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The Nuclear Option:

Avoiding Critical Delays with Advanced Constraints Analysis

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Abstract

NNSA construction projects are often subject to funding constraints. The ripple effect of funding shortfalls can be severe; projects are forced into suboptimal execution profiles that produce costly schedule slips with drastic mission implications. This experience is not unique to NNSA construction projects. Funding constraints occur in most government sectors, negatively impacting many types of projects' progression, schedule, and mission. However, since inadequate funding is often unavoidable, it is imperative to use a data-driven methodology to predict schedule deviations and calculate ideal cost phasing to mitigate additional or unanticipated implications on project timeline. This paper demonstrates how a constrained phasing model uses historic project cost and schedule data to estimate a new project timeline based on a constrained funding profile. It also reveals how the model re-phases costs for the remainder of the project duration to generate a viable execution plan.

Keywords: *Data-Driven, Scheduling, Statistics, Phasing, Weibull, Funding constraints*

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1. Introduction

1.1 National Nuclear Security Administration

The National Nuclear Security Administration (NNSA) was established in 2000 as a semi-autonomous agency within the U.S. Department of Energy (DOE). The NNSA enhances national security through four major missions: Maintaining the Stockpile, Nonproliferation, Counterterrorism and Counterproliferation, and Powering the Nuclear Navy.

The Office of Programming, Analysis, and Evaluation (PA&E) is part of the NNSA Office of Management and Budget and provides financial support for Headquarters by performing a variety of functions. This includes designing and administering the corporate planning, programming, budgeting, and evaluation (PPBE) system. PA&E develops models and tools to support PPBE and capital acquisition processes, and to help inform decision-making at the highest levels. The PA&E models currently support:

- Weapons Programs
- Capital Acquisition
- Programming
- Portfolio Management

As of Fiscal Year 2024, DOE/NNSA has over 5,500 facilities with an average age of 47 years. [1] Much of the NNSA infrastructure needs complete replacement or modernization making the capital acquisition process a top priority. The NNSA's ability to replace or update this quantity of infrastructure will depend on a coordinated effort from many offices, and starts with an optimized, efficient, and thorough capital acquisition process. This can be made possible through continued improvement of data collection, as well as updating and creating new models and tools.

This paper discusses PA&E's newly developed model for NNSA constrained cost phasing analysis. This model combines historic data with innovative techniques to offer a one-stop solution for analyzing funding constraints on project schedule. This paper offers the framework for other government agencies to use their unique capital acquisition data to develop their own models.

1.2 Government Funding: What are we trying to solve?

The terms "funding" and "execution" will be used throughout the paper. Funding refers to the money received through the federal budget process for specific agencies, offices, and programs. Execution refers to how projects spend that money.

All government entities request and receive funding the same way: through the White House Office of Management and Budget (OMB) and Congress. The federal budget process is time consuming, detailed, and often requires a great deal of tradeoff analysis.

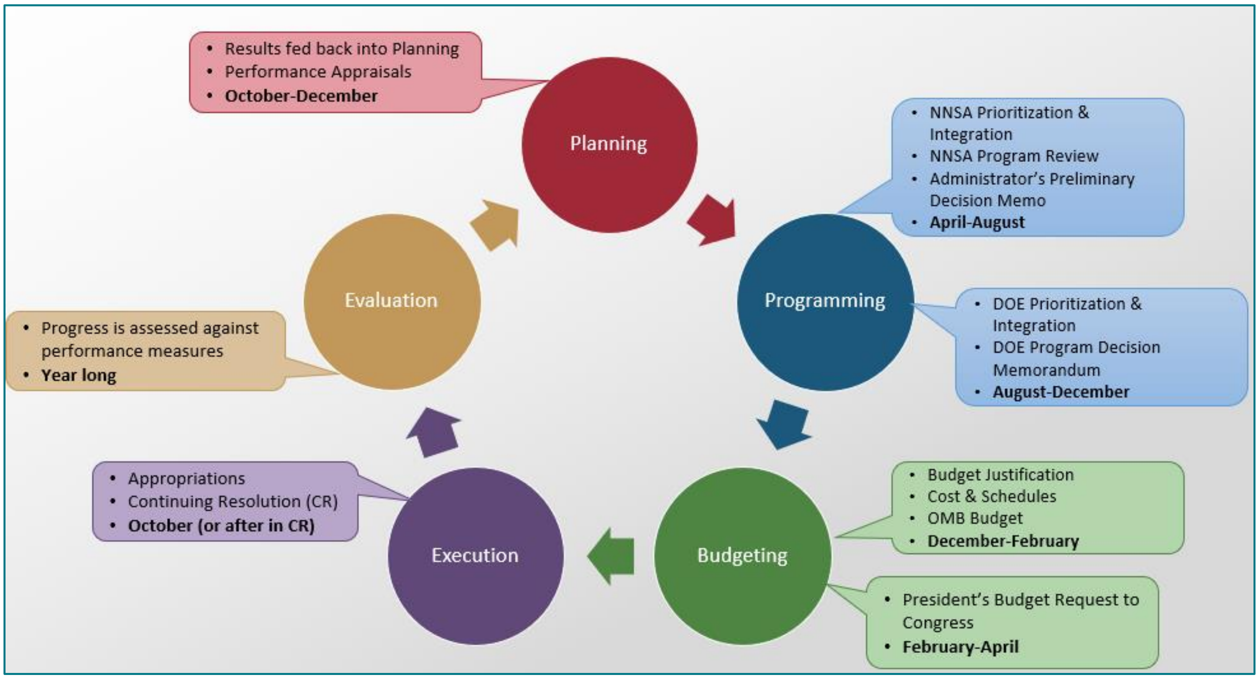

Figure 1. NNSA Budget Formulation & Execution

Agencies like the NNSA spend months, if not years, preparing for submission of the Presidential budget request (Figure 1). This involves a great deal of data collection, portfolio analysis, prioritization, and inter-office collaboration. Every agency has its own process to prioritize projects and justify funding requests, but this does not preclude the potential for funding cuts or disapproved execution plans. What happens to projects when an agency receives less funding than required? The short answer is they are forced to adopt suboptimal execution plans that generally produce costly schedule slips with drastic mission implications.

This problem is certainly not unique to the NNSA; all agencies face the reality of constrained funding each year. The National Aeronautics and Space Administration (NASA) described in their Cost Estimating Handbook, "…the U.S. Government Accountability Office (GAO) found that nearly 50 percent of recently assessed projects had issues due to 'budgets that did not match the work expected to be accomplished.'" [2] NASA also argued that these funding issues are primary contributors to NASA project cost and schedule growth.

Since funding is always inadequate, it is imperative to use a data-driven methodology to mitigate the associated impact on project timeline, as well as provide leadership with an understanding of the impact. With the right data and modeling rigor, the constrained phasing model can positively transform the PPBE process within any government agency, resulting in time and money savings for many mission-critical projects.

1.2.1 Unconstrained Phasing

In order to understand the concept of constrained cost phasing, it is important to first discuss **unconstrained** cost phasing.

