The Cost of Bureaucracy

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Abstract

The National Nuclear Security Administration (NNSA) has separate management methods for capital construction projects, with enhanced requirements for larger projects. Naively, one might expect that enhanced requirements might increase program management costs and possibly impact schedule. However, as the enhanced management requirements are tied to a dollar threshold, comparing costs is not straightforward. In this paper, we share results of a regression analysis that developed separate cost and schedule regressions for each management method and a comparison of the costs by management type.

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Introduction

The National Nuclear Security Administration (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. The Office of Programming, Analysis, and Evaluation (PA&E) supports the NNSA mission by providing analytical services such as cost analyses to aid informed planning and decision-making.

To fulfill its mission, NNSA owns and operates a variety of facilities in several locations across the country. Some of these facilities date back to the Manhattan Project, while others are currently under construction or planned for future construction. When planning and budgeting for future facilities, NNSA must balance the competing needs for efficiency on the one hand with transparency and accountability on the other. To do this, NNSA has separate management methods for capital construction projects, with enhanced requirements for larger, more expensive projects.

Large NNSA construction projects over $50 million must be individually submitted to and approved by Congress to receive funding. These projects are required to follow an enhanced project management process, which dictates the division of funding and specific milestones throughout the project's duration. Projects under the $50 million threshold are funded internally by the NNSA Office of Infrastructure and have relatively less guidance and fewer requirements surrounding the project's development. This paper seeks to compare the cost and schedules for these two types of projects to determine if the additional requirements of the enhanced project management process significantly increase the cost and schedule.

Methodology

Across DOE, project costs for large construction projects are divided into two buckets:

- Total estimated costs (TECs), which include design, engineering, and construction costs
- Other project costs (OPCs), which include project management, policy compliance, management reserve and contingency, and other overhead costs

The summation of TECs and OPCs constitutes total project cost (TPC).

For the purposes of this analysis, PA&E focused on TECs since OPCs are clearly broken out for projects with enhanced scrutiny requirements, but do not exist for internally-funded projects with standard scrutiny requirements. OPCs are generally around 12% of the total cost of enhanced-scrutiny projects, so if we included OPCs in this analysis, we would see that the TPC for enhanced-scrutiny projects is slightly larger than the TPC for standard projects.

The comparison of these project types depends on model form. For instance, the simplest model form uses a single binary variable to predict TEC, specifically the project management (PM) method, i.e., either enhanced or standard. The corresponding model selects the mean value from each dataset, and the p-value of this predictor variable is significant. This is to be expected since there is a policy-mandated cost threshold of $50 million separating the two datasets. However, PA&E is not simply interested in the difference in cost or schedule as an absolute value, and instead is analyzing if cost and schedule differs once the other contributing drivers have been accounted for.

Data for Projects with Enhanced Requirements

To evaluate the costs of enhanced-scrutiny projects, PA&E collected and analyzed data on 126 historical NNSA projects using the following sources:

- Project Assessment and Reporting System II (PARS) [2]
- Facilities Information Management System (FIMS) [3]
- Annual Congressional Budget Request

These sources all provide a variety of information. Specifically, PARS includes cost and schedule data, FIMS includes property information – such as building size, location, and facility hazard category – and the Annual Congressional Budget Requests provide information on historic project costs. The combination of these data sources provides a holistic overview of each historical project.

By focusing only on projects for which complete and usable cost information is available, the dataset was reduced to 17 projects for analysis. To enable a comparison of projects executed in different timeframes, the data was normalized by converting costs into constant base year 2018 dollars using the *Engineering News-Record* Construction Cost Index. A locality factor was then applied to these costs based on RSMeans [4] to eliminate any difference in cost due to location.

To analyze a project's duration from the start to end date, PA&E reviewed the same historical dataset of 126 projects and found that 58 projects had complete and accurate data to enable schedule analysis. Projects were again normalized to a constant base year to enable comparison. The range of project data is shown in Table 1.

