# Foundational Cost Models

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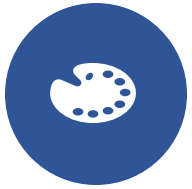
# Outline



STATE OF THE ART

RESEARCH OBJECTIVE

DATA OVERVIEW

CER REPOSITORY

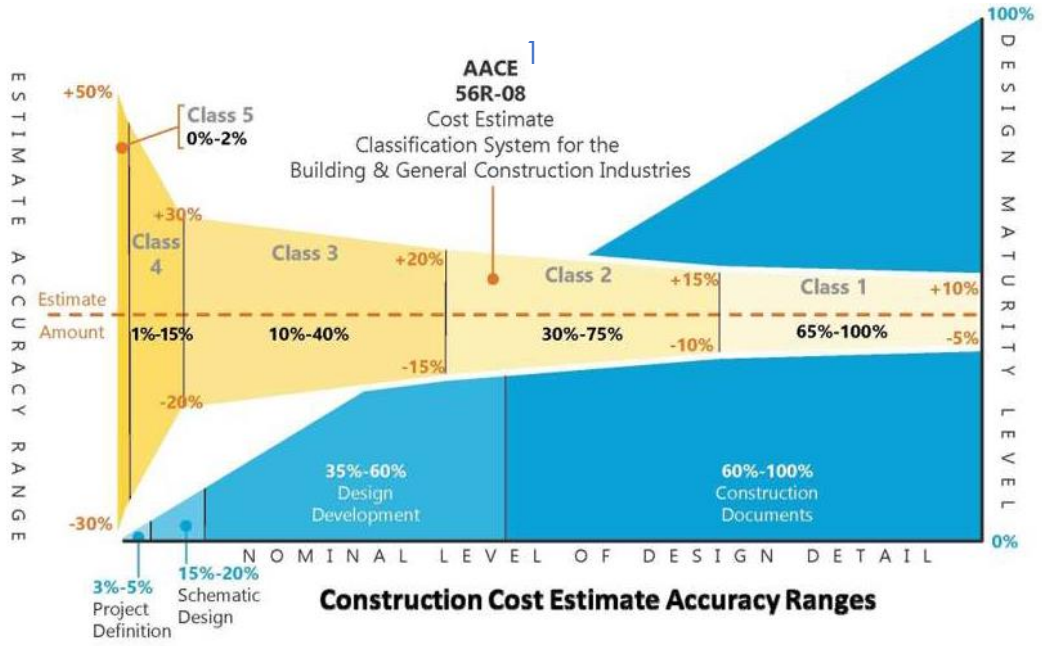
LABOR APPROXIMATION ANALYSIS

UNCERTAINTY ANALYSIS

RECOMMENDATIONS

# State of the Art

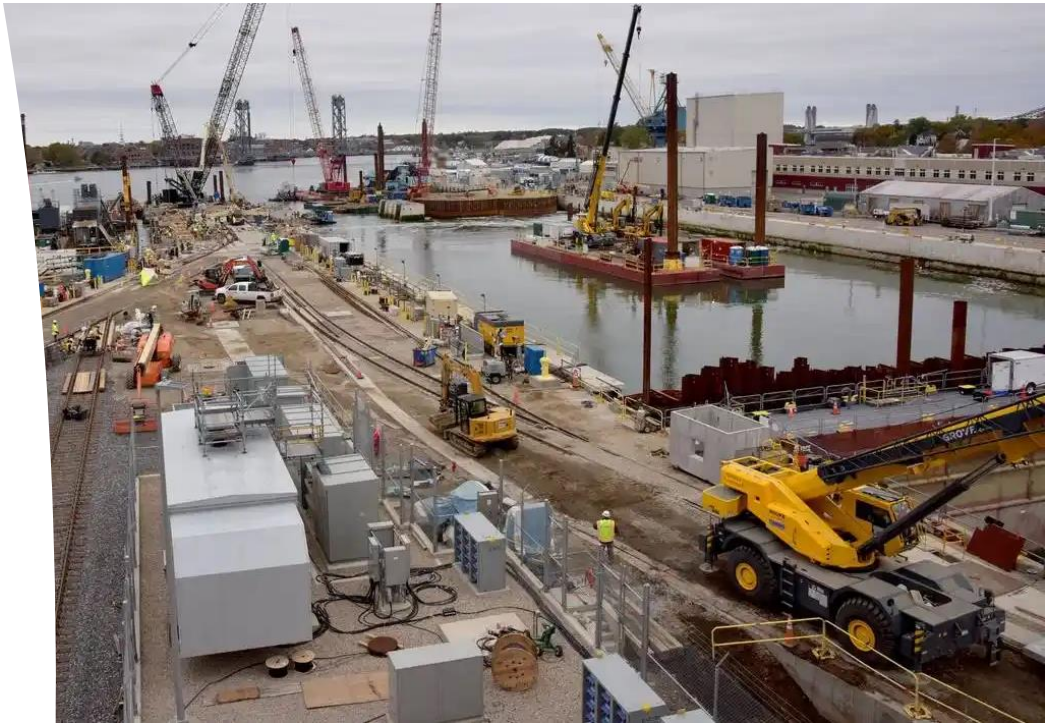
1. Low-level equipment, material, and labor cost data is difficult to find or expensive to acquire, square footage is the default
2. Available data is already totaled
3. Little uncertainty distribution guidance, so estimators rely on "Contingency Factors"



