.80$ and $p_1 = 0.50$, definitions 4 and 5 above, and inequalities *(6)* and *(8)* yields the following:

$$C_1(0.5, 0.8) = F_Y^{-1}(0.8) - F_Y^{-1}(0.5) = F_Y^{-1}(0.8) - \sum_{i=1}^{n} F_{X_i}^{-1}(0.5) < \sum_{i=1}^{n} F_{X_i}^{-1}(0.8) - \sum_{i=1}^{n} F_{X_i}^{-1}(0.5)$$
$$= C_2(0.5, 0.8)$$

$$C_1(0.5, 0.8) < C_2(0.5, 0.8) \quad (9)$$

Equation *(9)* shows that traditional contingency calculations allocated at level 2 (project level) are higher than contingency calculations allocated at level 1 (portfolio level) for independent, normally distributed portfolio level cost estimates. Note that for large bottoms-up risk-informed cost models for a portfolio of projects, the Central Limit Theorem implies that both project and portfolio estimates can be reasonably approximated by a normal distribution and the result in equation *(9)* generally applies.

The surface plot in Figure 2 illustrates the difference between portfolio and project level contingency calculations. The x-axis of the plot represents the number of identical normal distributions being summed together in an integrated portfolio model, the y-axis represents the probability level that cost output is being generated to, and the z-axis represents the percent difference between the portfolio level and project level uncertainty allocation at the given probability level and for the given number of projects in the portfolio sum. Values along the z-axis greater than 0 are cost outputs where the portfolio level output is less than the sum of project level output. Note that the surface plot intersects the xy-plane when the probability level is set to 0.5 (see inequality *(8)*) and when the number of distributions in the sum is 1 (singular project portfolio is just a project).