Table 1: Enhanced Scrutiny Project Range

	Range
Gross Square Footage (GSF) Added	9,260 ft^2 – 696,968 ft^2
Total Estimated Cost (BY21$)	$17,574,370 – $6,000,540,472
Hazard Category	1. Nuclear Hazard Category 2/3 2. Chemical & High Explosive 3. Radiological 4. Nanoparticle & Beryllium 5. Biosafety Levels 1/2 & No Hazard
Equipment Complexity	1. Custom scientific or production equipment 2. Off-the-shelf industrial or scientific equipment 3. Office or light laboratory equipment

Data for Projects with Standard Requirements

Data on standard NNSA projects was collected from G2, a platform which integrates NNSA project information, including scopes, schedules, and budgets. To evaluate the cost of these projects, PA&E narrowed down the total dataset of 312 standard NNSA projects by focusing only on projects that fell in the "new footprint" category, meaning new facility construction versus existing facility modification. Incomplete projects or those missing data were excluded, resulting in 13 projects for analysis.

To evaluate the duration of standard projects, PA&E expanded the dataset to include both new and modification projects. Incomplete projects were again excluded from the dataset, resulting in 143 projects with complete and accurate data for analysis. These two datasets were also normalized to a constant base year and adjusted for location costs for the purposes of this analysis.

Table 2: Standard Scrutiny Project Range

	Range
Gross Square Footage (GSF) Added	80 ft^2 – 28,736 ft^2
Total Estimated Cost (BY21$)	$233,498 – $17,313,426
Hazard Category	1. Nuclear Hazard Category 2/3 2. Chemical & High Explosive 3. Radiological 4. Nanoparticle & Beryllium 5. Biosafety Levels 1/2 & No Hazard
Equipment Complexity	1. - 2. Off-the-shelf industrial or scientific equipment 3. Office or light laboratory equipment

Comparing Acquisition Strategies

<u>Cost Comparison</u>

To begin, PA&E identified three key variables that drive TEC:

- Size of the newly constructed facility measured in gross square footage (GSF)
- Projected hazard category (HC) rating of the facility, rated on a scale from 1-5, where 1 represents a high hazard facility and 5 represents a low hazard facility
- Complexity of equipment (EC) that will be installed in the facility, rated on a scale from 1-3, where 1 represents high and 3 represents low equipment complexity

Project costs for the two different project types were compared visually across these three variables in both log-space and unit-space, as shown in Figures 1 - 6, where the red points represent enhanced-scrutiny projects, and the blue points represent standard projects.