# Research Objectives

Improve the accuracy of DOD construction estimates and expedite them by…

1. Compiling a repository of unit cost relationships
2. Exploring ways to extract time-dependent costs (especially labor)
3. Identifying uncertainty distributions to apply



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# Data Sources

1. Army Corps of Engineers' Programming and Execution (PAX) System Newsletter2
2. Army Corps of Engineers' Engineering Pamphlet (EP) 1110-1-83
3. NELO PMO-Commissioned Studies
4. Internet Research and quotes
5. Craftsman National Electrical Estimator 20224
6. OASD(S) Military Construction *Status Reports* to Congress[5]*

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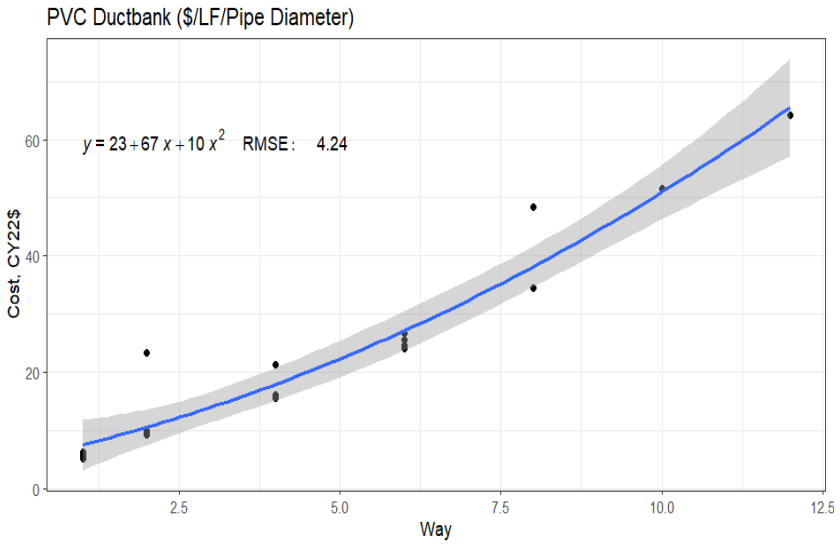
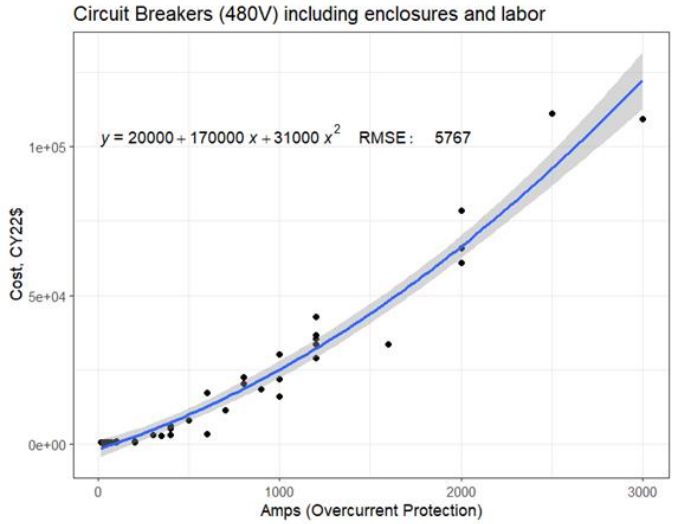
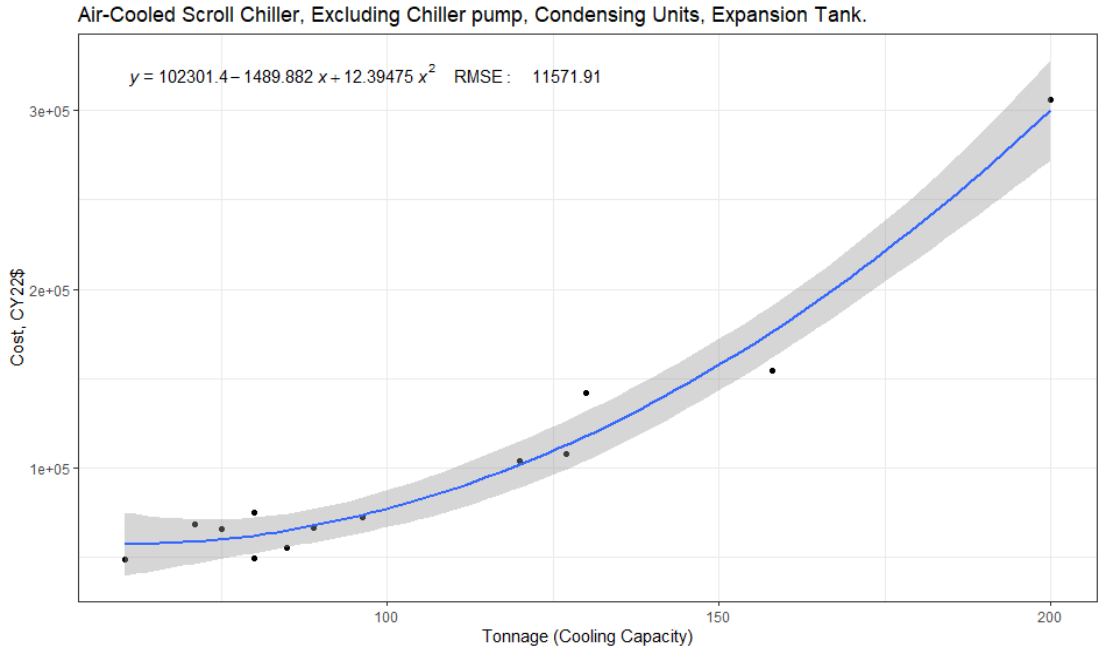
# CER Repository Methodology