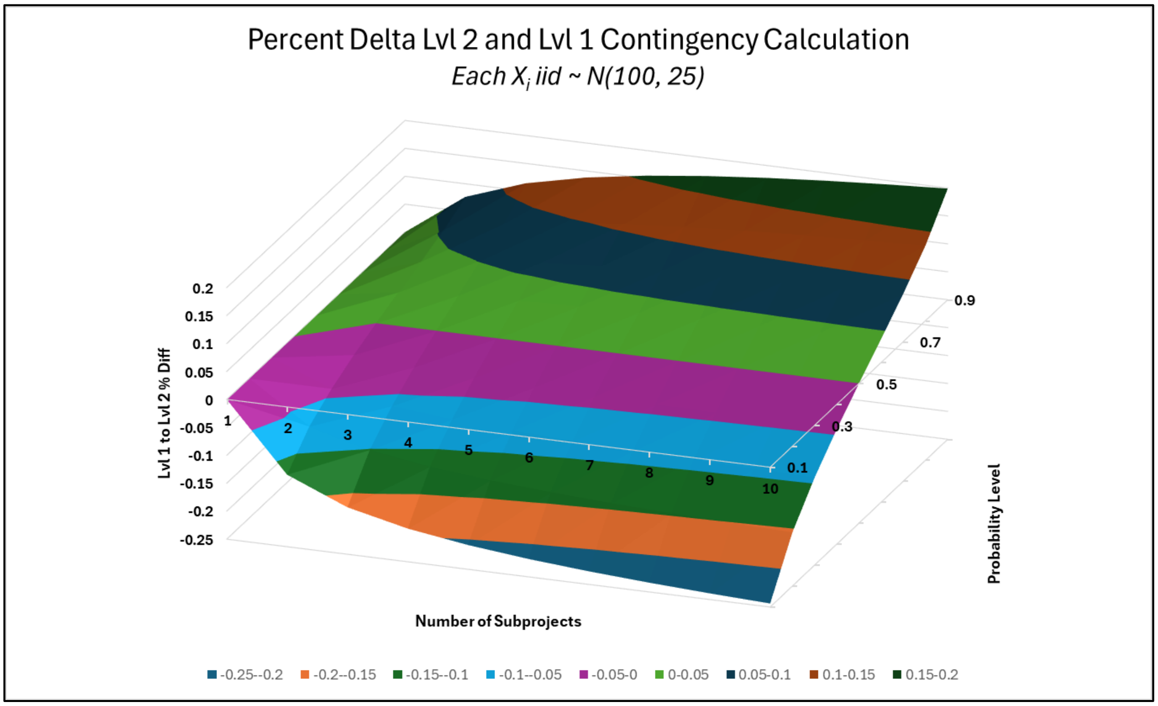

Figure 2: Surface Plot of Level 1 to Level 2 Percent Delta

The work so far has primarily focused on a sum of independent random variables, although the results still hold in the context of cost estimation under the Central Limit Theorem. Correlation of level 2 elements in a WBS will increase the resulting variance of the level 1 total element, which will reduce the discrepancy between portfolio level and the sum of project level allocations for a given probability value. [8] Thus, the addition of correlation between projects in a portfolio will result in portfolio level contingency calculation being closer, but generally still less, than the sum of project level contingency calculations.

In a portfolio of projects setting, defining portfolio contingency as the sum of uncertainty-based calculations from project level will generally result in a higher portfolio contingency value than defining portfolio contingency based as the uncertainty-based calculation at the portfolio level.

3. Alternative Method to Calculating Portfolio Contingency

A portfolio manager can define their portfolio contingency by running uncertainty calculations at the portfolio level, but how should they allocate the portfolio contingency to individual projects? Cost models using Monte Carlo simulations will allocate level 1 output calculations to lower levels based on the variability of each lower level element so that sums of lower level elements add up to the total value. Portfolio managers could utilize a similar approach, but in practice, certain projects will have a higher priority than others within the portfolio. This proposed 5-step process will generate portfolio level contingency and allocate to the project level based on the variability and priority of each project:

1) **Develop a consolidated portfolio cost model.** It is required for this step that each project has a well-built, risk/uncertainty-informed cost model. The portfolio cost model will be comprised of the sum of the output distributions for each project.

2) **Define correlations between projects in the portfolio model.** As noted in section 2.1, assuming independence between projects will result in an underestimated portfolio contingency value. Since this alternative approach prioritizes contingency optimization over risk minimization, failing to account for project correlation would add significant risk to the portfolio. Correlation between projects can be identified by having the consolidated portfolio model be a detailed bottoms-up model down to project level input variables, with common inputs defined. In the absence of information or viability of a detailed portfolio model, a correlation coefficient of between 0.2-0.6 is recommended for each project in the consolidated model. [10]

3) **Generate probabilistic contingency at the portfolio level**. Using the consolidated portfolio cost model, generate the 50% confidence level and 80% confidence level output at the portfolio level. The difference between the two values, $C_1(0.5, 0.8)$ from definition *4*, is the contingency of the portfolio.

4) **Prioritize projects and generate net weight factor**. Projects in a portfolio will have differing variance in their individual output distributions that should be accounted for when allocating the portfolio contingency. Additionally, certain projects will have a higher priority than others due to scheduling, importance, and/or political factors that should also be considered. At present, stakeholder surveys should inform the priority ranking for each project in the portfolio. Let $X_1, \ldots, X_n$ be the output project variables with standard deviations σ_i and priority ranking function $r_i\colon [1, n] \rightarrow [1, n]$.

    a. Program variability weight. Define function $w_v(\sigma_i)\colon (0, \infty) \rightarrow [0,1]$ such that:

        i. $w_v\big(max(\sigma_i)\big) = 1$

        ii. $w_v(t) \rightarrow 0$ as $t \rightarrow 0$

    b. Prioritization level weight. Define function $w_r(r_i)\colon \mathbb{N} \rightarrow [0,1]$ such that:

        i. $w_r(1) = 1$

        ii. $w_r(t) \rightarrow 0$ as $t \rightarrow \infty$

    c. Net weight. Define function w_i as:

$$W_i = \frac{w_v(\sigma_i)w_r(r_i)}{\sum_{i=1}^{n} w_v(\sigma_i)w_r(r_i)} \tag{10}$$