Figure 1: TEC vs. GSF

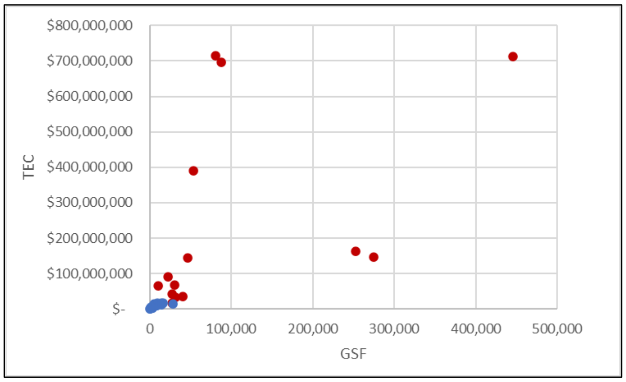


Figure 2: Log of TEC vs. Log of GSF

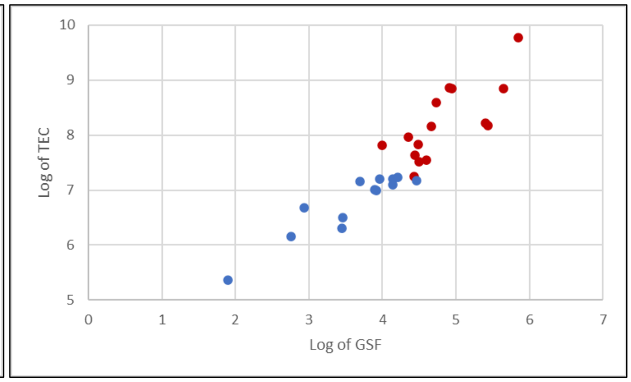


Figure 3: TEC vs. Hazard Category

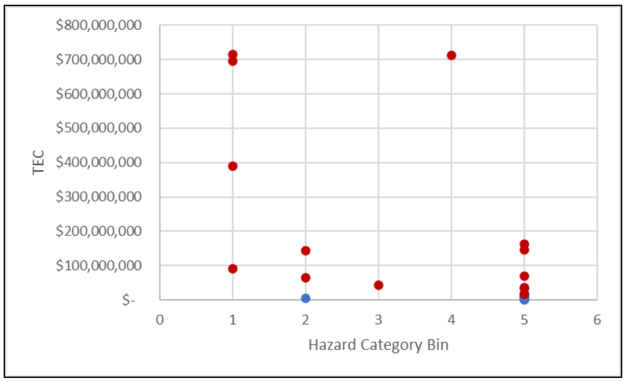


Figure 4: Log of TEC vs. Hazard Category

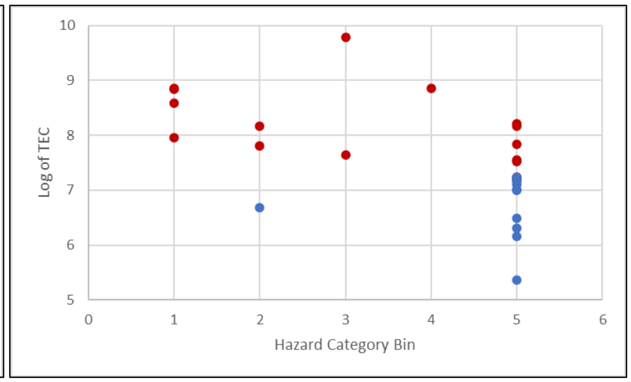


Figure 5: TEC vs. Equipment Complexity

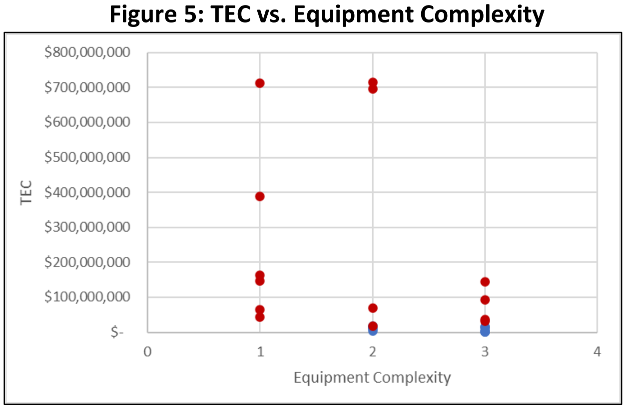
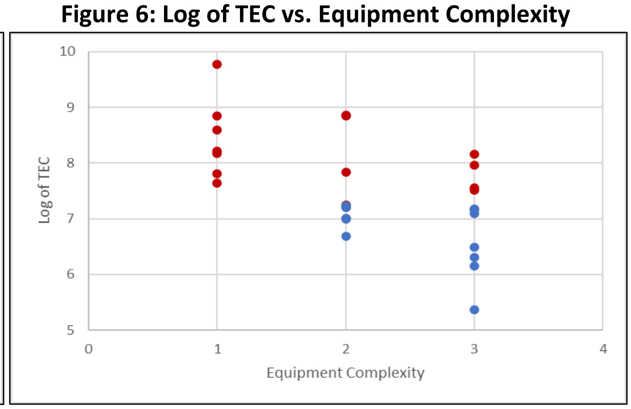


Figure 6: Log of TEC vs. Equipment Complexity



Viewed qualitatively in log-space, enhanced-scrutiny projects appear to follow a natural-looking linear extension of standard projects to higher cost ranges.