The total cost of a project needs to be phased over the entire project duration. Properly phasing costs is trickier than it sounds. So, what is the ideal (unconstrained) way to phase construction project costs? The answer depends on the type of project and who is executing the project. Following is a list of a few key pieces of information needed to phase costs for a new construction project:

- Total project cost
- Project start date
- Project end date
- Project type
- Who is executing the project

Within the NNSA, construction projects are phased using multiple Phasing Estimating Relationships (PERs). The PERs were developed by PA&E using a variety of historic NNSA construction projects. These PERs address questions like:

- Historically, how has the NNSA phased project costs over project duration?
- How can costs for a new project based on previous project phasing?
- Does project cost phasing vary depending on the type of cost and type of project?

Answers to these questions are possible for any government agency if the data is available. In general, a PER can be developed using comprehensive cost and schedule data from completed projects. The data must be normalized for inflation by converting Then Year dollars to Base Year dollars with appropriate inflation indices. This will be discussed in more detail in Section 3.1.2. Similarly, phasing data is typically normalized to 0-100 percent cost and schedule. This normalization allows users to fit a distribution to all phased projects, regardless of project length. Types of distributions will be discussed further in Section 2.1.

It is important to note here that all data for completed projects reflect funding changes (cuts or adds), so they represent imperfect execution plans. Therefore, the PERs developed already take these “imperfections” into account and by doing so reflect reality. Unlike typical regressions and outlier treatment, phasing distributions can be manipulated to best fit the normalized, historical data. The chosen distribution can be optimized by minimizing the sum of squares error (SSE), setting bias equal to 0, and incrementally adjusting distribution parameters to best fit the given data. This creates an idealized phasing profile based on your historical project data.

Since the unconstrained cost phasing profile is based on historic project data that reflects the impact of funding cuts and schedule slips (i.e., reality), we consider it to be an ideal profile. Therefore, we use ideal profile and unconstrained profile interchangeably throughout the paper.

We will use an example to help demonstrate both cost phasing concepts – unconstrained and constrained. This notional NNSA construction project example does not contain any real information or data.

Project CON is a construction project that is planned to start in 2024 and end in 2034. Figure 2 shows the year-over-year cost phasing for Project CON as determined by the PERs. Ideally, Project CON would execute according to the unconstrained cost phasing profile predicted by the PER. And, since the historic project data underlying the PER reflects funding cuts and schedule slips, there would be no reason to expect Project CON's schedule to slip.

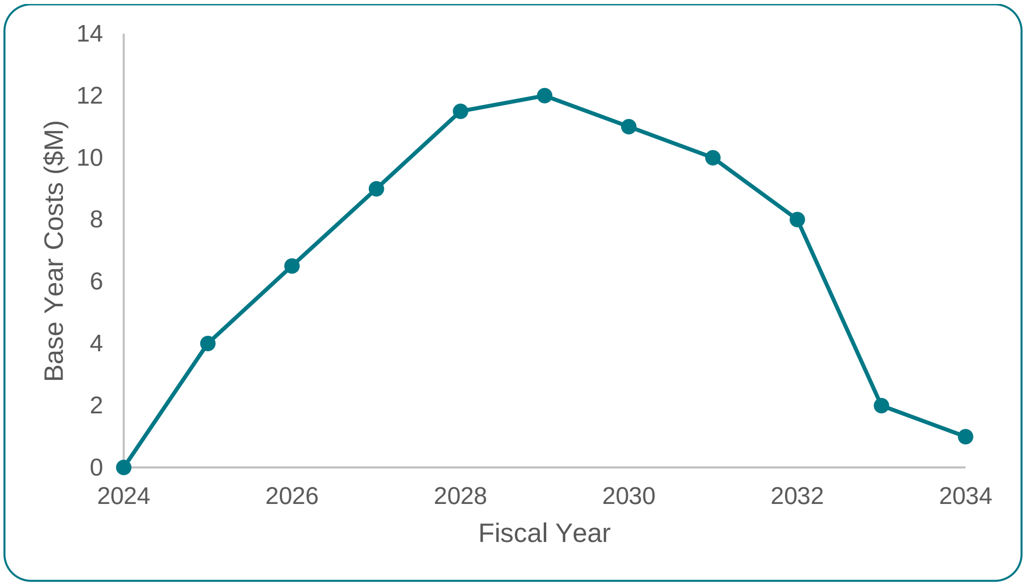

Figure 2. Project CON Unconstrained Phasing

However, for the purposes of this notional example, Project CON is much more likely to face cost constraints, due to affordability, prioritization, or funding impacts.

1.2.2 Constrained Phasing

Most NNSA projects are required to execute according to some amount of funding constraint. To explain this concept, we will continue with our Project CON example.

After extensive portfolio analysis, Project CON was determined to be lower priority than other projects and, as a result, funding was reduced in fiscal years 2025-2029 (Figure 3; gold). Therefore, Project CON will *not* be able to execute as predicted by the PER (Figure 3; teal). This project has been negatively impacted by NNSA's funding and will be considered a constrained project in this context.

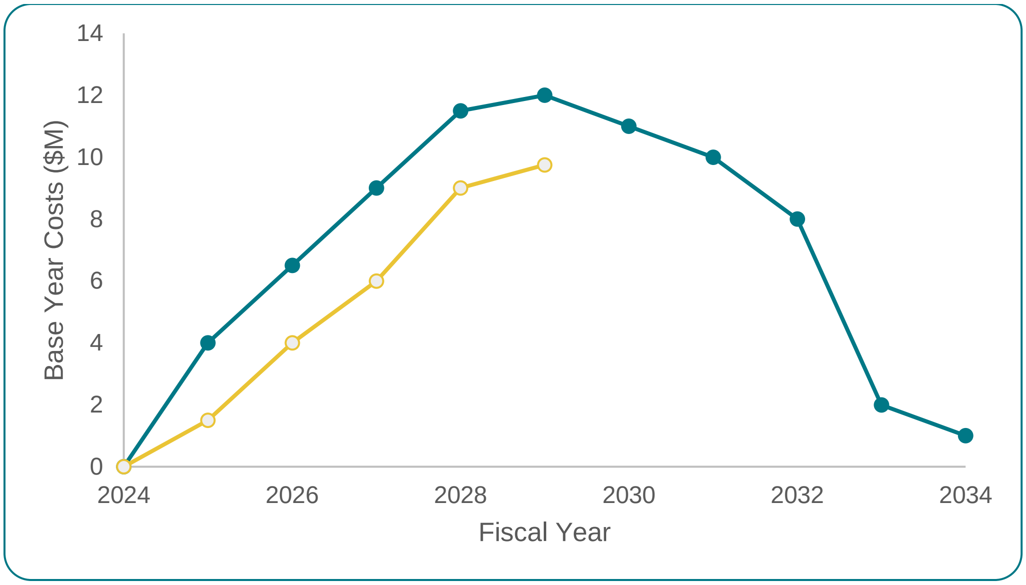

Figure 3. Project CON Constrained Phasing

What does this funding cut mean for Project CON's estimated end date? Will the project still be completed by fiscal year 2034 or will it slip schedule? This example is just one of the ways a project can be forced into a constrained cost execution profile. If funding constraints prohibit the project from executing in an ideal manner year-over-year, the project will be considered constrained in the context of this paper.

