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Benchmarking Tool for Planning and Assessing Construction Estimates

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Abstract–The Office of Programming, Analysis, and Evaluation (PA&E), NA-MB-90 within the National Nuclear Security Administration (NNSA) is charged with leading programmatic cost estimating and associated analytical support throughout the Federal budgeting process. As part of this effort, the office has developed a benchmarking tool that incorporates both similar historic projects and modeled parametric results. This tool enables analysts to rapidly assess the reasonableness of newly proposed estimates based on simple high-level factors such as facility size, facility hazard category, and equipment complexity.

The development team created the tool by normalizing cost and schedule data from completed and near-completed projects. The benchmarking tool outputs graphics comparing the proposed estimates with a similar set of analogous facilities. The graphs also compare the estimates with prediction intervals developed from a set of NNSA parametric cost and schedule estimating relationships, previously presented at the 2019 AACE International Conference & Expo. Applications include the generation of standard, data-informed visualizations to help decision makers understand estimates in a broader historical context and to also aid analysts in tracking estimate variability over time.

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Introduction

The NNSA a semi-autonomous organization within the U.S. Department of Energy (DOE), contributes to national and global security through nuclear deterrence, nonproliferation, counterterrorism, naval nuclear propulsion, and national leadership in science, technology, and engineering. PA&E supports the NNSA mission by providing analytical services such as cost analyses to aid informed planning and decision-making.

Coordinating the work performed by NNSA and its management and operating (M&O) partners is a major effort that requires robust long-term planning. PA&E supports capital acquisition projections throughout the planning process by developing early stage cost and schedule estimates for NNSA's major capital acquisitions projects. In 2020, PA&E developed a cost and schedule benchmarking tool with the intent to develop a user-friendly model that can be used to quickly assess the reasonableness of project estimates by comparing them to similar historic actuals.

Background

NNSA Capital Acquisition

NNSA's capital acquisition projects are governed by DOE Order 413.3B, *Program and Project Management for the Acquisition of Capital Assets* [1]. Since NNSA's terminology may be unfamiliar to some readers, some key terms and phrases relevant to the benchmarking tool will be briefly described. The acquisition process includes five phases, each concluding with a critical decision (CD) milestone shown in **Table 1**.

Critical Decision (CD)	Milestone
CD-0	Approve Mission Needs Statement
CD-1	Approve Alternative Selection and Cost Range
CD-2	Approve Performance Baseline
CD-3	Approve Start of Construction or Execution
CD-4	Approve Start of Operations or Project Completion

Table 1–Critical Decisions in the DOE Capital Acquisition Process

DOE Order 413.3B divides project costs into two types:

- Total estimated cost (TEC), defined as "engineering design costs after conceptual design, facility construction costs, and other costs specifically related to construction efforts."
- Other project costs (OPC), defined as "all other costs related to the project that are not included in the TEC" such as conceptual design, policy compliance, and startup.

Together, TEC and OPC sum to total project cost (TPC).

The Need for a Benchmarking Tool

The process described above ensures NNSA receives a variety of cost estimates throughout a project's design and construction. For example, a program manager may receive initial high-level parametric estimates from NNSA's PA&E office, subsequent bottoms-up estimates during design from bidders, and eventually estimate at complete projections as the project executes from the contractor.

At each stage, NNSA benefits by having a benchmarking tool that allows rapid comparisons of new incoming estimates to its historic projects. To satisfy this need, PA&E developed the benchmarking tool as an easy-to-use tool for visually and quantitatively assessing the reasonableness of an estimate.

Cost and Schedule Benchmarking Tool

The benchmarking tool is a dashboard-style tool with a user-friendly interface. The tool provides charts directly comparing user-inputted estimates against historic project data, as well as estimates and prediction intervals from a parametric model developed and used by PA&E. Each of these components is described below.

Capital Acquisition Cost and Schedule Model Overview

The benchmarking tool was built around PA&E's capital acquisition early stage cost and schedule estimating relationship, *Cost Schedule and Phasing, Estimating Relationship for Construction (CSPER-C)* [2]. For planning and budget purposes, the CSPER-C model considers characteristics of a project, which are known at an early stage of the planning process to estimate the cost and schedule for a proposed project. CSPER-C is a parametric model derived from historical project cost and schedule data extracted from NNSA construction project data sheets and two DOE databases: *Facilities Information Management System (FIMS)* [3] and *Project Assessment & Reporting System II (PARS)* [4].