1. Explore traits (predictors) already listed in the databases.
2. Consider a variety of fits, linear, non-linear, multiple regression, etc.
3. Choose models on the basis of visualization and Root Mean Squared Error (RMSE) rather than R-squared. 6,7,8




# CER Repository Results

MORE THAN FIFTY STRONG UNIT COST RELATIONSHIPS

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# CER Repository Takeaways

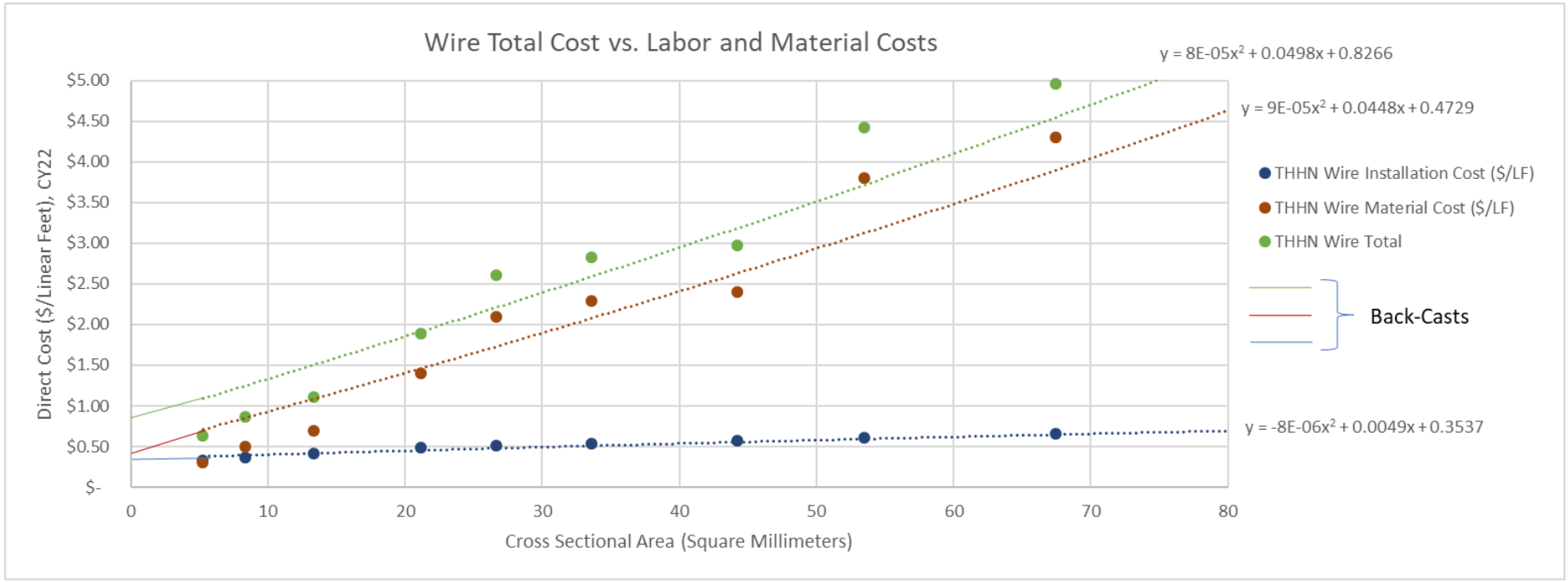
a) Estimates could provide population means
b) Faster than soliciting quotes, cheaper than commercial databases
c) Applicable to multi-purpose facilities or renovation
d) Key limitation: no way to adjust duration of labor

| CER Category | Count |
|---|---|
| HVAC | 6 |
| Power Distribution | 19 |
| Power Generation | 6 |
| Lighting | 3 |
| Structural | 4 |
| Liquid Storage | 2 |
| Lift Equipment and Transport | 4 |
| Plumbing | 7 |
| Other | 4 |