1.2.2.1 Common Constraints

There are numerous ways funding for a government construction project can be constrained. The most common constraints are:

- Five-year funding plan (FYNSP)
- Topline
- Project holds
- Early optimism

Government agencies submit a five-year funding plan to Congress annually. This five-year plan is used as the basis for that year's Congressional budget request. [3] In the NNSA, this is referred to as the Future Years Nuclear Security Program (FYNSP). The Department of Defense (DoD) five-year plan is referred to as the Future Years Defense Program (FYDP) and the Department of Homeland Security has the Future Years Homeland Security Program (FYHSP), to name a few.

Each year the NNSA prepares for the ***FYNSP*** by prioritizing and balancing projects within various national security endeavors. The FYNSP is developed through the PPBE process to accommodate these selected programs. The FYNSP funding plan can negatively impact specific project funding profiles. Since FYNSP development is reliant on project prioritization, funding is largely allocated to the most mission critical projects, leaving lower priority projects under-funded and constrained. In March 2023 the American Institute of Physics stated, "…House appropriators registered concern that the budget demands of warhead production and refurbishment have 'placed significant downward pressure on other critical activities,' including NNSA science programs." [4] It's understandable that this is a common challenge for the NNSA and likely other government entities.

Even the highest priority projects can run into funding constraints due to ***topline*** funding. A topline constraint may be imposed for several reasons by the FYNSP, program offices, or specific projects. It's common to hear phrases like "this project cannot execute more than $5M per year in 2024" or "this project's funding has been cut by 25 percent for the next two years." This will impose cost execution constraints on a project, likely impacting project schedule.

It is not uncommon for a project to be put on ***hold*** for any number of reasons. This can include project de-prioritization to allocate funds for more mission-critical projects. If a project is placed on hold and not able to execute funds for one or several fiscal years, this will certainly have an impact on the project's timeline. Projects on hold may also incur additional costs for things like de-mobilization (e.g., removal of contractor equipment) or hotel load (e.g., continued security of property), which can negatively impact funding and execution down the line.

Lastly, ***optimistic*** cost estimates or technical assumptions with inherent bias can ultimately impose constraints on project funding. This can occur when a contractor or program office has the desire to fund their projects and advertises a cost estimate that's unrealistically low. This will likely under-fund projects in the early stages until the cost estimate is adjusted to reflect the true, higher cost. Under funding in this scenario will likely lead to a schedule slip.

While there are many ways a construction project's funding may be constrained, the ***FYNSP***, ***topline***, project ***hold,*** and early ***optimism*** constraints are frequently encountered, and the constrained phasing model seeks to alleviate the burden associated with these constraints.

1.3 Constrained Phasing Model

As explained in the preceding sections, funding constraints are a prominent issue within the government. Unfortunately, data-driven tools are not readily available to address these constraints. A comprehensive model is required to predict schedule changes, re-phase costs after overcoming constraints, and mitigate additional, negative implications on project timelines.

The constrained phasing model that's the focus of this paper was developed by NNSA PA&E to address this gap. Although the ability to estimate costs, schedule, and phasing for construction projects has been available to the NNSA for years, the resultant unconstrained cost phasing is an unlikely outcome for many projects. The constrained phasing model seeks to answer questions like:

- What happens if funds cannot be executed ideally for this project?

- Will this project finish on time if the funding is cut in half?
- How will funding cuts impact project schedule?
- How can I recover from constraints and re-phase costs ideally again?

These types of questions can be answered using the data-driven methodologies built on historic NNSA data that are the foundation of the constrained phasing model. It's important to reiterate that although this model has been developed using NNSA data, the concepts of this model can be applied to any government agency with available data. This will be discussed further in Section 5.

1.3.1 Status Quo: Guess and Check

As expected, this is a very real problem for many government entities. Previous work within the National Reconnaissance Office (NRO) studied cost deviations (from their model) on their schedule estimates. [5] Their tool was developed for estimating Space Systems and presented in 2019.

However, there is no official method to analyze cost deviations within the NNSA. Many cost estimators use lengthy, manual processes to try and address constraints. This involves graphing an execution profile and forcing it, by hand, to fall under the funding topline. Although this may offer a temporary solution, this process is not data-driven and therefore lacks analytical rigor.

1.3.2 Applicability

The constrained phasing model is the first of its kind within PA&E. This model has been and will continue to be a useful tool for the PPBE and capital acquisition processes. However, it is important to note that it is not an end all be all solution. The use of the constrained phasing model should be supplemented with SME input or additional tools and methodology that best support the unique project being examined. Also, certain projects will be outside the scope of this model and therefore the model should not be used in those instances or at the very least used with caution.

1.3.2.1 When this model can be used

- NNSA capital acquisition line-item projects
- New construction or facility modification projects
- Constraints are cost execution-based

1.3.2.2 When this model should not be used[1]

- Non-NNSA projects
- NNSA minor construction projects
- Constraints that are commodity-based or manpower-based

[1]Development of a similar model for other government agencies will be discussed in Section 5. This particular model should be used for NNSA projects only.

This model does not take the constraint type into account; it can only examine the impact of the constraint on the execution plan. For example, if the constraint is due to a project hold or the FYNSP, it does not change the analysis. As with any other tool, general judgement and cross checks should be utilized where appropriate.

2. Approach & Methodology

2.1 CSPER-C Model

To understand the PERs used in the constrained phasing model, a review of the PA&E-developed Cost, Schedule, Phasing Estimating Relationship-Construction (CSPER-C) model is necessary. The CSPER-C model was developed to support the NNSA capital acquisition process by calculating cost, schedule, and phasing estimates based on NNSA project data. The CSPER-C PER was developed using historic projects with complete cost and schedule information. For an in-depth review of CSPER-C, please refer to the publication titled “Planning the Future: Estimating the U.S. Nuclear Stockpile Infrastructure Costs” published in 2019. [6]

There are three PERs used in the constrained phasing model: one for Total Estimated Costs (TEC) and two for Other Project Costs (OPC). The TEC PER uses a Weibull distribution, OPC-Nuclear PER uses Exponential, and the OPC-Non-nuclear PER uses an Exponential decay model. To build these PERs, we curve-fitted the normalized historical data, as briefly described in Section 1.2.1. TEC is mainly spent during construction, whereas OPC typically bookends construction. The Total Project Cost (TPC) is the combination of TEC and OPC.

The CSPER-C PER development approach can work with multiple types of data and distributions. Other common PER distributions include but are not limited to: Beta, lognormal, uniform, and Rayleigh. Both the Weibull and Rayleigh distributions model the ramp-up, peak, and ramp down that are typical of many project types. [2] When developing a PER using different agency data sets, there may be more appropriate distributions outside of those listed here. However, it is important to note that the chosen distribution needs to be a continuous function, otherwise it’s not possible to normalize to a similar percent complete for between years.