5) Allocate contingency to projects with net weighting factors. $C_{1,i}$ is defined as the allocated contingency value for project i. Using the net weighting factors in *(10)*:

$$C_{1,i} = w_i\, C_1(0.5, 0.8) \tag{11}$$

4. Example Portfolio

Example Portfolio Context: To further compare the traditional portfolio contingency calculation with this alternative approach and its potential advantages, consider the following realistic example portfolio. A portfolio of capital asset projects for a laboratory campus supporting 1,000 personnel is made up of five independent construction projects. The portfolio is comprised of the following projects:

1. *Building A: Office with Personnel Facilities*
   a. Dining hall, kitchen, gym & locker-room, etc.,
2. *Building B: Site Visitor Site*
   a. Reception desk, security personnel, etc.,
3. *Building C: High Energy Laser Laboratory*
   a. State of the art equipment for complex research
4. *Building D: Production & Fabrication facility*
   a. Factory equipment, assembly lines, etc.,
5. *Building E: Parking Garage*

Each building project has an independent cost estimate which includes an appropriate risk and uncertainty analysis given the underlying circumstances of each project. The risk profiles of each project are as follows:

Example Portfolio	Risk (Variability)
Building A	Medium Risk
Building B	Low Risk
Building C	High Risk
Building D	Medium Risk
Building E	Low Risk

Table 2: Portfolio Risk by Project

Example Portfolio Constraints and Ground Rules: As is often the case in program planning, this example portfolio operates within a certain set of constraints. The principal funding constraint is that the portfolio operates under an annual funding limit of $17.5M (BY24). It is assumed that the planned total project costs are equally phased for the length of their duration. In other words, each project's total cost is equally divided by the duration producing a cost per year—the yearly total cost just cannot breach the $17.5M cap.

In addition, each project has a fixed duration (shown in Table 3).

Example Portfolio	Duration (Years)
Building A	3
Building B	2
Building C	5
Building D	4
Building E	2

Table 3: Project Durations

Example Portfolio Costs: Each building project in this example portfolio has an integrated risk/uncertainty adjusted cost model. Table 4 shows the cost output of those models at the 50% and 80% confidence level draws for each project. The variability of the cost output is related to the qualitative risk score for each project shown in Table 2.

Example Portfolio	50% CL	80% CL
Building A	$ 7,357	$ 8,803
Building B	$ 13,906	$ 16,196
Building C	$ 39,015	$ 47,952
Building D	$ 20,178	$ 25,471
Building E	$ 14,859	$ 17,919

Table 4: Project Costs (BY24, $K)

4.1. Traditional Contingency Calculation

Example Portfolio Contingency: Utilizing each project's cost model and the traditional calculation approach shown in Table 5, the contingency for the portfolio totals ~$21M. This total represents the sum of the differences between the 80% CL draw and the 50% CL draw from the Monte Carlo simulation of each project's cost probability distributions.

Sample Portfolio	50% CL	80% CL	Contingency
Building A	$ 7,357	$ 8,803	$ 1,446
Building B	$ 13,906	$ 16,196	$ 2,289
Building C	$ 39,015	$ 47,952	$ 8,936
Building D	$ 20,178	$ 25,471	$ 5,293
Building E	$ 14,859	$ 17,919	$ 3,060
Total	**$ 95,315**	**$ 116,340**	**$ 21,025**

Table 5: Traditional Contingency Approach for Portfolio (BY24, $K)

Example Portfolio of Project Contingency Loaded Schedule: To ensure projects plan for the potential for overruns, the corresponding contingency value is added to each project, effectively anticipating overruns to the 80% CL. When these costs are applied within the previously outlined constraints, the optimized schedule starts in 2024 with a finish date in 2032 (shown in Table 6 and Figure 3). While there are different possible iterations of the schedule displayed, the portfolio cannot be planned to finish any faster than nine years of total duration.