# Labor Approximation Methodology

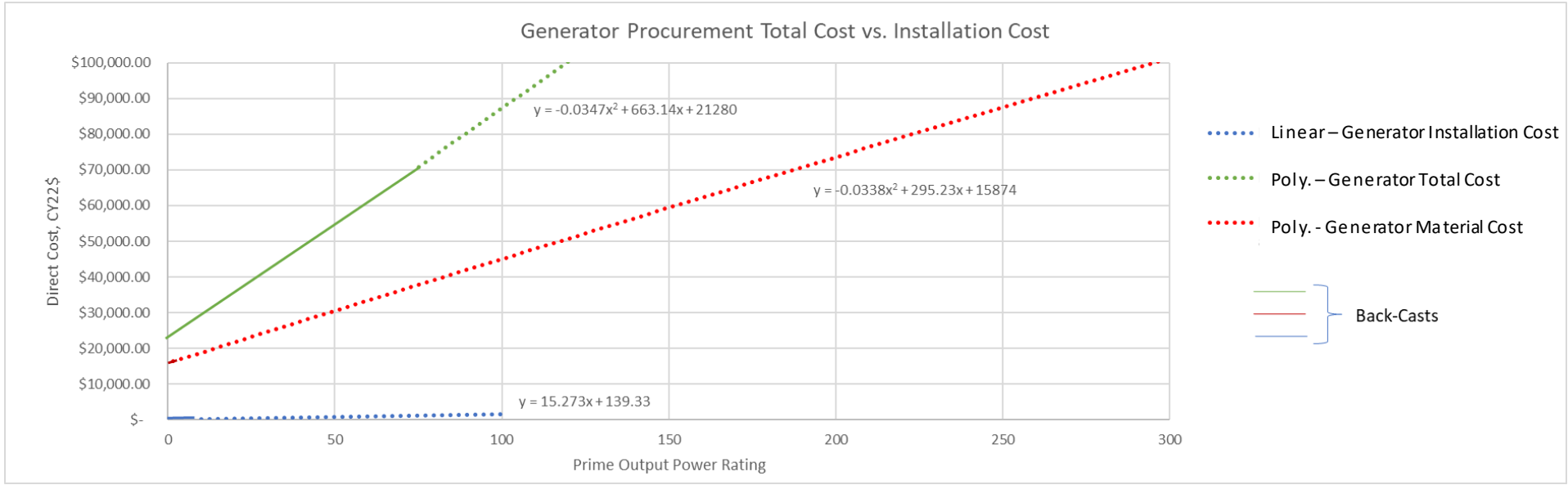
- According to Elbeltagi, labor constitutes **30-50%** of construction expenses.[9]
- One Navy project estimate showed **35%** of direct cost would be labor.
- Hypothesis: back-casting to the intercept may isolate approximate labor cost underlying composite expense data.

# Labor Approximation Results




- Intercepts behave as expected
- Difference may be due to manufacturing labor: 0.8266-0.4729=.3537

# More Generator Research Needed



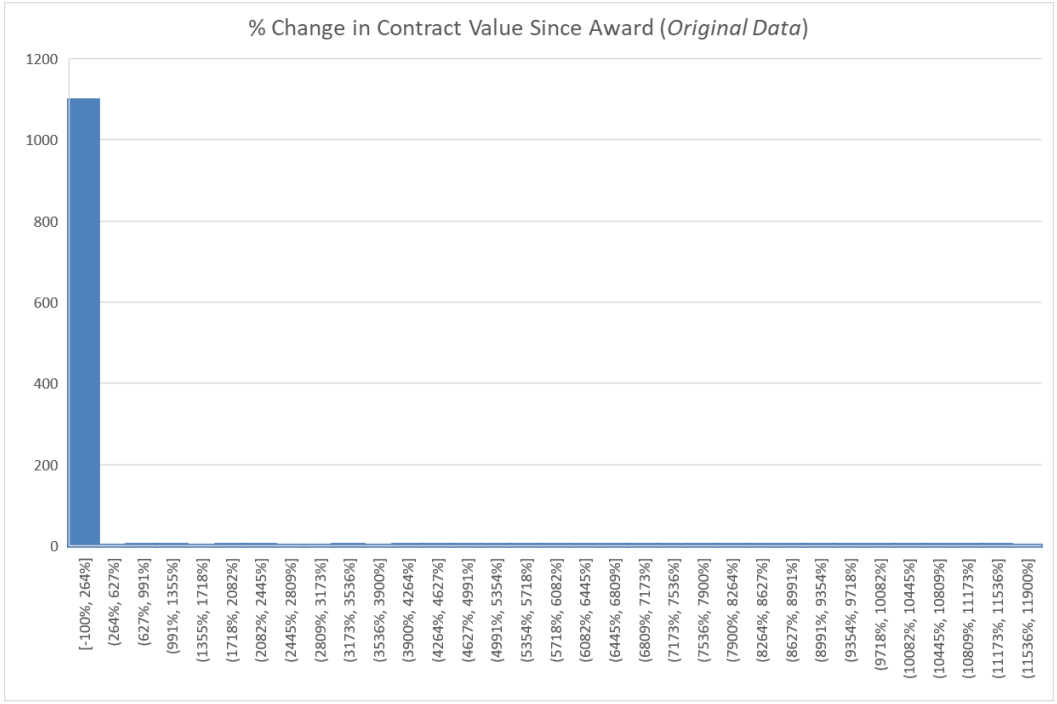

- Intercepts far overestimate labor necessary to build and install a generator at kW=1, likely due to different manufacturing processes and accessories.
- Stick to range of x-values