<u>Model Independent Variables</u>

CSPER-C has three inputs:

1) The approximate size of the facility.
2) The anticipated facility hazard category.
3) The overall complexity of facility equipment.

Facility Size: Facility size is estimated in gross square feet (GSF).

Facility Hazard Category: The model contains five hazard category bins, which are estimations of underlying requirements in key cost driver areas such as facility safety and security. They are ranked below, from highest to lowest hazard category:

1) Nuclear Category 2 and 3 Facilities
2) Chemical Hazard Facilities
3) Radiological Facilities
4) Nanoparticle and Beryllium Facilities
5) Biosafety Level 1 or 2, and No Hazard Facilities

Equipment Complexity: Equipment complexity is divided into three categories:

1) High: Custom one-of-a-kind scientific or production equipment
2) Medium: Off-the-shelf industrial or scientific equipment
3) Low: Office or light laboratory equipment

Cost and Schedule Estimating Model

With facility size (in GSF), hazard category (HC), and equipment complexity (EC) known for a particular facility, the following equations are used to estimate the project's total estimated cost (TEC), other project costs (OPC), and total project cost (TPC):

Equation 1: $\boldsymbol{TEC = aGSF^{b}HC^{c}EC^{d}}$
Equation 2: $\boldsymbol{OPC\%\ of\ TEC = wGSF^{x}HC^{y}EC^{z}}$
Equation 3: $\boldsymbol{OPC = OPC\% \times TEC}$
Equation 4: $\boldsymbol{TPC = TEC + OPC}$

Similarly, Equation 5 is used to calculate the project duration in months:

Equation 5: $\boldsymbol{CD-1\ to\ CD-4\ duration\ (months) = aTPC^{b}}$

The CSPER-C model parameters are derived according to the zero bias minimum percent error (ZBMPE) method [5], which eliminates the tendency of power law-based models developed using common optimization techniques to overestimate their predictions.

Prediction Interval

To further instill confidence in and to give additional context to the CSPER-C model predictions, the benchmarking tool calculates a statistical prediction interval around the estimate. The methodology for calculating the prediction interval begins by linearizing the equations, as with the CSPER-C model; however, where the CSPER-C model parameters and the best-fit curve are determined using the ZBMPE method, the prediction interval width is calculated using the ordinary least squares (OLS) method in log space. The difference in methods amounts to a different choice of loss function: $\sum_i \left(y_i - f(x_i, \beta)\right)^2$ for OLS compared to $\sum_i \left(\frac{y_i - f(x_i,\beta)}{f(x_i,\beta)}\right)^2$ for ZBMPE. ZBMPE gives a better fit to the data than OLS in log space but using OLS it is possible to derive an expression for the prediction interval width analytically. This means it is possible to update the prediction interval automatically without using macros or manual optimization.

Cost Benchmarking Tool

To use the benchmarking tool, users provide data for their projects, including estimated cost (TPC, TEC, and OPC), facility information (GSF, HC, and EC), and predicted CD dates. Up to two projects can be added, each with a range of estimates (low, medium, high). The tool then generates a chart such as Figure 1.

