Early-Stage Cost Growth CER Development for NNSA's Line-item Acquisition Projects

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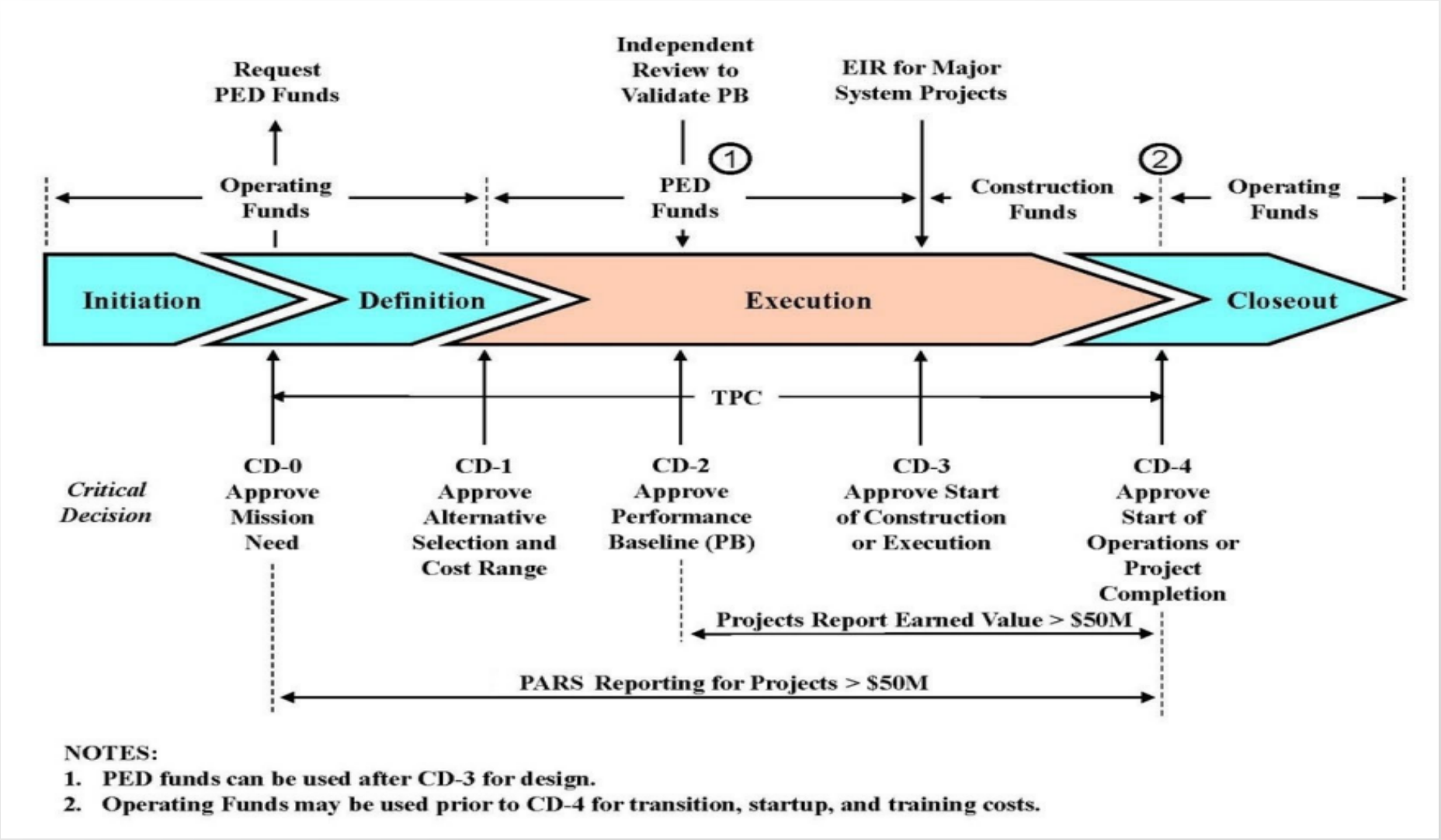
BLUF

- Scope: The National Nuclear Security Administration's (NNSA) line-item acquisition projects have been experiencing early-stage cost estimate growth. To quantify this growth, the NNSA's Office of Programming, Analysis, and Evaluation (PA&E) developed an early-stage cost estimating relationship (CER) for new construction projects.