2.2 Constrained Phasing Model Functionality

There were three main questions that we sought to answer when developing the constrained phasing model:

- Is the *year-over-year* execution plan for a given project executable?
- Can the project meet its *Mission Need date* with the given execution plan? If no, what would the new project end date be?
- How can costs be *re-phased* after facing constraints?

2.2.1 Question One: Executability

Is the year-over-year execution for a given project executable? To answer this question, we collected information from historical projects to understand what is considered executable and not. The same historical projects from CSPER-C, with complete cost and schedule data for TEC and OPC, were normalized from 0-100 percent schedule, at every 7.1 percent. This interval was chosen to fit the longest project in the dataset, 14 years.[2] The data collected was expressed in Then Year dollars, converted to Base Year 2018 dollars[3], and normalized linearly.[4] Figure 4 below shows an example of the normalized project data.

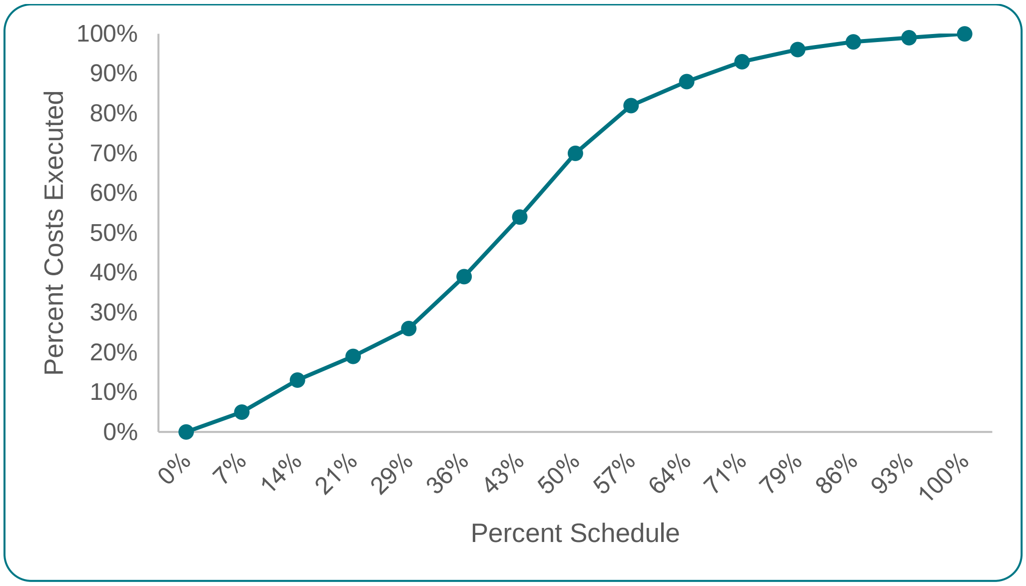

Figure 4. Normalized Phasing Data

Once all project data was normalized, we calculated the standard deviation at each percent schedule. This allowed us to add upper and lower bounds to the historical phasing data, giving us a range of executable cost percentages. An example of the normalized data with upper and lower bounds is shown below (Figure 5).

[2] Using a continuous distribution, our model can fit any project duration. The longest project was 14 years, so all projects were normalized to every 1/14th.
[3] The CSPER-C model was developed in 2018 and all projects were converted to BY18$ using ENR CCI.
[4] Often referred to as “max min” normalization.

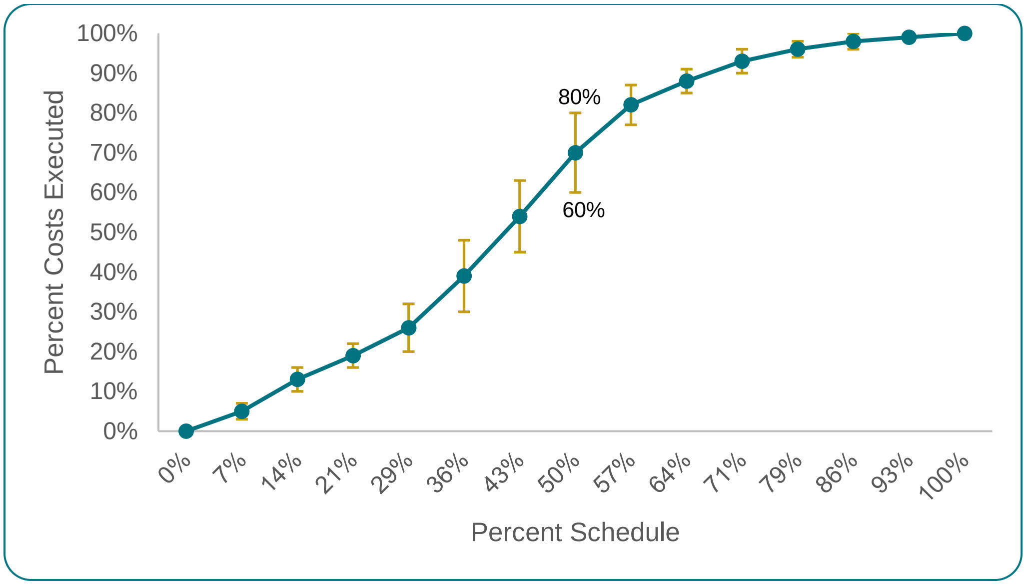

Figure 5. Normalized Phasing Data with Bounds

With these standard deviations and bounds, we could confidently analyze the executability of a year-over-year execution plan. For example, if Project CON is planning to execute 65 percent of its TEC halfway through its schedule (50 percent), this would be considered in bounds and executable based on this data (Figure 5).

To take the analysis one step further, we analyzed the year-over-year ramp-up values of these historic projects. Is it realistic for a project to execute 20 percent of its TEC in year two, then jump to executing 60 percent of its TEC in year three? We answered this question using the same methodology as above: we collected the ramp-up between every 7.1 percent schedule for all projects, then calculated the standard deviations to create a range of executable ramp-up values. An example of this data is shown in Figure 6.