Duration	Example Portfolio	2024	2025	2026	2027	2028	2029	2030	2031	2032	Total
3	Building A	$ 2,934	$ 2,934	$ 2,934							**$ 8,803**
2	Building B	$ 8,098	$ 8,098								**$ 16,196**
5	Building C			$ 9,590	$ 9,590	$ 9,590	$ 9,590	$ 9,590			**$ 47,952**
4	Building D				$ 6,368	$ 6,368	$ 6,368	$ 6,368			**$ 25,471**
2	Building E								$ 8,959	$ 8,959	**$ 17,919**
	Total	$ 11,032	$ 11,032	$ 12,525	$ 15,958	$ 15,958	$ 15,958	$ 15,958	$ 8,959	$ 8,959	**$ 116,340**
	Funding Constraint	$ 17,500	$ 17,500	$ 17,500	$ 17,500	$ 17,500	$ 17,500	$ 17,500	$ 17,500	$ 17,500	
	Delta	$ 6,468	$ 6,468	$ 4,975	$ 1,542	$ 1,542	$ 1,542	$ 1,542	$ 8,541	$ 8,541	

Table 6: Phased Costs Traditional Contingency Approach (BY24, $K)

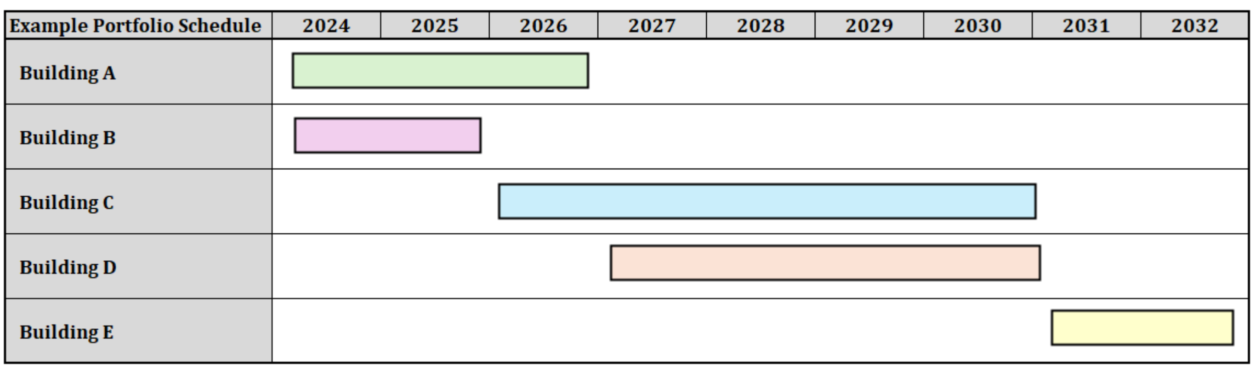

Figure 3: Project Contingency Schedule

4.2. Alternative Approach Contingency Calculation

In a resource limited environment, the laboratory campus construction portfolio in Section 4.1 takes 9 years to complete despite the longest project construction duration only being 5 years. This scenario begs the question: can an alternative, probabilistic method of accounting for cost overruns within the portfolio be utilized to better optimize the schedule? Within this section, the alternative approach outlined in Section 3 will be applied to the same sample portfolio to demonstrate potential benefits.

Example Portfolio Costs: By organizing the exact same cost estimates with their corresponding risk distributions in a new portfolio WBS (see Table 1), results provide a new total of portfolio contingency (see Table 7).

Example Portfolio	50% CL	80% CL	Contingency
Portfolio	$ 97,176	$ 107,609	$ 10,433
Total	**$ 97,176**	**$ 107,609**	**$ 10,433**

Table 7: Alternative Contingency Approach for Portfolio (BY24, $K)

The alternative approach calculated portfolio contingency value is ~$10M, which is less than half of the sum of the project contingencies and represents a more aggressive but more strategic opportunity for allocation of that contingency. Allocation of that contingency is the next step in the process of taking advantage of those strategic planning opportunities.