# Labor Approximation Takeaways

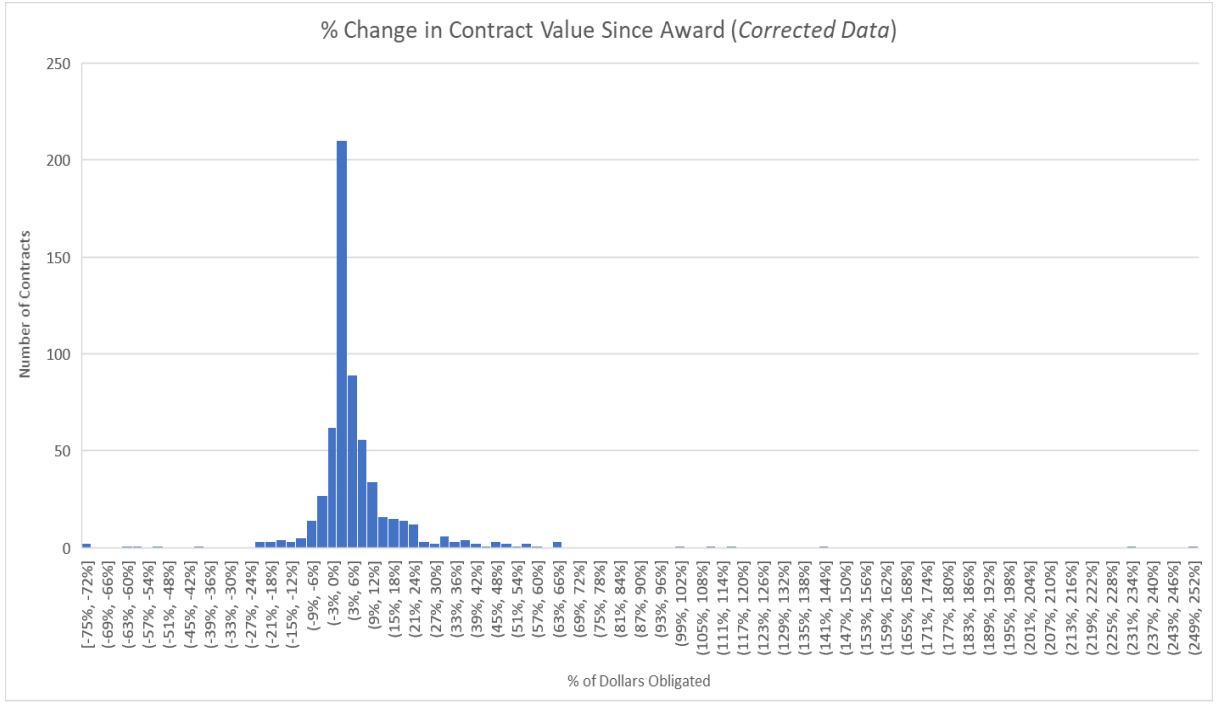
- There's mixed evidence as to whether back-casting is a viable way to extract labor data.
- Physical attributes (size, weight) may be more appropriate for this technique than performance attributes (power output, horsepower, etc.)
- When in doubt, consider trying the Elbeltagi factor (30-50%)

# Uncertainty Analysis Data Introduction

Before




After



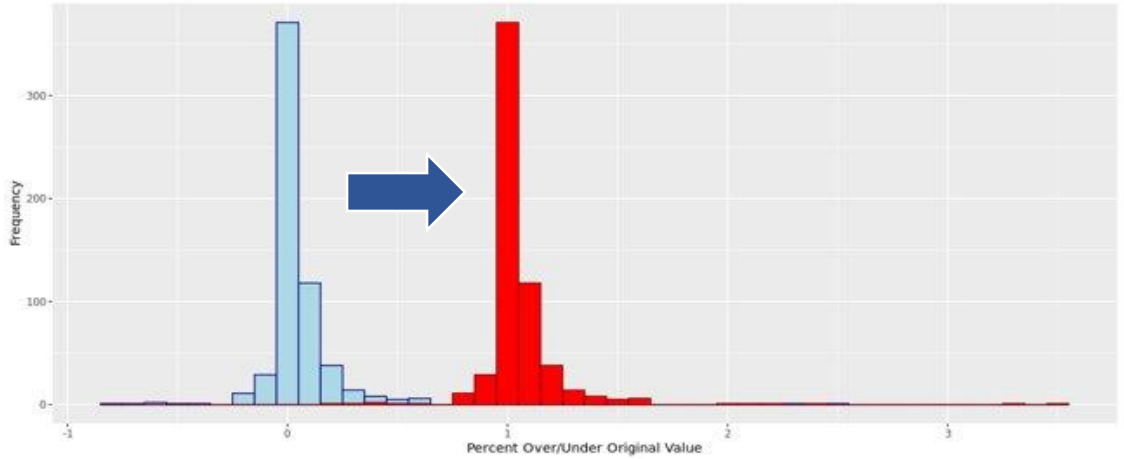

- MILCON status reports by OASD(S) form the backbone of the uncertainty analysis. Corrected with the Federal Procurement Data System (FPDS)
- Histograms can reveal whether data needs attention