- Methodology: PA&E collected scope and cost data at the Analysis of Alternatives (AoA) stage along with actual costs at project completion (for completed projects) and updated cost estimates (for ongoing projects). Most projects selected for this analysis have complete AoA data packages and achieved Critical Decision (CD)-0 after FY00.

- Final Results: Developed CER models to estimate cost growth based on an early-stage planned scope: simplified to estimated facility size and high-level safety, and equipment needs.

NNSA's Line-Item Acquisition Process



NOTES:
1. PED funds can be used after CD-3 for design.
2. Operating Funds may be used prior to CD-4 for transition, startup, and training costs.

Background

- NNSA has experienced early-stage cost growth with historic and ongoing construction projects (experiencing **1x-6x** cost growth from initial concept through completion)

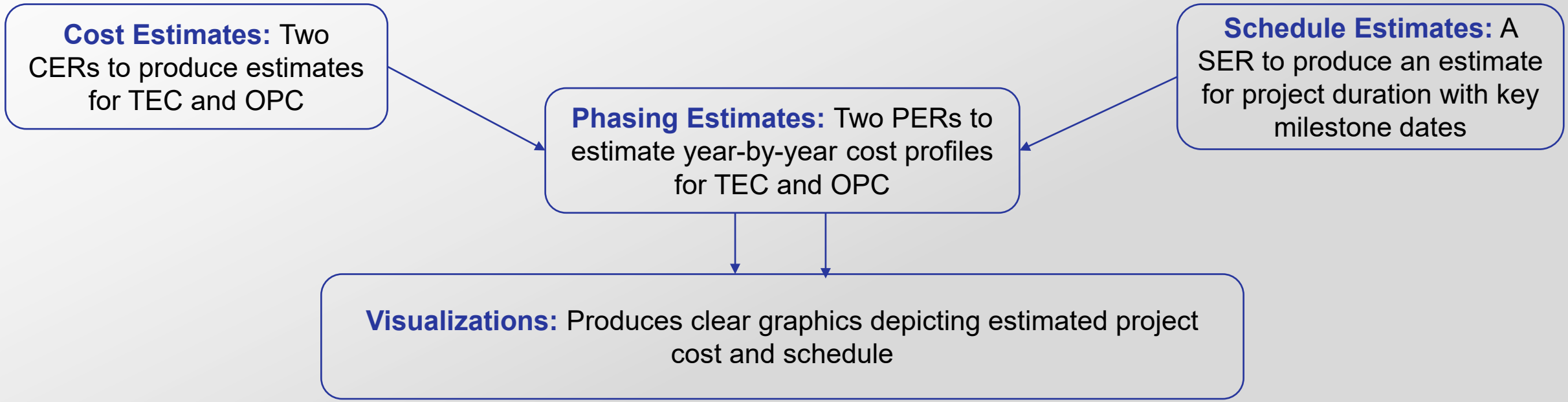
- Current models are based on actual cost of finalized construction projects
  - Modeling **actual** cost as a function of **actual** scope
  - Benchmarks actual projects well, but at early stages consistently underestimates

- Issue: Early-stage optimism bias (**missed scope**, scope creep)
  - NNSA has a consistent group of national labs, plants, and sites it operates

- For this model, a CER was built for costs based on **estimated** scope at the **AoA stage** (Pre CD-1/Class V-IV)

PA&E's Line-item Acquisition Model (CSPER-C)