Example Portfolio Weighting Allocation: As outlined at the beginning of Section 3, a net weight factor to divide the contingency is calculated in the example portfolio using the variability and priority of each project. The calculation is a three-step process: (1) variability of projects (2) priority of projects (3) net weight and contingency allocation.

Based on the risk and uncertainty distributions on each project, the resulting standard deviation value is a useful measure for developing the variability weighting factor. The highest standard deviation, Building C, receives the maximum factor of 1 in variability, and each project is measured in relation to that project. Therefore, each project is calculated by dividing its standard deviation value by the standard deviation value of Building C. Those derived factors are shown in Table 8.

Buildings	St. Dev.	w_v
Building A	$ 1,614	0.18
Building B	$ 2,466	0.28
Building C	$ 8,766	1.00
Building D	$ 6,002	0.68
Building E	$ 3,433	0.39

Table 8: Variability Weight Factor Calculation ($K)

The second step in this process addresses the qualitative priority of each project. Priorities for different projects are subject to many external factors, so, for the purposes of this example, priority was assumed based on presumed importance within the overall construction of the campus. The buildings were ranked in the following order: Building C, Building D, Building B, Building A, and Building E. To calculate the weighting factor, an exponential decay formula was chosen to stratify priority in a non-linear format. This non-linear, exponential decay formula emphasizes the ability to modify the priority weights to align to stakeholder inputs for any portfolio criteria. The weights are listed in Table 9.

Buildings	w_r
Building A	0.51
Building B	0.64
Building C	1.00
Building D	0.80
Building E	0.41

Table 9: Priority Weight Factor Calculation

The final step in deriving net weighting factors and its corresponding allocated contingency is calculated as shown by the function in Section 3, equation 10. Each weight is multiplied together and divided by the sum of the weights' products. Following that calculation, the net weight (represented by W_i) is multiplied by the total portfolio contingency value resulting in the contingency allocated to each project for more effective planning. Each net weighting factor represents the project percentage allocation of the overall portfolio contingency. The results are shown in Table 10.

Weighting Scale	Building A	Building B	Building C	Building D	Building E
Variability (w_v)	0.18	0.28	1.00	0.68	0.39
Priority (w_r)	0.51	0.64	1.00	0.80	0.41
W_i	**0.05**	**0.09**	**0.50**	**0.28**	**0.08**
Portfolio Contigency	$10,433				
C_{1i}	**$ 496**	**$ 948**	**$ 5,263**	**$ 2,883**	**$ 844**

Table 10: Net Weight Factor Calculation ($K)

Example Portfolio Contingency Planned Schedule: Once the total planned costs for each project are determined, optimizing the constraint-bound schedule is the next step. And, as displayed in Table 11 and Figure 4, the resulting schedule shows a reduction in planned duration by two years.

Duration	Example Portfolio	2024	2025	2026	2027	2028	2029	2030	Total
3	Building A	$ 2,618	$ 2,618	$ 2,618					**$ 7,853**
2	Building B	$ 7,427	$ 7,427						**$ 14,854**
5	Building C			$ 8,856	$ 8,856	$ 8,856	$ 8,856	$ 8,856	**$ 44,278**
4	Building D	$ 5,765	$ 5,765	$ 5,765	$ 5,765				**$ 17,295**
2	Building E					$ 7,851	$ 7,851		**$ 15,703**
	Total	$ 15,810	$ 15,810	$ 17,238	$ 14,621	$ 16,707	$ 16,707	$ 8,856	**$ 105,748**
	Funding Constraint	$ 17,500	$ 17,500	$ 17,500	$ 17,500	$ 17,500	$ 17,500	$ 17,500	
	Delta	$ 1,690	$ 1,690	$ 262	$ 2,879	$ 793	$ 793	$ 8,644	