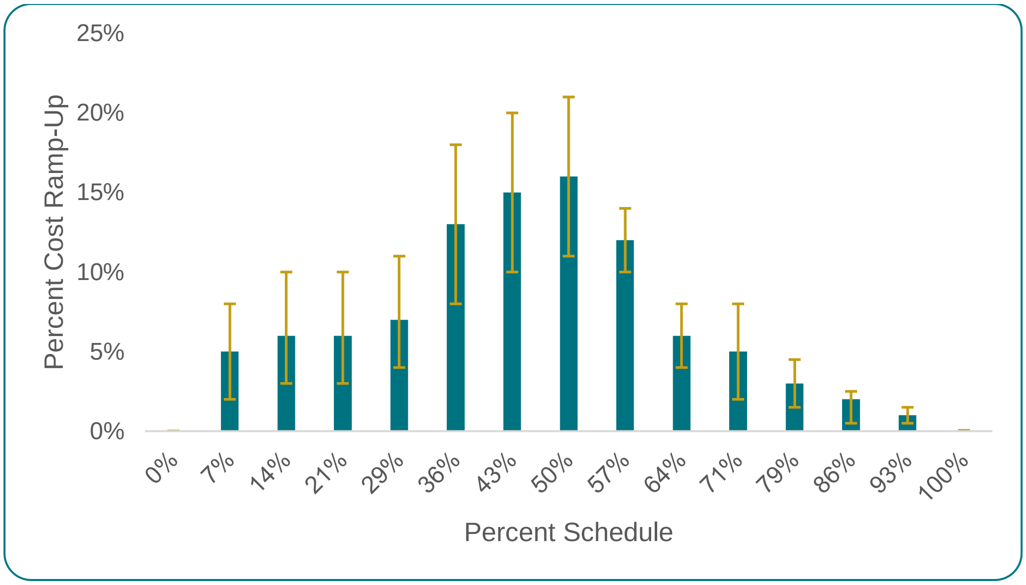

Figure 6. Normalized Phasing Data Ramp-up Rates with Bounds

In summary, the analysis of year-over-year execution is intended to ensure that a project is not executing too much or too little of its costs at any given percent schedule. The analysis for ramp-up is to ensure that the project is not ramping-up costs too slowly or too quickly at any given percent schedule. Both metrics allow us to assess the overall executability of a project execution plan in a way that has not been modeled before in PA&E.

2.2.2 Question Two: Mission Need Date (Project End)

Can the project meet its Mission Need date with the given execution plan? If no, what would the new project end date be? Traditionally, it has been a challenge to forecast project end date without dedicating significant effort to building an Integrated Master Schedule (IMS). The constrained phasing model can be used to efficiently forecast constraint impacts on project end date.

We gathered data from 20 historic projects to develop a methodology to predict project end date. We collected actual project duration (years), estimated project duration (years), and project cost phasing. The project cost phasing data was collected and normalized as described in Section 2.2.1. Estimated project duration was generated using the CSPER-C tool.[5] We used this information to determine if a project: a) ended behind or ahead of its estimated schedule and b) over- or under-executed funds relative to its predicted execution. We categorized projects into four bins:

1. Under-executing/Behind Schedule
2. Under-executing/Ahead of Schedule

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[5] Refer to Section 2.1 for more information regarding CSPER-C.

3. Over-executing/Behind Schedule
4. Over-executing/Ahead of Schedule

We hypothesized that most projects would fall into bins one and four. To visualize this, we created a series of quad charts with the x-axis as "Cost Difference" (Actual Execution – Predicted Execution) and the y-axis as "Schedule Difference" (Actual Duration – Predicted Duration.)[6] Each quad chart represents a unique percent schedule (every 7.1 percent) to match the normalized data. An example quad chart at 50 percent project schedule is shown below (Figure 7).

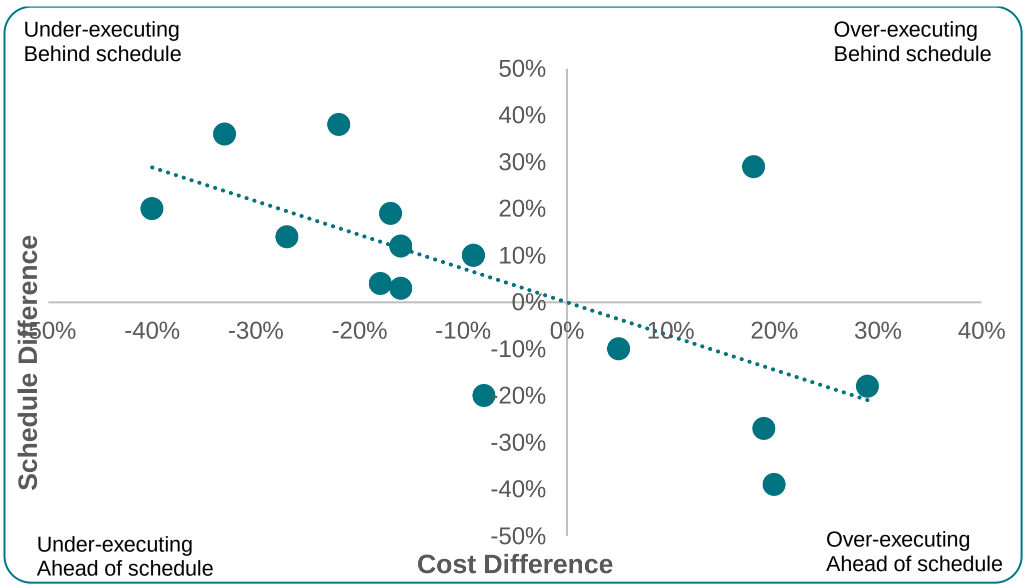

Figure 7. Example Quad Chart at 50% Schedule

Most projects do fall into bins one and four as expected. The linear trendline runs through (0,0), indicating a project executing funds ideally would end as predicted. This trendline can be used to predict schedule shifts based on a project's execution plan at 50 percent schedule. The cost difference percentage would be the x-value (independent variable) in the trendline equation, and the y-value (dependent variable) would be the predicted schedule difference.

An astute reader will notice there are two projects that fall into categories two and three. Although less likely, some projects do fall into these bins for several reasons. In general, most projects do not finish ahead of schedule. This can happen due to a few reasons including scope changes or an initial over estimation of project timeline. On the other end, some projects over-execute funds but still finish behind schedule. This is also likely due to changes in scope or project management shortcomings.

[6] The y-axis value does not change for each quad chart.

This predictive ability is unique to the constrained phasing model and is the first NNSA data-driven methodology to offer an estimated schedule end date based on funding constraints.

2.2.3 Question Three: Cost Re-Phasing

How can costs be re-phased after facing constraints? The third question can be answered with the results produced in response to the first two questions. If we determine a project falls outside our executability bounds and is estimated to slip schedule, we must offer a viable plan to re-phase costs.

The fiscal years following the funding constraints are phased using the appropriate PER and new end date given by the quad chart prediction. The difference between the last fiscal year with a constraint and first fiscal year without a constraint must also be re-phased appropriately. This cost is spread over the remaining years in the project schedule proportional to the PER. This ensures that no fiscal year is burdened with additional costs; each fiscal year is allocated a realistic and reasonable additional cost. The viability of the new cost phasing is analyzed within the model, and this topic will be discussed in Section 3.

3. Results & Assessment

3.1 Inputs, Normalization, Outputs, Cross Check

This section provides a general overview of model inputs and outputs. The discussion covers how data is normalized for analysis within the model (i.e., using the same technique as explained in Section 1.2.1) and how the model implements a cross check to validate the suggested execution plan.

3.1.1 Inputs

The model requires the following inputs, regardless of whether they are official estimates, rough order of magnitude (ROM) estimates, or actual dates and costs:

- Project Start Fiscal Year Quarter (FYQ)
- Construction Start FYQ
- Project End FYQ
- Total Cost of the Project (TEC and OPC)
- Base Year
- Standard Deviation (default is 1.0)
- Execution Plan

Project start FYQ and project end FYQ will be used to phase OPC. Construction start FYQ and Project end FYQ will be used to phase TEC. The combination of OPC and TEC phasing will be the TPC phased over the entire project duration.