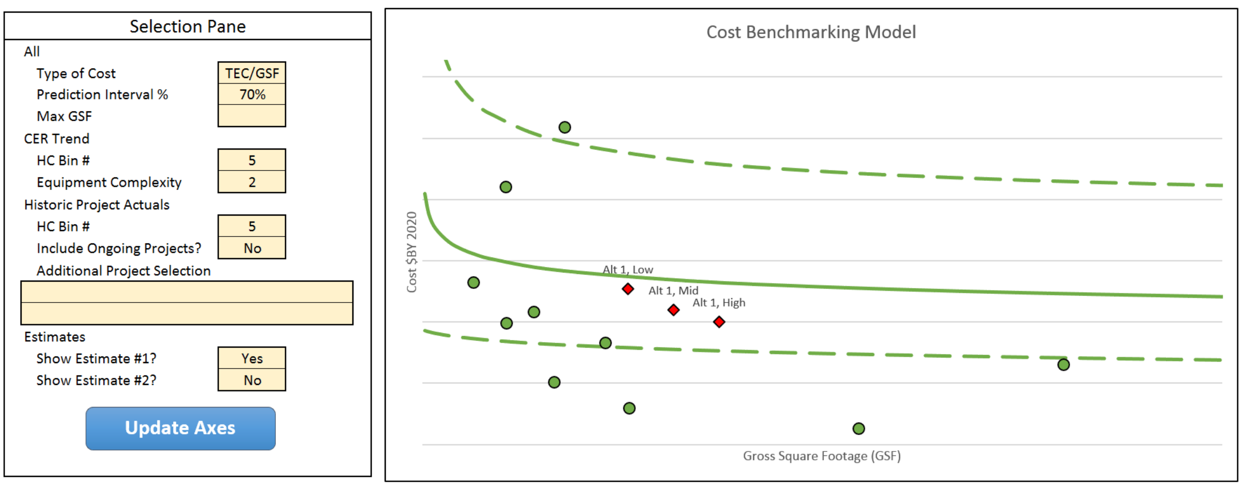

Figure 1–Example Output from the Cost Benchmarking Tool[1]

In Figure 1, the solid green trendline represents the CSPER-C cost estimates of projects with the same levels of HC and EC as the given projects. The two surrounding dashed curves represent the lower and upper bounds of the estimates according to the user defined prediction interval.

The red diamonds, which correspond to a low, medium, and high estimate for the project of interest, can be compared against the CSPER-C trendline as well as historic actuals from PARS, marked by green circles. The chart supports several user options:

- **All**
    - *Type of Cost*: Allows the user to choose which cost to display on the y-axis out of the following options: TEC, TEC per GSF (TEC/GSF), TPC, and TPC per GSF (TPC/GSF).
    - *Prediction Interval %:* Determines the confidence level of the CSPER-C prediction interval.
    - *Max GSF*: Determines the rightmost extent of the x-axis.
- **CER Trend**
    - *HC Bin #*: Sets the hazard category parameter for the CSPER-C trendline.
    - *Equipment Complexity:* Same as *HC Bin #*, but for EC.

[1] All figures created using Microsoft Excel 2013

- **Historic Project Actuals**
  - *HC Bin #*: Display historic project actuals belonging to the hazard category bin selected.
  - *Include Ongoing Projects:* Up-to-date cost estimates are available for several high-profile projects that have not yet reached CD-4. The user can toggle whether they are displayed on the chart.
  - *Additional Project Selection*: If the user would like to compare his or her project to a specific historic project that is not already shown, the user can select up to two from a dropdown list.

Schedule Benchmarking Tool

The schedule tool (Figure 2) is similar to the cost tool, but with fewer options. The user can still choose which estimates to show, which historical projects to compare against, and the prediction interval confidence level. Note that cost, which was the dependent variable in the cost benchmarking tool, is now the independent variable.