# Uncertainty Analysis: Put a Name to a Face

1. Study the distribution of contracts exceeding their initial values per congressional reports such that

$$Percent\ Cost\ Overrun = \frac{(Final\ Value - Original\ Value)}{Original\ Value}$$

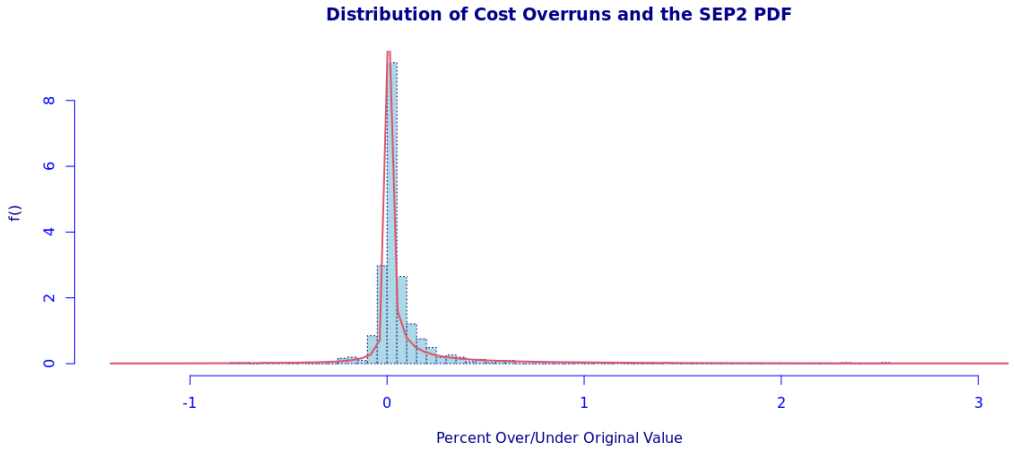
2. Shift to apply distributions on positive real line {0,Inf.}



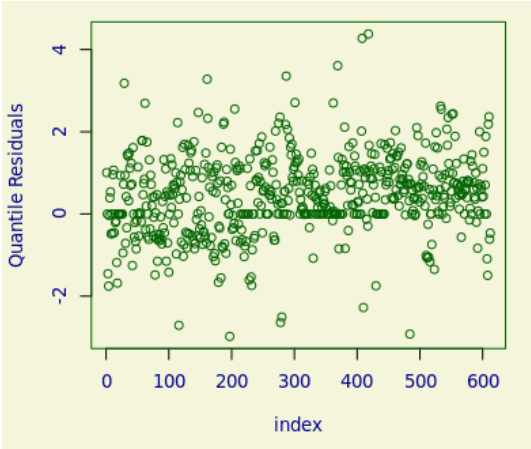

3. Consider >50 distributions, select via Akaike's Information Criterion (AIC).[10] Which distribution is best?

# Best Fit: SEP Type II

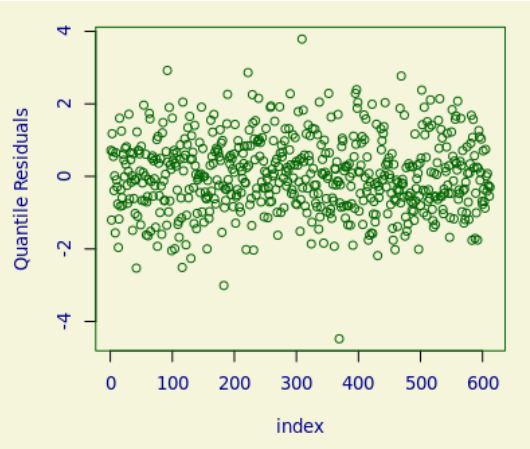
- Family: Skew Exponential Power (SEP) Type II.[11]
- AIC: -1949 (Least amount of data information lost among attempted curves)
- n=612 completed Military Construction contracts