These FYQ inputs are also used to determine the percent schedule at each fiscal year within the project duration. For example, a project ranging from 2020-2030 will be at 50 percent schedule in 2025. The percent schedule information will be useful when generating the appropriate quad chart for analysis.

The Base Year chosen will be used for output generation. The final execution plan will be generated in both the chosen Base Year, as well as in Then Year. Base Year-to-Then Year conversions in the model is discussed in Section 3.1.2.

The standard deviation chosen will set the bounds used to test executability of the execution plan. The default for standard deviation is 1.0, since our initial executability development was based on considering plus/minus 1.0 standard deviation (refer to Section 2.2.1). However, the user can choose any value between 0.5 and 2.0. to narrow or widen the executability bounds, respectively. A standard deviation different than 1.0 should only be chosen to supplement the current analysis and only after careful consideration.

The final input is the execution plan for the project. The plan will contain the year-over-year execution for each fiscal year up to and including the fiscal year(s) with constraints. The fiscal years following the constraints should be left blank. These will be the years that are re-phased after the quad chart analysis.

3.1.2 Normalization

The PERs were developed with data that had been converted from Then Year dollars to Base Year 2018 dollars.[7] In this model, the user will input their execution plan in Then Year dollars. The model uses NNSA Policy (NAP) 413.6 for years after 2023 and the Engineering News-Record Construction Cost Index (ENR CCI) for years 2018-2023 to adjust Then Year dollars to Base Year 2018 dollars to normalize all data for inflation.[8]

Once the execution plan is adjusted to Base Year 2018 dollars, the values are checked for executability within each fiscal year. This is done using the standard deviation bounds for both cost and ramp-up values.

The cost difference must be calculated for the quad chart analysis. This is still completed in Base Year 2018 dollars. Using the quad chart at the nearest percent schedule (refer to Section 2.2.2 for more information), the cost difference for the project is graphed to determine the schedule difference. The schedule difference, calculated as a percentage, is used to adjust the new project end date. When all quad chart analysis is complete, the final execution plan is converted to Base Year dollars (chosen from inputs) and Then Year dollars.

3.1.3 Outputs

The outputs for the model include:

- "Within bounds" or "Out of bounds" notices for executability

[7] Refer to Section 2.1 for more information regarding CSPER-C.
[8] NAP 413.6 Inflation Indices can be found in "Confidence Levels and Escalation for Cost Estimating."

- Quad chart
- New predicted project end date
- Re-phasing after constraints years

The model will immediately notify the user if their execution plan values are within or outside the standard deviation bounds. The notification will occur for both cost and ramp-up values. This will quickly indicate if the execution plan is executable relative to the historical project data.

As previously discussed, the project cost difference will be graphed on the applicable quad chart and the schedule difference will be calculated. This calculation will be displayed as “years added to project.” The new project end date will be determined using this information and will be displayed to the user.

Finally, the cost re-phasing that constitutes a viable execution plan will be given in a table as a year-over-year profile and as a graph showing the cumulative cost phasing over the new project duration.

3.1.4 Cross Check

The constrained phasing model offers a cross check to evaluate if the new, estimated execution plan is viable. The new execution plan is automatically entered into the cross check and analyzed for executability like the original inputs: standard deviation bounds for both cost and ramp-up values. This is the final confirmation that the new execution plan is appropriately phased.

3.2 Example Use-Case

A lot of information has been provided regarding the ins and outs of the constrained phasing model, but it’s likewise important to demonstrate its capabilities using the Project CON example.

Project CON is a non-nuclear construction project that will start in fiscal year 2024 and is expected to end in fiscal year 2034. The TPC is estimated to be $100M with TEC and OPC representing $90M and $10M, respectively. Project CON has funds requested in the 2025-2029 FYNSP. The entire execution plan, including the FYNSP years, is shown in Figure 8 along with the ideal execution plan, as generated by the PERs.

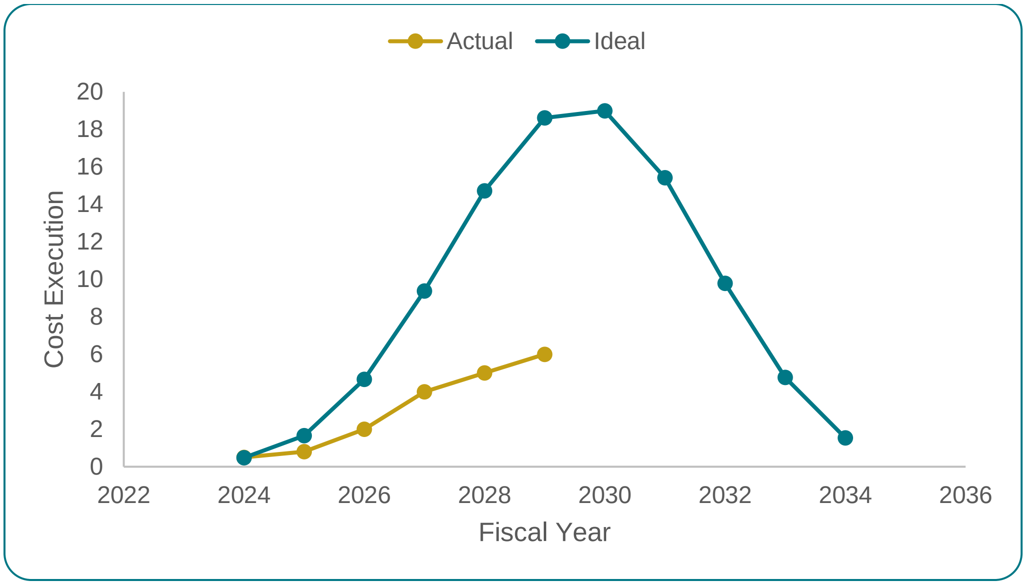

Figure 8. Project CON Actual vs. Ideal Execution

It's evident the actual cost execution plan is *not* ideal for this project. The funding within the FYNSP is too low for Project CON. Cumulative executed costs through fiscal year 2029 will be $18.2M, but the PER estimated $49.5M at that point. Will this affect the project timeline? Can Project CON still be completed in fiscal year 2034? If not, what will be the new project end date?

The model inputs for Project CON are as follows:

- Project start: FY 2023 Q1
- Construction start: FY 2024 Q1
- Project end: FY 2034 Q4
- Base Year: 2024
- Standard deviation: 1.0
- Total Project Cost: $100 M
- Estimated Executed Plan

Based on this information, the model determined that four out of five FYNSP years are inexecutable (Table 1) relative to historic project execution. The cost value falls outside the bounds set by 1.0 standard deviation in 2029, and the ramp-up values fall outside the bounds in years 2026-2029.