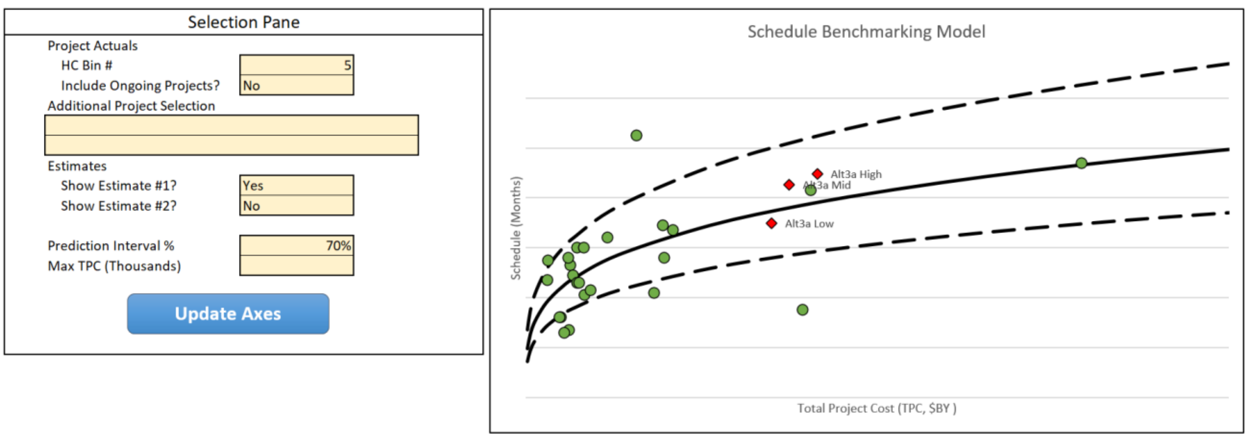

Figure 2–Example Output from the Schedule Benchmarking Tool

Results

In a recent NNSA capital acquisition project, the program received four separate cost estimates between the CD-0 phase and the conceptual design phase. Each estimate was more expensive than the previous, by a significant margin. Due to a large jump in the cost estimate from the initial CD-0 estimate, PA&E was asked to benchmark the conceptual design estimate and identify the source of increased costs.

PA&E used the benchmarking tool to understand the nature of the discrepancies as well as to present the results to stakeholders. As a result of the reconciliation process, it was discovered that the scope of the project had increased from the early estimates and that some portions that had been inadvertently double counted. These differences, which are clearly depicted in Figure 3 and **Figure 4**, are as follows:

1. The initial CD-0 estimate was derived from a parametric model.
2. An independent analysis of alternatives (AoA) estimated a larger facility size and leveraged information from an analogous facility to derive a second cost estimate. The additional low-cost space increases the project's overall TPC but decreases the cost per GSF.
3. The project conceptual design included plans for an additional building, larger overall facility size, and additional site improvements that were not covered by the CD-0 estimate or the AoA.
4. An independent cost estimating team added additional indirect costs and contingency funds to the original conceptual design estimate.

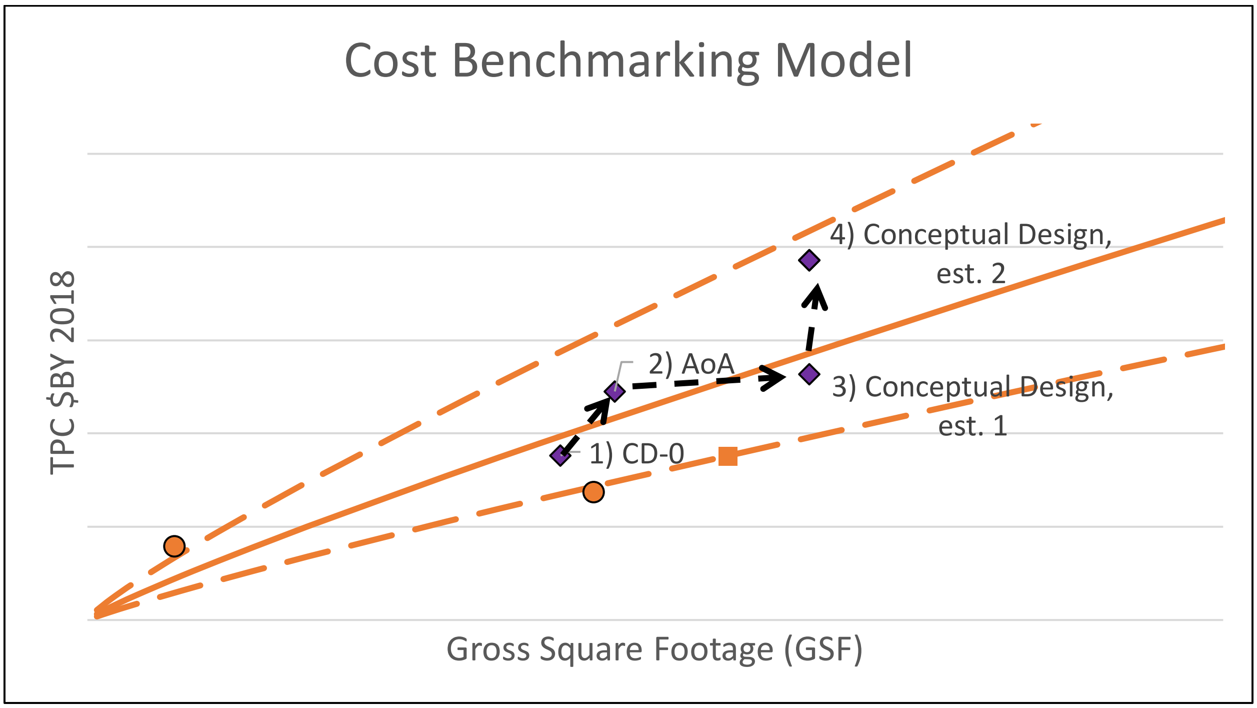

Figure 3–Four Different Cost Estimates for a Recent NNSA Project, Depicted Using the Benchmarking Tool