Table 11: Alternative Contingency Approach Phased Costs (BY24, $K)

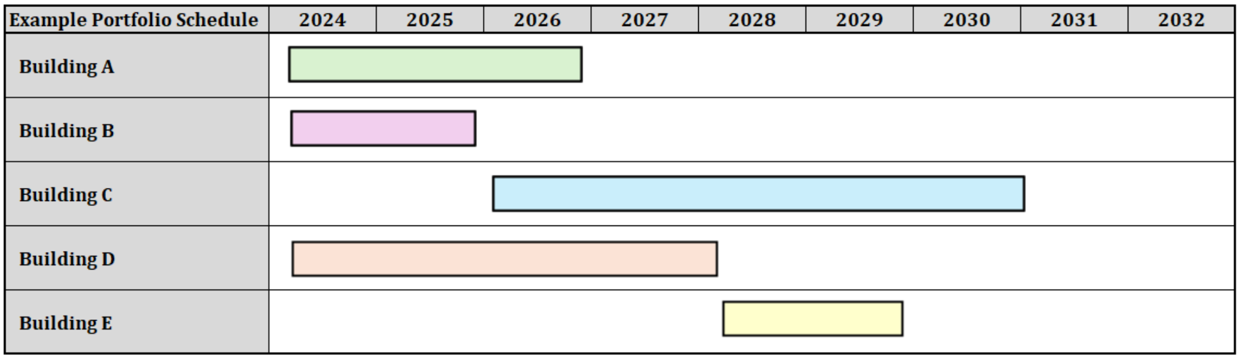

Figure 4: Portfolio Contingency Schedule

Since the contingency value is optimized over the portfolio and appropriately distributed amongst the portfolio's component projects, the duration of the portfolio was greatly reduced (shown in Figure 5). This alternative approach represents the strategic opportunities presented when contingency is calculated from the portfolio aggregation, or Level 1 WBS. In addition, not only does this improve portfolio planning in a funding constrained environment, but it also emphasizes the ability to more directly take advantage of the contingency reserved for overruns. If certain projects have a lower likelihood and need for managing overruns, contingency sitting in its reserves with more effective uses proves inefficient and not an optimal planning solution.

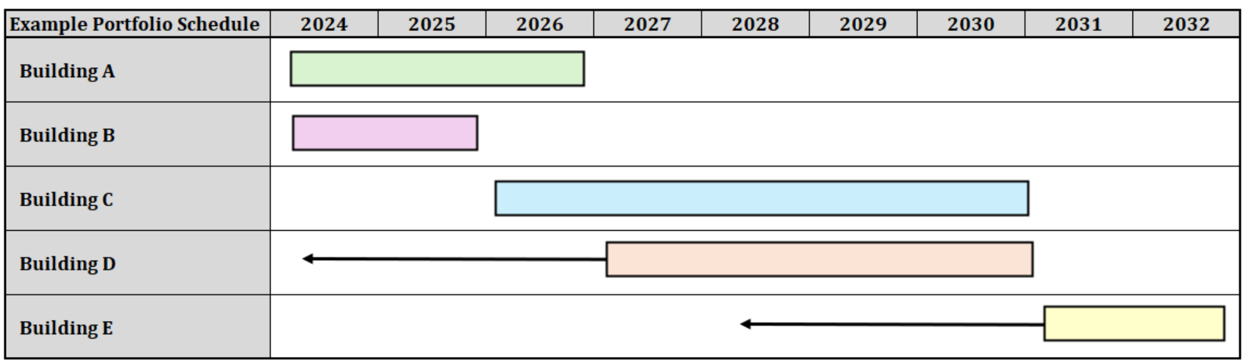

Figure 5: Contingency Schedule Comparison

4.3. Issues with Alternative Approach

However, given the advantages described, the stated alternative approach is a new and immature method for defining portfolio contingency values. There are yet to be defined aspects of this approach which need to be refined prior to formalization. This alternative approach to calculating portfolio contingency should not be implemented until formalization of the approach. Additionally, inherent risks will still be present with this approach, even in a mature form.