- PA&E's Cost, Schedule, and Phasing Estimating Relationship-Construction (CSPER-C) model is a traceable, unbiased, and user-friendly methodology that calculates the cost, schedule, and phasing estimates for construction projects based on **historical project data (i.e., actuals)**
- Model inputs include location & proposed dates, GSF, hazard category (HC), equipment complexity (EC), preferred confidence level, and preferred base year



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F. Gebeyehu-Houston; C. Loelius; C. Fitzpatrick; D. Amin; J. Anderson; C. Ballowe; J. Beck; C. Daughters; C. Jones; A. Levinson; C. Massey; and M. Proveaux, "Planning the Future: Estimating U.S. Nuclear Stockpile Infrastructure Costs," *AACE International Cost Engineering*, 2019

Methodology and Assumptions for Early-stage CER Development: CSPER-Growth (CSPER-G)

- Objective: Relate final costs to scope at project initiation (CD-0)
- Problem: Few projects have both final costs and well documented early scope assessments
  - Finished projects initiated one or more decades ago
- Solution: Development of the early-stage CER used the CSPER-C model framework
  - AoA to CD-2/3 or CD-1 regressions were developed first: **AoA to CD-X regressions**
- All cost estimate data normalized by locality and into F23 $
  - For all cost estimates where it was unclear whether the estimate was in base year or then-year (TY), assumed the estimate was in TY $ for normalization purposes
- Total project cost (TPC) and GSF alternative estimates were selected based on the approved alternative documented in the CD-1 final report
- Dependent variables analyzed
  - **CD-4 actual cost (completed projects) or updated TPC estimate (ongoing projects)**
  - CD-1 GSF
  - Cost Growth Factor
    - CD-4 TPC (or updated TPC estimate) divided by AoA TPC
- Independent variables analyzed
  - **AoA GSF**
  - AoA TPC
  - CD-1 TPC
  - **Equipment Complexity**
  - **Hazard Category**

Dataset

- Type of Data Collected
  - TPC actuals or estimates
  - HC quantified into 5 bins (1=highest, 5=lowest)
  - EC quantified into 4 bins (1=very high, 4=low)
  - GSF estimate

- Based on the data needs, 12 projects were selected for the regression model
  - All projects outside of Savannah River Plutonium Processing Facility (SRPPF) are new construction projects (i.e., new GSF is added)
  - Exclusions:
    - The Digital Infrastructure Capability Enhancement project was not included in the dataset since it was difficult to capture the project's high equipment density (the project has a very high $/GSF when compared to other NNSA no hazard facilities with low/medium EC)

NNSA Projects Selected for Analysis

Project Name	Current CD Milestone
Material Staging Facility (MSF)*	CD-0
High Explosives Synthesis Formulation and Production Capability (HESFP)	CD-1
Tritium Finishing Facility (TFF)	CD-1
Power Source Capability (PSC)	CD-1
Lithium Processing Facility (LPF)	CD-1
Plutonium Modular Approach (PMA) / Savannah River Plutonium Processing Facility (SRPPF) **	CD-1
Uranium Processing Facility (UPF)***	CD-2/3
High Explosive Science and Engineering (HESE)	CD-2/3
NNSA Albuquerque Complex Project	CD-4
High Explosive Pressing Facility (HEPF) ****	CD-4
Transuranic (TRU) Waste Facility Project*****	CD-4
Y-12 Fire Station	CD-4

*MSF never went through the CD-1 approval process, but a conceptual design report (CDR) was developed, and the CD-1 total project cost (TPC) was extracted from it

**Alternative selected from the PMA AoA does not exactly match the SRPPF scope

***UPF AoA GSF was extracted from the FY12/FY13 project data sheets when the CD-1 Reaffirmation Alternative Analysis was completed

****HEPF alternatives analysis was only located on CDR, so data from that document was used to calculate AoA GSF

*****TRU Waste Facility Project did not have an AoA. CD-1 data used for the AoA GSF while CD-1 TPC was replaced by CD-4 TPC