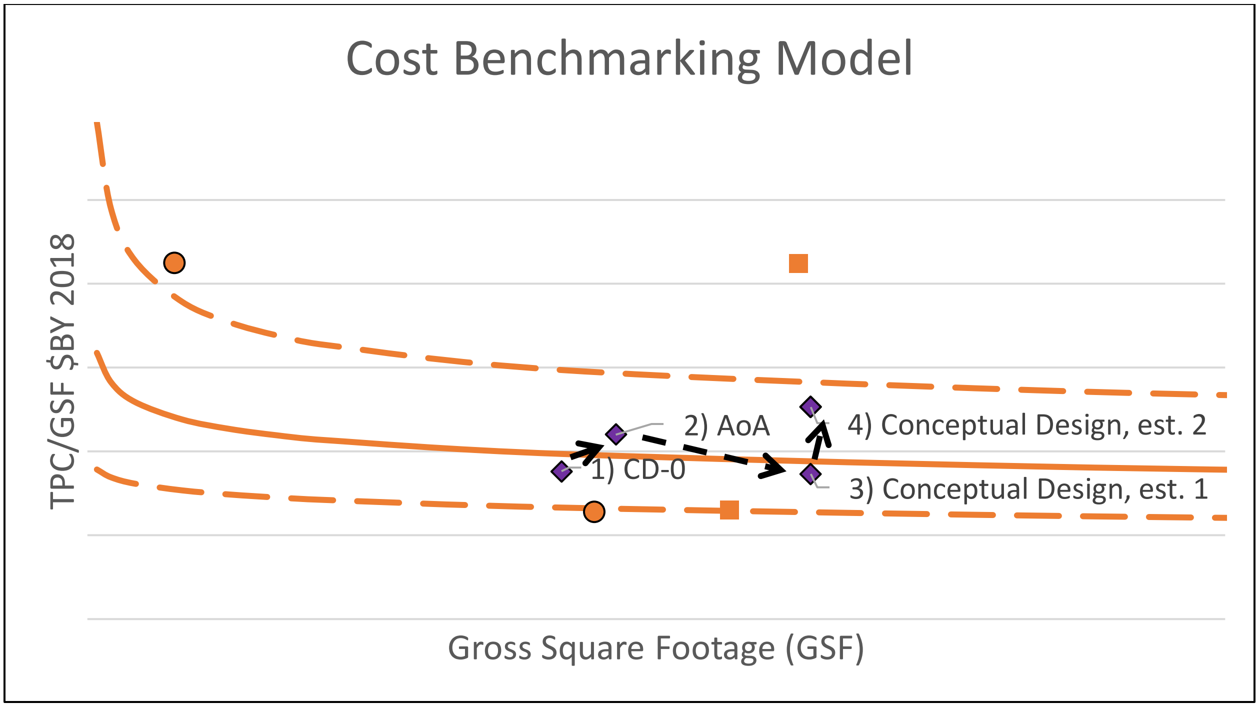

Figure 4–Same as Figure 3, Except Showing TPC/GSF Instead of TPC

The benchmark tool identified the differences in both scope and cost over time, and helped focus the team on clear cost drivers from CD-0 to conceptual design. The comparison with the CER showed that the cost had shifted upwards over time from a combination of scope and cost increases. The scope increases and contingency amounts were identified for the program manager to review, modify, and approve. As a result, the program rejected some scope growth and affirmatively accepted the remaining new scope and cost.

Conclusion

The benchmarking tool developed by PA&E enables NNSA to rapidly assess a proposed cost or schedule estimate for reasonableness. Users can easily compare cost and schedule estimates with historic project actuals and parametric model predictions, adding an important tool to the agency's cost estimating capabilities.

Looking ahead, the PA&E office anticipates additional features such as data from similar projects at other Federal agencies, a convenient quad chart for displaying all information simultaneously, and/or the possible creation of a standalone applet that does not require Microsoft Excel.

References

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