Assigning weighting values for variability and prioritization is not defined beyond broad definitions of general weighting factors. A multitude of functions will satisfy conditions in step 4 of the approach, but additional research is required to define optimal strategies for defining these weighting functions in this approach. For example, it is unclear what the optimal project variability weight curve should be for any portfolio of projects. At present, project variability and project prioritization weights would need to be tailored for each project based on stakeholder input.

Even after formalization of this approach there will remain risks associated with its implementation. As stated in the previous section, this approach prioritizes contingency optimization over risk minimization. Use of even a single poorly built project estimate that underestimates cost output or fails to properly account for the joint risk/uncertainty of the project, will result in an insufficient portfolio contingency and/or a riskier allocation of the portfolio contingency down to the project level.

Lastly, project contingency is not liquid within a portfolio since each project traditionally manages its own contingency. If a single project exceeds its contingency reserves, contingency cannot simply be transferred from another project in the portfolio during execution without injecting additional risk to that other project. This obstacle may additionally require policy changes to fully overcome.

5. Conclusion

Regardless of the term used, this paper has addressed funding held by the government (or private sector entity) to address risk and uncertainty on projects. Calculating contingency at the project level will result in a higher value than calculating contingency at the portfolio level. This higher value from the traditional, probabilistic method may over-estimate portfolio contingency and hinder the ability to maximize cost and schedule efficiency. In a funding constrained environment, program contingency can push schedule to the right and not harness the advantage of portfolio contingency set aside for other projects. However, for these claims to hold true, the following caveats and assumptions must be acknowledged: (1) well-constructed cost estimates and risk and uncertainty distributions are required (2) DOE Order 413.3B currently only advises to build program contingency (3) a lack of liquidity of contingency between projects could limit flexible planning and allocation. It remains pertinent that the industry continues seeking avenues within contingency optimization and to further refine the alternative approach proposed within this analysis.

Appendix A: Table of Acronyms

Acronym/Abbreviation	Meaning
AS	Acquisition Strategy
CD	Critical Decision
CDF	Cumulative Distribution Function
CL	Confidence Level
DOE	Department of Energy
WBS	Work Breakdown Structure

Appendix B: References

References

[1] U.S. Department of Energy, "DOE Order 413.3B: Program and Project Management for the Acquisition of Capital Assets," pp. Attachment 2, Page 3, 2010.

[2] U.S. Department of Energy, "DOE Guide 413.3-7A: Risk Management Guide," p. Page 54, 2021.

[3] U.S. Department of Energy, "DOE Order 413.3B: Program and Project Management for the Acquisition of Capital Assets," pp. Attachement 2, Page 9, 2010.

[4] AACE International, "Recommended Practice No. 44R-08: Risk Analysis and Contingency Determination Using Expected Values," *AACEI RP,* p. 9, 2021.

[5] U.S. Department of Energy, "DOE Order 413.3B: Program and Project Management for the Acquisition of Capital Assets," pp. Attachment 2, Page 10, 2010.

[6] U.S. Department of Energy, "DOE Order 413.3B: Program and Project Management for the Acquisition of Capital Assets," p. 4, 2010.

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[8] T. Anderson, "The Trouble With Budgeting to the 80th Percentile," *Washington Area Chapter of SCEA,* 2006.

[9] S. Koellner, "Spread Too Thin: Managing Coefficient of Variation in Monte-Carlo Based Cost Models," *ICEAA 2023 Professional Development & Training Workshop,* p. 17, 2023.

[10] A. Harris, K. McRitchie and C. Smart, "One Number to Correlate Them All – Efficiently Incorporating Stochastic Dependency in a WBS," *ICEAA 2023 Professional Development & Training Workshop,* p. 16, 2023.