The "LOW" values in 2026-2028 indicate the ramp-up from 2026 to 2027 and beyond is not high enough. At this point in the project schedule, the ramp-up needs to be higher than the actual execution plan. The "HIGH" value in 2029 indicates the ramp-up from 2029 to 2030 is too high. It's important to note why this is the case, considering the user did not input a value for 2030. The value in 2030 is assumed to be the 2030 model cost as determined by the PER. The ramp-up percentage from 2029 to 2030 would be too high within this execution plan, meaning historically projects have not ramped-up their costs to that extent at this point in their schedule.

Table 1. Project CON Executability Check

		CUMULATIVE CONSTRAINT TESTS	
FY	**TEC ($M)**	**Value**	**Ramp-Up**
2023	0.0	✓ 1 σ	✓ 1 σ
2024	0.5	✓ 1 σ	✓ 1 σ
2025	0.8	✓ 1 σ	✓ 1 σ
2026	2.0	✓ 1 σ	✗ 1 σ LOW
2027	4.0	✓ 1 σ	✗ 1 σ LOW
2028	5.0	✓ 1 σ	✗ 1 σ LOW
2029	6.0	✗ 1 σ LOW	✗ 1 σ HIGH

Now that we know our project falls outside the executability bounds, the following figures will show the schedule implication of this execution plan, as well as the re-phasing of costs.

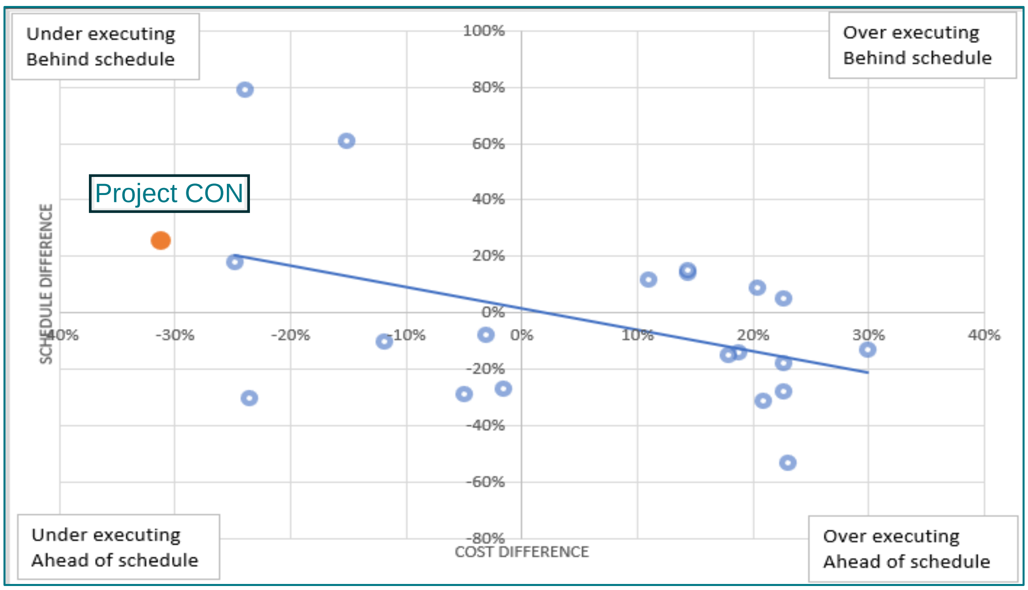

Figure 9. Quad Chart with Project CON

Table 2. Project CON Estimated End Date

Previous End Date	
Q04	2034
New Estimated End Date	
Q02	2037

Table 3. Project CON Re-Phasing

Re-Phasing (Constraints Locked)	
FY	**TEC ($M)**
2023	0.0
2024	0.5
2025	0.8
2026	2.0
2027	4.0
2028	5.0
2029	6.0
2030	16.3
2031	17.3
2032	16.4
2033	13.4
2034	9.3
2035	5.5
2036	2.7
2037	0.7

To summarize the outputs, Project CON does not have a sufficient execution plan to end in Q4 of fiscal year 2034. The cost difference was graphed on the historic quad chart to estimate the project end date (Figure 9). Project CON is estimated to finish in Q2 of fiscal year 2037 based on where it falls within historic project performance (Figure 9, Table 2). Table 3 is the generated execution plan using the new end date and remaining project cost.

Table 4 shows the cross check of the execution plan to ensure it is executable.

Table 4. Project CON Cross Check

		CUMULATIVE CONSTRAINT TESTS	
FY	**TEC ($M)**	**Value**	**Ramp-Up**
2023	0	✓ 1 σ	✓ 1 σ
2024	0.5	✓ 1 σ	✓ 1 σ
2025	0.8	✓ 1 σ	✓ 1 σ
2026	2	✓ 1 σ	✓ 1 σ
2027	4	✓ 1 σ	✓ 1 σ

2028	5	✓ 1 σ	✓ 1 σ
2029	6	✓ 1 σ	✓ 1 σ
2030	16.3	✓ 1 σ	✓ 1 σ
2031	17.3	✓ 1 σ	✓ 1 σ
2032	16.4	✓ 1 σ	✓ 1 σ
2033	13.4	✓ 1 σ	✓ 1 σ
2034	9.3	✓ 1 σ	✓ 1 σ
2035	5.5	✓ 1 σ	✓ 1 σ
2036	2.7	✓ 1 σ	✓ 1 σ
2037	0.7	✓ 1 σ	

The cross check passes all executability tests indicating that our generated execution plan is viable according to NNSA historical project performance.

This is just one example of how the constrained phasing model can be used. As stated in the introduction, there are other types of constraints that may impact a project. Those types of constraints can be analyzed in this model using the same process as outlined above.

3.3 Impacts

The constrained phasing model will positively impact the PPBE and capital acquisition processes, thereby delivering value to decision makers at the highest levels of the NNSA.

Many program offices and sites spend years planning their projects, but this is not always enough for approval. Leadership needs to see a comprehensive plan, complete with alternatives outlining cost and schedule risk and uncertainty. Implementing the constrained phasing model into project planning will provide data-driven solutions for the "what ifs" of schedule risk. The model will allow analysts and leadership to conduct side-by-side comparisons of execution plans for the most mission-critical projects.

Programming is often considered a "zero sum game." Agencies share a funding pool; when one area gets a funding increase, there must be a corresponding decrease in another area. The constrained phasing model will better prepare leadership and project leads for these unavoidable funding setbacks. Although funding is not controllable, the ability to make data-driven and informed decisions in these instances is not.

This model is already being utilized in long-term portfolio analysis within PA&E. For any agency with a long-term plan, this type of model can complete project funding profiles by developing post-FYNSP costs that may otherwise be unknown. A comprehensive execution plan for each project in a portfolio is critical for completing any portfolio analyses.

These are just a few ways the constrained phasing model will be useful within the NNSA and potentially within other government agencies.

4. Limitations

It is important to acknowledge that there are some limitations to this model, including:

- Assumed one-year "catch up" to ideal execution
- No commodity-based or manpower-based constraints
- Limited number of historical project data
- Ability to execute different than history

The ability to select catch-up length would be beneficial for assessing executability. In the example from Section 3.2, it is noted that the value in FY 2029 fails the executability test because the ramp-up is "HIGH." This failure assumes the constrained value in FY 2029 needs to "catch-up" to the model value in 2030. Implementing additional functionality for catch-up length would give users the ability to select the number of years required to catch-up, as opposed to the default always being one year. Inclusion of this functionality allows for more flexibility in the executability analysis.