Cost Drivers

- AoA GSF, EC, and HC were the three cost drivers selected to develop CERs

Bin	Equipment Complexity	Definition
1	Very High	Custom scientific and production equipment, including very complex gloveboxes
2	High	Custom scientific and production equipment
3	Medium	Off-the-shelf industrial or scientific equipment
4	Low	Office or light laboratory equipment

Bin	Hazard Category
1	Nuclear Facility Categories 2 and 3
2	Chemical Hazard Facility
3	Radiological Facility
4	Nanoparticle and Beryllium Facilities
5	Biosafety Level 1 and 2 Facilities and No Hazard

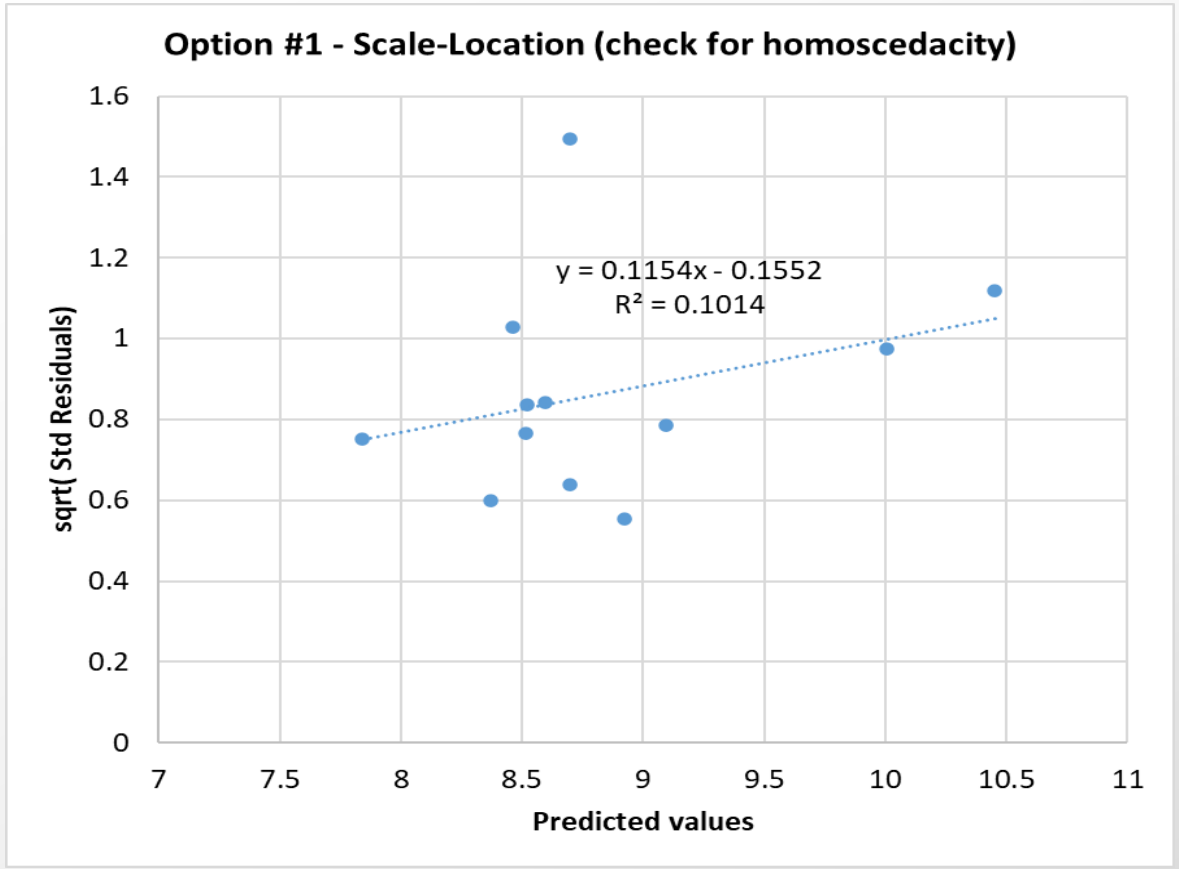
CER Modeling Options

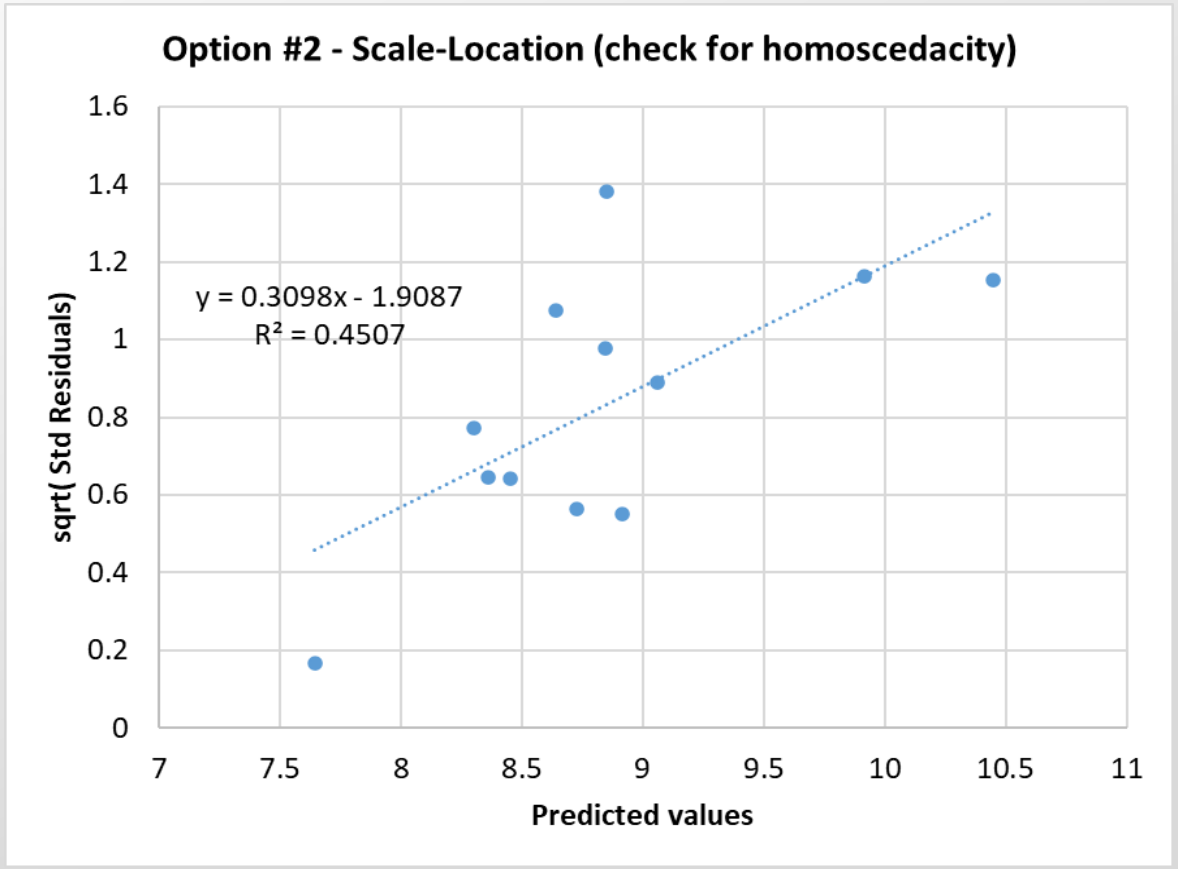
- 2 Model variations: log space vs log/unit space and SRPPF inclusion
  - The SRPPF cost estimate was based on a parametric model developed by PA&E