PA&E combined all capital construction cost data into a single dataset and, after trialing several model forms, ultimately settled on the following model form:

$$\textbf{Equation 1:} \quad \boldsymbol{log(TEC) = \alpha + \beta * log(GSF) + \gamma * HC + \delta * EC}$$

The crux of PA&E's cost comparison was to introduce an additional categorical variable, PM, which represents the project management method that was used for each project:

$$PM = \begin{cases} 0 \; if \; enhanced \; scrutiny \\ 1 \; if \; standard \; scrutiny \end{cases}$$

This was handled as a dummy variable, as shown in Equation 2:

Equation 2: $$log(TEC) = \frac{\alpha_1+\beta_1*\log(GSF)+\gamma_1*HC+\delta_1*EC+}{PM*(\alpha_2+\beta_2*\log(GSF)+\gamma_2*HC+\delta_2*EC)}$$

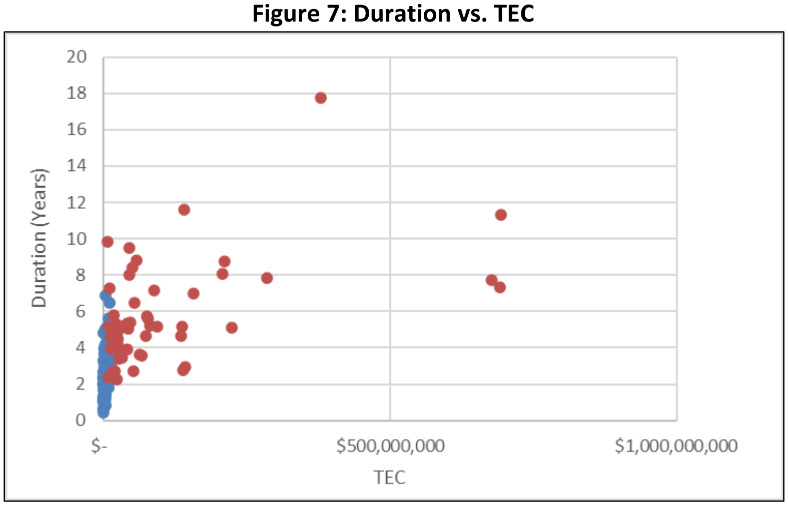
PA&E performed a regression on the coefficient values deterministically using log-space ordinary least squares. The main statistical metric analyzed through this process was the p-value of the coefficients, which indicates if the relationship is statistically significant. PA&E set a significance level of 95%, and therefore any coefficients with a p-value below 0.05 can be considered significant. Terms were subsequently dropped from Equation 2 based on their regression p-values, starting with the term that had the highest p-value above 0.05. This procedure was repeated systematically, dropping one coefficient at a time, until all remaining coefficients had p-values below the 0.05 threshold. If, after performing this procedure, no coefficients tied to the PM variable were found to be significant, then PA&E could conclude that PM is not a meaningful predictor of TEC.

To convert from a log-space prediction $\hat{y}_i$ to an actual dollar amount $\widehat{TEC}_i$, the value $10^{\hat{y}_i}$ is multiplied by a zero-bias factor: $\widehat{TEC}_i = ZBF \cdot 10^{\hat{y}_i}$. The purpose of a zero-bias factor is to correct for the tendency of power law-based models to overestimate [9]. The zero-bias factor is equal to $ZBF = \sum_{i=1}^{n} \frac{1}{n} 10^{y_i - \hat{y}_i}$ where y_i is the actual value of $\log(TEC_i)$ and $\hat{y}_i$ is the prediction.