## Actual Residuals

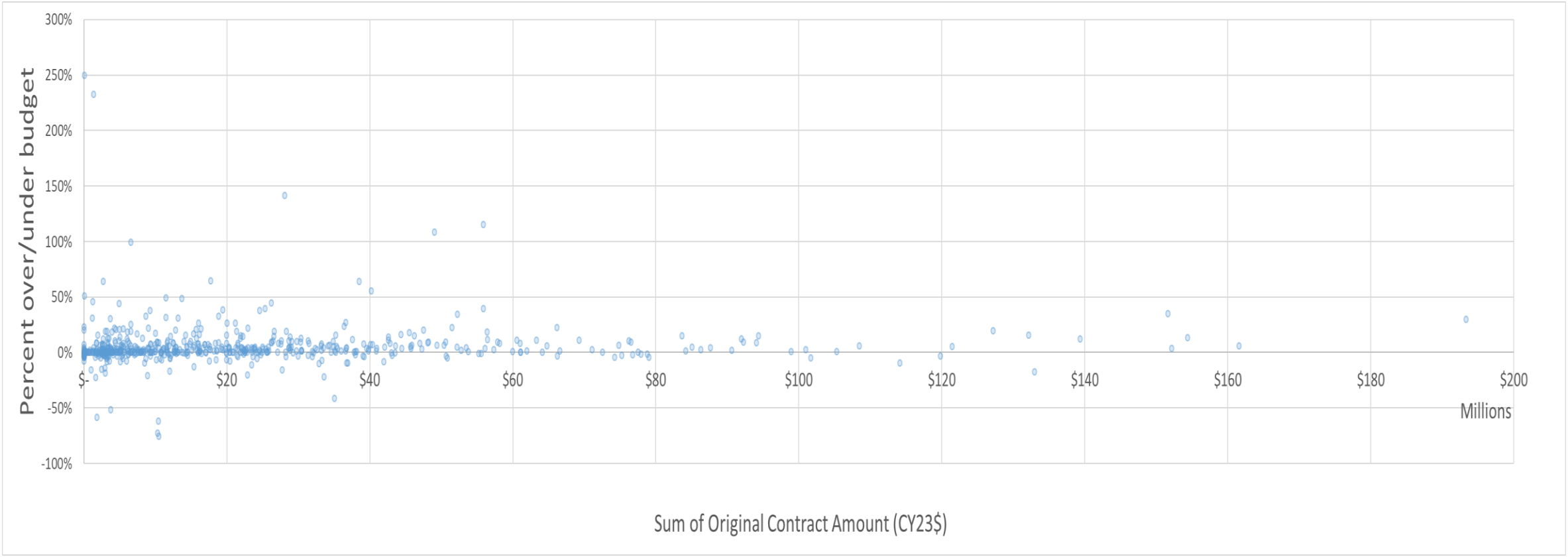



## Simulated Residuals




- It's the best fit, but is it a good fit? Residuals suggest yes.

# Smaller Contracts Have a Wider Range

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# Uncertainty Analysis Takeaways

- Parametric models suggest DOD construction errors tend toward a Skew Exponential Power (II) Distribution.
- Evidence that we should not always default to lognormal.[12]
- Combined with our CERs, we have several uncertainty parameters for our simulations.
- Small contracts have a wider uncertainty range.

# What's next?

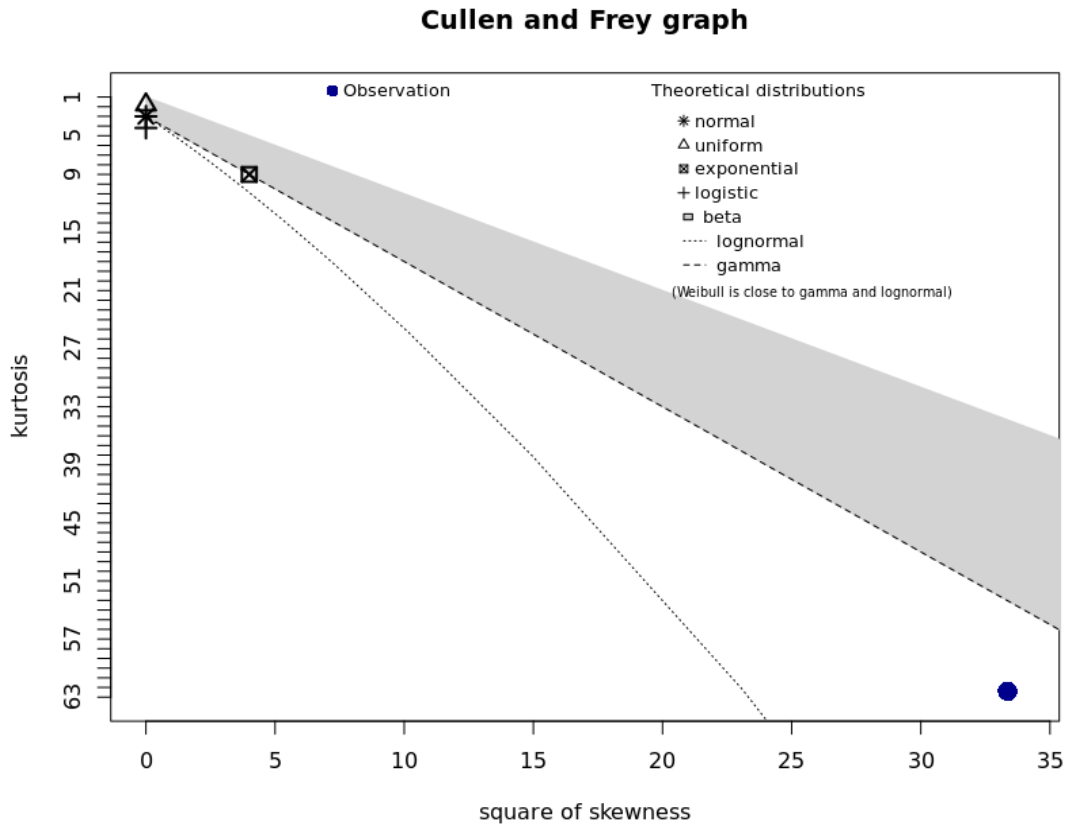
a) More potential CERs in these databases