Option #	Option Description
1	All variables in log space
2	HC & EC in unit space while other variables are in log space
3	SRPPF removed; All variables in log space
4	SRPPF removed; HC & EC in unit space while other variables are in log space

- Options #2 and #4 did not pass statistical tests linear regression
- Regression was also developed using CSPER-C dataset to compare results with the early-stage CER (all variables converted to log space)
  - While early-stage CER model contained 4 bins for EC, the regression with CSPER-C data only included 3 bins since there are no “very high” EC projects in that dataset

Linear Regression Test (Option #1 vs Option #2)





Option #	Option Description
1	All variables in log space
2	HC & EC in unit space while other variables are in log space

All variables should be transformed to log space as outlined in Options #1 & #3 since the data proved to be heteroscedastic in Options #2 & #4

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Regression Results

All variables in log space; AoA GSF (upper range) and most recent TPC estimate or CD-4 actuals

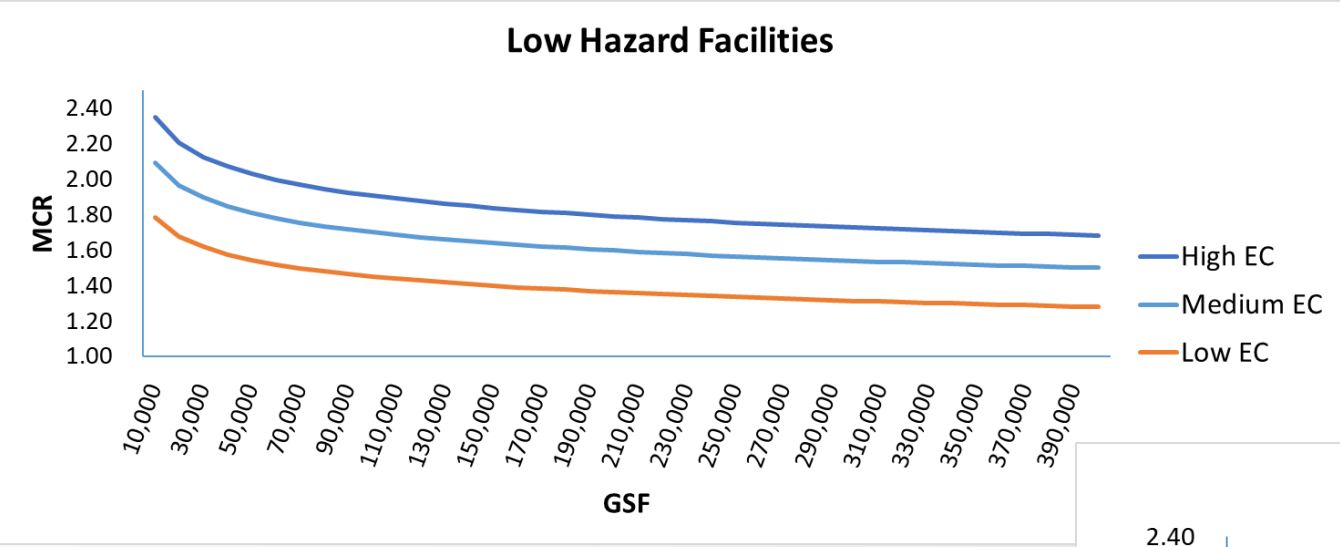
Option #	Intercept	Hazard Category	Equipment Complexity	AoA GSF	R Square
Early-stage CER #1	6.007	-1.028	-1.818	0.794	0.842
CSPER-C Data CER	4.766	-1.084	-0.898	0.884	0.895