<u>Schedule Comparison</u>

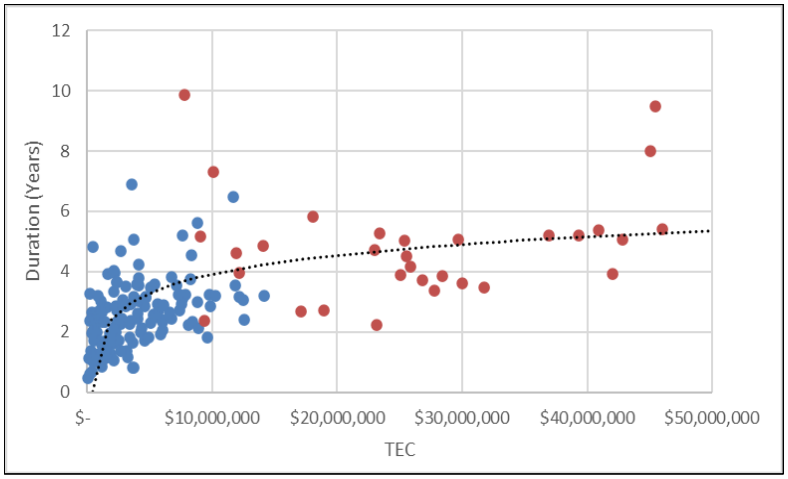
Similar to the cost comparison, PA&E began by visualizing enhanced-scrutiny project schedules compared to standard project schedules, shown in Figure 7.

Figure 7: Duration vs. TEC



Narrowing in on projects under $50 million allows one to better visualize the transition between standard and enhanced-scrutiny projects, shown in Figure 8.

Figure 8: Duration vs. TEC under $50M



It is evident that the two project types overlap around the $7 million to $15 million range. Therefore, to develop a model demonstrating the difference between the enhanced-scrutiny and standard construction projects, PA&E used a subset of 33 data points that fell in this range. When zooming in on this range, the data seems to have a linear relationship with increasing TEC, almost resembling a flat line. We can further analyze this relationship by developing a linear regression using the following equation:

Equation 3: $$\boldsymbol{Duration = \alpha + \beta * TEC}$$

As with the cost comparison, PA&E added to this equation by introducing the project management method as a dummy variable, PM:

Equation 4: $$\boldsymbol{Duration = \alpha + \beta * TEC + \gamma * PM + \delta * PM * TEC}$$

PA&E performed the same methodology detailed above for the cost comparison, dropping any coefficients with a p-value above 0.05 until all remaining coefficients were statistically significant. If this process resulted in dropping both coefficients tied to the PM variable, it could be concluded that the project management method does not influence project duration.

Results

Cost Comparison

At the conclusion of this regression procedure, PA&E was left with four significant coefficients: $\alpha_1, \beta_1, \gamma_1, \delta_1$, none of which are associated with the PM variable. Therefore, project management method was not considered a good predictor of TEC for NNSA construction projects.

It is interesting to compare the performance of this model against the PM method-specific models, where one model was developed using only enhanced-scrutiny projects, and another model was developed using only standard projects. As shown in Table 3, based on the log-space sum of squared estimate of errors (SSE, also known as the residual sum of squares), the combined model, which includes both standard and enhanced scrutiny projects, is a better predictor of standard construction costs than the standard construction-specific model (0.273 vs. 0.301). It is also evident that the combined model performs almost as well for enhanced-scrutiny projects as the enhanced scrutiny-specific model (0.369 vs. 0.368).

Additional statistical metrics that are commonly used to evaluate a regression are the coefficient of variation (CV) and the R-squared. The CV describes the relative proximity of the predicted values to the actual values, where a smaller number represents a more accurate model. The R-squared describes how much of the variance in the dependent variable can be described by the variance in the independent variables, where a higher number represents a more accurate model. Both statistics also demonstrates that the combined model performs better than either of the two PM method-specific model, as shown in Table 3.

Table 3: Cost Model Performance

Model	SSE – Enhanced Scrutiny Projects	SSE – Standard Scrutiny Projects	R^2 – All Projects	CV – All Projects
Combined	0.369	0.273	0.939	0.020
Enhanced Scrutiny	0.368	-	0.882	0.046
Standard Scrutiny	-	0.301	0.920	0.023

Since the combined model performs roughly the same or better than the PM method-specific models, PA&E is unable to detect an impact to TEC related to project management method. Therefore, when given two identical projects, one subject to enhanced scrutiny and one not, both projects are expected to have generally the same TECs.