b) Replicate uncertainty analysis with contract schedules

c) Explore switch from raw to orthogonal polynomials

d) Plot Skewness vs. Kurtosis for more families (Cullen and Frey Chart[14])

With these methods, we could more definitively state whether costs are SEP distributed and gain schedule insight.



# Recommendation Summary

PLOTTING CERS CAN LOCATE CENTRAL TENDENCIES AND SAVE TIME VIA INTERPOLATION

USE CAUTION WHEN APPROXIMATING LABOR VIA BACK-CASTING

APPLY EMPIRICAL OR SEP II DISTRIBUTIONS TO OUR CONSTRUCTION SIMULATIONS

# References


1. Association for the Advancement of Cost Engineering International. *Cost Estimate Classification System - As Applied in Engineering, Procurement, and Construction for The Building and General Construction Industries* 56. 56R-8th ed. Vol. 56. 124 vols. Recommended Practices. Fairmont, WV: AACE International, 2020. August 7, 2020.
2. Army Corps of Engineers, Programming Administration and Execution (PAX) System Newsletter 3.2.2 Army Facility Unit Costs §. Army Facilities Pricing Guide (2021). https://www.usace.army.mil/Cost-Engineering/PAX-Newsletter-322-Army-Facility-Unit-Costs/.
3. Army Corps of Engineers, EP1110-1-8 Construction Equipment Ownership and Operating Expense Schedule §. EP 1110-1-8 (2020), EP 1110-1-8 Equipment Rates (army.mil).
4. Tyler, Mark C. 2022 National Electrical Estimator. Carlsbad, CA: Craftsman Book Company, 2021.
5. Office of the Assistant Secretary of Defense for Sustainment, Military Construction Status Report § (2022). https://www.acq.osd.mil/eie/FIM/FIM_Library.html.
6. Ford, Clay. "Is R-Squared Useless?" University of Virginia Library Research Data Services + Sciences. University of Virginia Library, October 17, 2015. https://data.library.virginia.edu/is-r-squared-useless/.
7. Book, Stephen A., and Philip H. Young. "The Trouble With $R^{2}$." *Journal of Parametrics* 25, no. 1 (July 2006): 87–114. https://doi.org/10.1080/10157891.2006.10462273.
8. Spiess, Andrej-Nikolai, Natalie Neumeyer. "An evaluation of R2 as an inadequate measure for nonlinear models in pharmacological and biochemical research: a Monte Carlo approach". *BMC Pharmacology.* 2010; 10: 6.
9. Elbeltagi, Emad. "Chapter 4: Cost of Construction Labor and Equipment." Essay. In *Cost Estimation In Construction Projects,* 67–67. mepwork.com, 2021.

   *Accessible here: https://www.mepwork.com/2021/04/project-cost-estimation-pdf.html*
10. Stasinopoulos, D. Mikis, and Robert A. Rigby. 2007. "Generalized Additive Models for Location Scale and Shape (GAMLSS) in R". Journal of Statistical Software 23 (7):1-46. https://doi.org/10.18637/jss.v023.i07.

    *This is the R package used to perform the analysis. Also see https://www.gamlss.com/wp-content/uploads/2018/01/DistributionsForModellingLocationScaleandShape.pdf for a full definition of the SEP Type II distribution.*

# References


11. Azzalini, Adelchi. 2020. "Further Results on a Class of Distributions Which Includes the Normal Ones – Looking Back". Statistica 80 (2):161-75. https://doi.org/10.6092/issn.1973-2201/10421.
12. Kunc, Wendy, Kathy Watern, Stephen Barth, Douglas Comstock, Christian Smart, Duncan Thomas, John Fitch, Alfred Smith, and Jeff McDowell, Joint Agency Cost Schedule Risk and Uncertainty Handbook § (2014).
13. Rossi, Riccardo, Andrea Murari, Pasquale Gaudio, and Michela Gelfusa. "Upgrading Model Selection Criteria with Goodness of Fit Tests for Practical Applications." Entropy 22, no. 4 (2020): 447. https://doi.org/10.3390/e22040447.
14. Cullen Alison C and H. Christopher Frey. 1999. Probabilistic Techniques in Exposure Assessment : A Handbook for Dealing with Variability and Uncertainty in Models and Inputs. New York: Plenum Press.


Data from this talk is available upon request: paul.b.franklin11.civ@us.navy.mil

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