All results are averaged between 10k to 400k GSF (10k intervals)

$$\text{Model Comparison Ratio (MCR)} = \frac{New\ Model\ TPC}{CSPER{-}C\ TPC}$$

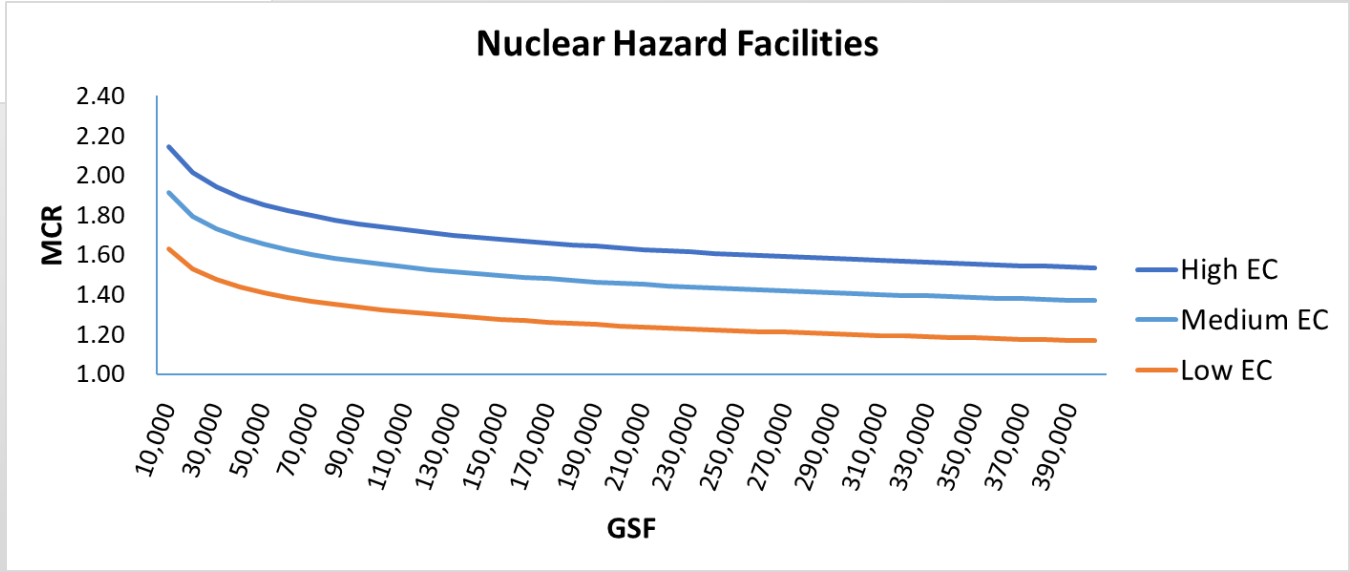
Option #	Nuclear Hazard & High EC Avg. MCR	Nuclear Hazard & Medium EC Avg. MCR	Nuclear Hazard & Low EC Avg. MCR	No Hazard & High EC Avg. MCR	No Hazard & Medium EC Avg. MCR	No Hazard & Low EC Avg. MCR
1	1.68	1.49	1.27	1.83	1.64	1.40

MCR Results



The cost difference of the CSPER-G model when compared to the CSPER-C like model tends to increase for higher ECs (~30% increase from high to low EC)

The cost difference of the CSPER-G model when compared to the CSPER-C like model tends to slightly decrease for higher HC facilities (~10% decrease from nuclear hazard to low hazard)



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Conclusion and Future Work

- Utilizing early-stage scope of a project to develop a CER may allow NNSA to more accurately capture the uncertainty surrounding an estimate, allowing estimators to handle some of the original optimism bias surrounding an estimate and lower some of the cost estimate growth experience at the CD-0/AoA stage

- The estimated costs modeled through the early-stage CER (estimated scope inputs) are **1.4x - 2.4x** larger than the estimates developed through the CSPER-C model (final scope inputs). The higher estimates of the CSPER-G model when compared to the CSPER-C like model tend to:
  - Increase for higher ECs (~30% increase from high to low EC)
  - Slightly decrease for higher HC facilities (~10% decrease from nuclear hazard to low hazard)