Schedule Comparison

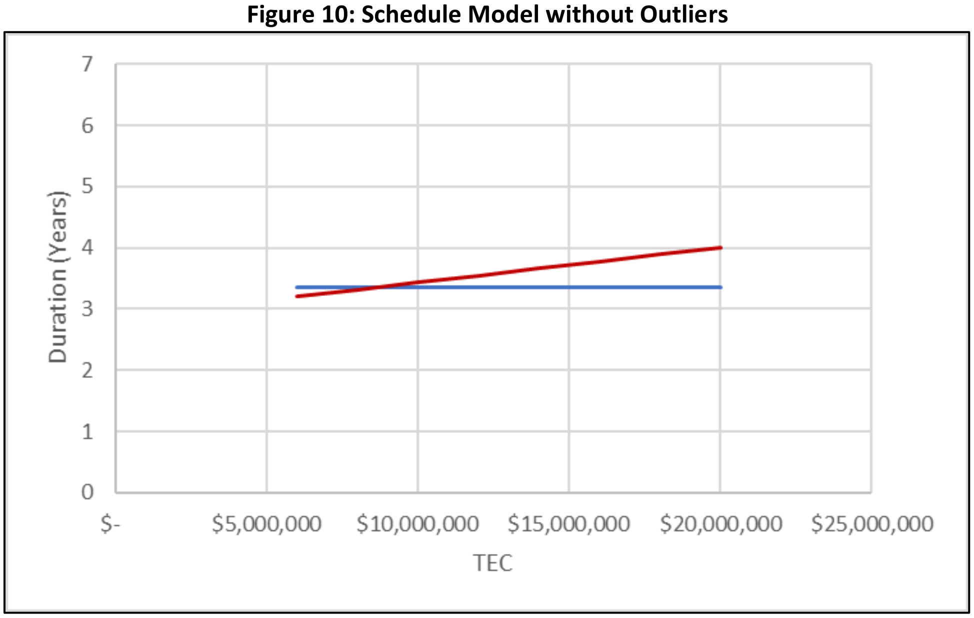
After dropping insignificant variables, PA&E was left with the PM variable and the interaction between PM and TEC. This model is shown in Figure 9, with the red line representing enhanced scrutiny projects.

Figure 9: Schedule Model

This model is counterintuitive, as it shows for enhanced scrutiny projects, as TEC increases, project duration decreases. PA&E then performed influential data point analysis to determine if one or two data points were driving this decreasing relationship.

Using Cook's Distance, two enhanced scrutiny projects were identified as high-influence points. These two projects were subprojects of a larger project, which caused them to have a low cost, but long duration. We therefore had reason to remove these projects, which caused the pattern to change. The new model demonstrates that for enhanced scrutiny projects, as TEC increases, duration increases as well, shown in Figure 10.

Figure 10: Schedule Model without Outliers



While this model behaves more intuitively, it is important to recognize that none of the coefficients are considered statistically significant, and therefore PA&E has low confidence in this model. Further, this model produced an R-squared of 0.022, meaning only 2.2% of the variation in schedule can be explained by the PM method and the interaction between PM method and TEC. PA&E therefore concludes that in most cases, project duration is independent of management method. However, based on the data, PA&E cautions that there is a small (6-7%) risk of enhanced-scrutiny projects taking significantly longer than expected.

Conclusion

PA&E's analysis has shown that there are almost no differences between the total estimated cost and total duration of NNSA projects which are subject to enhanced scrutiny and those which aren't. It is important to recognize that this analysis excludes OPCs, as these are not typically tracked on a project-by-project basis for standard construction. Looking ahead, PA&E would like to increase the fidelity of the combined cost model using advanced techniques, such as unsupervised clustering to identify additional cost drivers and data imputation to augment the dataset with existing incomplete data. It is possible that increasing the fidelity of the model will cause differences between PM methods to emerge which were not visible at the current level of detail.

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