Executability is often driven by commodities or manpower at a given site. What happens if a site needs to execute five construction projects at a time? Right now, the constrained phasing model cannot address this issue. This is not a near-term addition to the model and will require a great deal of data collection and analysis.

The model dataset for both executability and quad chart analysis could use more data points. Dataset expansion will be a gradual process as projects finish over the next few years and represent new data point. Similarly, other project types could be included (i.e., minor construction projects). A more robust dataset will provide even more accurate schedule predictions.

It is possible that a project may be able to execute funds in a way that has not historically been achieved. When the constrained phasing model deems a new construction project "inexecutable," this finding is the result of a comparison to historic data, but not necessarily correct if other information indicates otherwise. As stated previously, general judgment, SME input, or the use of other tools should still be leveraged to make informed decisions for certain projects.

5. Non-NNSA Development

The framework used to develop NNSA's constrained phasing model can be leveraged by any government agency to develop a similar model to evaluate their construction projects. A high-level process flow for developing a similar model is shown in Figure 10.

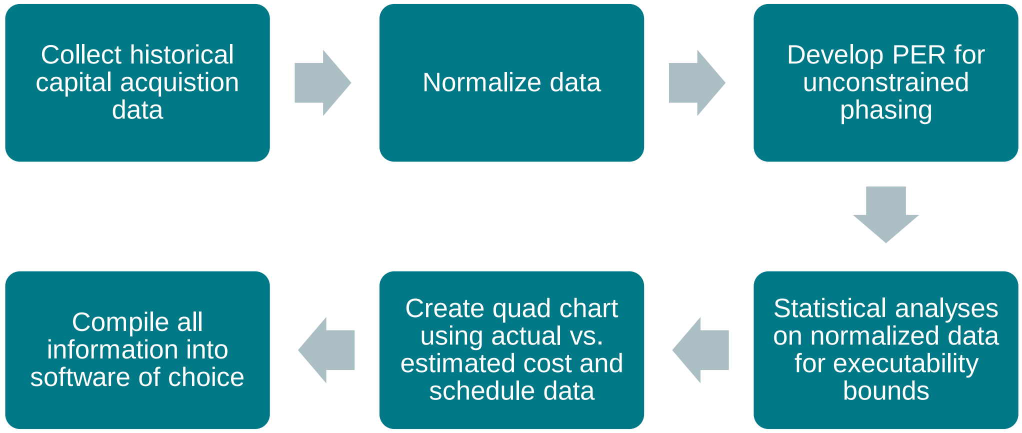

Figure 10. Constrained Phasing Model Development Process Flow

This process relies on a solid foundation of complete construction project data. Incomplete cost and schedule data will prevent the development of the PER. Normalization for inflation, using the appropriate indices, should be done after collecting data. Similarly, percentage normalization of project costs and schedule must be done to compare all projects and for determining the appropriate PER distribution. For an in-depth review of general PER development, refer to the Naval Center for Cost Analysis (NCCA) “Cost Estimating Relationship (CER) Development Handbook” published in 2016. [7] Common PER distributions are also briefly discussed in Section 2.1 of this paper.

Linear normalization of data should be completed for determining executability bounds. This ensures that each project, regardless of length, has the same number of data points for standard deviation calculations. This is needed to set executability bounds at multiple percent schedules. Please refer to Section 2.1.1 for more information regarding executability.

The predictive quad chart relies on estimated costs and schedules for all projects. This will vary depending on agency and project type. If the estimated values are consistent and documented for each project, any type of estimate should work for this purpose. Multiple quad charts will be developed, depending on the linear normalization data. If project data is normalized at every 10 percent of project schedule, there will be nine quad charts (10-90 percent). Quad charts are not compiled at 0 or 100 percent project schedule. Refer to Section 2.2.2 for how this was completed using NNSA data.

With a robust data set, the functionality within the constrained phasing model can be leveraged to inform decision making within any agency and become a useful tool for any PPBE process. This can save time, money, and resources for many types of mission-critical capital acquisition projects.

6. Future Analysis

The constrained phasing model will be continuously updated and improved as more NNSA construction projects conclude and constitute historic data points. This will strengthen the accuracy of the PER, executability bounds, and quad chart. Further, as more project types enter the portfolio, this will widen the scope of projects that can be analyzed by the model.

Project executability will be studied in greater depth as most NNSA infrastructure needs to be remodeled or replaced at the same site and same time. This will likely cause manpower- or commodity-based constraints at a given site, which is a very real problem the NNSA faces. The ability to analyze multiple types of constraints on a given project will be highly beneficial to the PPBE and capital acquisition processes.

As mentioned in Section 1.2.2.1, it is common for projects to be placed on hold, negatively impacting their schedule. Projects placed on hold often incur additional costs, contributing to unplanned cost growth. The ability to drill down on additional costs incurred by constraints would be a beneficial new capability to include in the constrained phasing model. This type of analysis will be addressed and included in further iterations of the model.

Although not elaborated on here, other limitations discussed in Section 4 are currently being addressed as well.

7. Conclusion

The constrained phasing model addresses gaps in the analysis of various aspects of the PPBE and capital acquisition processes. It can become the cornerstone for programming, and supplement essential studies, including Analysis of Alternatives (AoAs), planning studies, and portfolio analyses. NNSA decision-makers have started to rely on the analyses possible with the model.

In this paper, we have provided a framework for developing a constrained phasing model using any construction project data. With a solid foundation of data, the model can benefit mission-critical projects within any government agency.

As the NNSA faces a pivotal time for national security in the face of ever-present funding constraints, models and tools to enable informed mission-critical decisions are essential. The constrained phasing model is a data-driven, predictive methodology built on historic construction project data. This model can inform decisions that prevent costly schedule overruns, positively impacting the overall missions of the NNSA.

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Appendix 1: List of Acronyms

AoA: Analysis of Alternatives

CER: Cost Estimating Relationship

CSPER-C: Cost, Schedule, Phasing Estimating Relationship-Construction

DOE: Department of Energy

ENR CCI: Engineering News-Record Construction Cost Index

FYDP: Future Years Defense Program

FYHSP: Future Years Homeland Security Program

FYNSP: Future-Years Nuclear Security Program

FYQ: Fiscal Year Quarter

GAO: Government Accountability Office

IMS: Integrated Master Schedule

NAP: NNSA Policy

NASA: National Aeronautics and Space Administration

NCCA: Naval Center for Cost Analysis

NNSA: National Nuclear Security Administration

NRO: National Reconnaissance Office

OMB: Office of Management and Budget

OPC: Other Project Cost

PA&E: Office of Programming, Analysis & Evaluation

PER: Phasing Estimating Relationship

PPBE: Planning, Programming, Budgeting and Evaluation

ROM: Rough Order of Magnitude

SSE: Sum of Squares Error

TEC: Total Estimated Cost

TPC: Total Project Cost