- Future Work
  - Continuously update the model with updated actuals.
  - Use model to benchmark potential early missed scope

Backups

Acronyms

AoA	Analysis of Alternatives
CD	Critical Decision
CER	Cost Estimating Relationship
CSPER-C	Cost, Schedule, and Phasing Estimating Relationship-Construction
DOE	Department of Energy
EC	Equipment Complexity
GSF	Gross Square Footage
HC	Hazard Category
HEPF	High Explosive Pressing Facility
HESE	High Explosive Science and Engineering
HESFP	High Explosives Synthesis Formulation and Production Capability
ICE	Independent Cost Estimate
ICR	Independent Cost Review
LPF	Lithium Processing Facility
MCR	Model Comparison Ratio
MSF	Material Staging Facility

NNSA	National Nuclear Security Administration
O	Order
OPC	Other Project Cost
PA&E	Programming, Analysis, and Evaluation
PCE	Program Cost Estimate
PER	Phasing Estimating Relationship
PMA	Plutonium Modular Approach
PSC	Power Source Capability
SER	Schedule Estimating Relationship
SRPPF	Savannah River Plutonium Processing Facility
TEC	Total Estimated Cost
TFF	Tritium Finishing Facility
TPC	Total Project Cost
TRU	Transuranic

(AoA to CD-1 CER) CER Modeling Options

- 3 Model variations: log space vs log/unit space, SRPPF inclusion, AoA GSF/CD-1 TPC average vs high

Option #	Option Description
1	All variables in log space; AoA GSF and CD-1 TPC average values used
2	HC & EC in unit space while other variables are in log space; AoA GSF and CD-1 TPC average values used
3	SRPPF removed; All variables in log space; AoA GSF and CD-1 TPC average values used
4	SRPPF removed; HC & EC in unit space while other variables are in log space; AoA GSF and CD-1 TPC average values used
5	All variables in log space; AoA GSF and CD-1 TPC upper ranges used
6	HC & EC in unit space while other variables are in log space; AoA GSF and CD-1 TPC upper ranges used
7	SRPPF removed; All variables in log space; AoA GSF and CD-1 TPC upper ranges used
8	SRPPF removed; HC & EC in unit space while other variables are in log space; AoA GSF and CD-1 TPC upper ranges used

(AoA to CD-1 CER) CER Options Summary (Constants & Outputs)

Option #	Intercept	Hazard Category	Equipment Complexity	AoA GSF	R Square
1	5.871	-0.817	-1.532	0.767	0.823
2	5.639	-0.146	-0.305	0.887	0.837
3	5.563	-0.832	-1.186	0.794	0.770
4	5.392	-0.147	-0.235	0.888	0.805
5	5.792	-0.878	-1.543	0.800	0.826
6	5.565	-0.158	-0.307	0.921	0.840
7	5.465	-0.895	-1.187	0.830	0.775
8	5.293	-0.159	-0.234	0.926	0.810

(AoA to CD-1 CER) Model Results Compared with CSPER-C Data Regression

- All results are averaged between 10k to 400k GSF (10k intervals)

$$\text{Model Comparison Ratio (MCR)} = \frac{New\ Model\ TPC\ at\ CD{-}1}{CSPER{-}C\ TPC}$$

Option #	Nuclear Hazard & High EC Avg. MCR	Nuclear Hazard & Medium EC Avg. MCR	Nuclear Hazard & Low EC Avg. MCR	No Hazard & High EC Avg. MCR	No Hazard & Medium EC Avg. MCR	No Hazard & Low EC Avg. MCR
1	1.57	1.62	1.52	1.68	1.68	1.55
4	1.54	1.72	1.47	1.58	1.72	1.44
5	1.92	1.97	1.85	1.86	1.85	1.71
7	1.65	1.96	2.04	1.56	1.80	1.84
8	1.87	2.10	1.80	1.73	1.88	1.57