Variability in Accuracy Ranges: A Case Study in the Canadian Power Transmission Industry

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ABSTRACT

This article presents a case study of the variability in accuracy ranges for cost estimates in the Canadian overhead power transmission industry. The study sought to improve the participant's understanding of risks and estimate accuracy for their major overhead power transmission projects. The study team also sought to verify the theoretical accuracy curves identified in the AACE® International Recommended Practice (RP) 18R-97: "Cost Estimate Classification System – As Applied in Engineering, Procurement, and Construction for The Process Industries." The study team collected and analyzed actual and phased estimate cost data from 39 projects with actual costs from 2 million to 655 million (2016$CAN) completed from 2007 to 2016. Greenfield and brownfield overhead transmission projects from across Canada were included. This study compares the range bandwidth (uncertainty) as stipulated in AACE® RP 18R-97 with the actuals from this study. The accuracy ranges and the project's under or over estimation of contingency is compared with published data from other industry studies. This article was first presented as PM.2639 at the 2017 AACE International Annual Meeting.

INTRODUCTION/BACKGROUND

Accuracy is a measure of how a cost estimate differs from the final actual outcome. Risk analysis provides forecasts of how the final actual outcome may differ from the estimate (such as a base estimate or an amount approved for expenditure). Historical analysis helps us to understand the variability of accuracy and to improve our risk analysis practice [2]. This study is such an historical analysis. [**Editor's Note: Draft RP 96R-18 for the classification of power transmission line infrastructure project estimates is open for public comment in the AACE website Communities until September 17, 2018.*]

Empirical estimate accuracy data has been researched for over 50 years [8]. In particular, the accuracy of process industry project estimates (e.g., oil and gas, chemical, mining, etc.) has been well documented [9]. Other studies have highlighted industry bias and misperceptions of the reality of estimate accuracy [5]. However, there has been a relative void in accuracy studies for overhead power transmission projects. One example study for the power industry included transmission projects but barely reported on their experience [10]. Most cost studies are of absolute costs (e.g., $/kW), not estimate accuracy. This study of the accuracy of estimates for the Canadian power industry will help fill a gap in our understanding of the power transmission element of the electric power industry.

One catalyst, and point of comparison, for this study was the development by the Construction Industry Institute® (CII) of a Project Definition Rating Index (PDRI) for "infrastructure" projects in 2011 [4]. The CII report included some limited historical accuracy data for cost and schedule, but only a small number of the projects were power transmission scope. CII defined infrastructure as providing "transportation, transmission, distribution, collection or other capabilities" that usually impact multiple jurisdictions and stakeholders across a wide area. CII characterized infrastructure as scope including "nodes and vectors"; in that respect, this study covers the power "vector" aspect; i.e., transmission lines as opposed to generation and substation "nodes." For this article's study, it was hypothesized that vector projects which include unique land, right-of-way, and permitting issues and risks may have different estimate accuracy characteristics than nodal projects.

In respect to the nodes (e.g., generation and substations), this study is partly an extension of a 2014 study on hydropower generation projects by the same group that sponsored this study [6]; this study's analytic methods were essentially the same.

In addition, this study was needed to help verify the applicability of the theoretical accuracy depiction presented in Figure 1 of the AACE® Recommended Practice 18R-97 "Cost Estimate Classification System – As Applied in Engineering, Procurement, and Construction for the Process Industries" [1]. The questions in regard to that RP were "does Figure 1 in RP 18R-97 reflect real accuracy ranges?" and if not, "how can we assure that this depiction does not feed bias in stakeholder expectations?" (See Figure 1 from RP 18R-97):

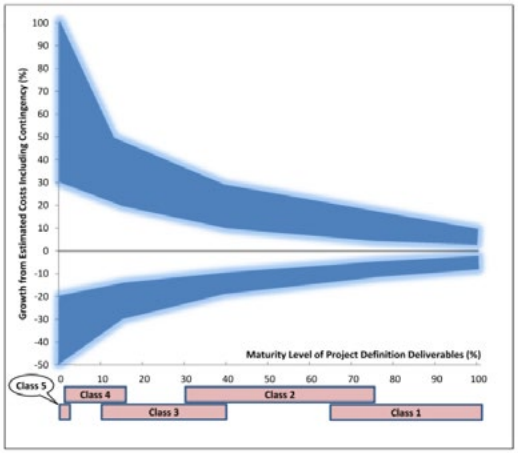

FIGURE 1 Example of the Variability in Accuracy Ranges for a Process Industry Estimate (Figure 1 from AACE International RP 18R-97) *Editor's note: This figure has since been changed by the Technical Board to remove the values on the y-axis considering the findings of empirical research such as this paper. Further, an RP on "Understanding Estimate Accuracy" is in development by the Cost Estimating technical committee.

BACKGROUND ON THE STUDY

Since the publication of the CII PDRI-Infrastructure, the AACE Technical Board has been considering a Recommended Practice (RP) for the classification of infrastructure industry estimates. An initial RP goal was to document the defining scope deliverables and their expected status to support project estimates of each Class. Optimally, the RP would be backed up by industry empirical data. In anticipation of this, and to address its own interests, the Canadian study team developed its own transmission scope deliverable list and status worksheet and performed an empirical analysis. Also, the Canadian study team (the membership has changed slightly) did a similar study of hydropower generation projects in 2014 [6]; this study would add to their cost knowledge of their asset base.

The Canadian study team collected estimated and actual project capital cost data from 39 recent projects with actual costs from $2 million to $655 million (average $61M in 2016 $CAN) completed from 2007 to 2016. A goal of the study was to assess the accuracy versus level of scope definition, so for each project, estimate data from each scope development phase was captured, resulting in data on 79 estimates. Only 25 of the projects had records of Class 5 (conceptual) estimate data.

The project scopes included overhead AC and HVDC transmissions lines (no substations) from 25 to 500kV, with 1 to 3 circuits on wood or steel support structures. The routes were new or existing from 0.4 to 340km in length (average 48km) in five Canadian provinces. Most of the projects did not require new regulatory approval (i.e., line was often covered under a wider regulatory umbrella); however, the larger the project, the more likely approval was required. To minimize bias, the dataset represented all the recent major project data available to the participants regardless of whether the project cost outcome met company objectives.

ANALYSIS APPROACH

The primary analytical methods used were descriptive statistics. The accuracy metric described by the statistics and the dependent variable of regression was the ratio of "base estimate/actual costs." "Base estimates" of each Class exclude contingency, escalation, and management reserves. This was used because the team wanted to understand how actual costs differed from the base so that they could improve future predictions of this difference (i.e., forecast the contingency required). The study also examined schedule duration estimate accuracy which is not included in this article.

The estimate/actual cost ratio format was used because sample data of this metric tends to be normally distributed and hence amenable to multiple linear regression analysis. As will be discussed later, the more commonly considered actual/estimate (inverse of estimate/actual) tends to be biased to the high side which can make regression analysis problematic.

The independent variables studied (estimate/actual being the dependent variable) included:

- Scope definition upon which estimate was based (i.e., AACE Class 3, 4 or 5)
- Province/Company
- Proximity to populated areas
- Cost/Schedule Strategy (i.e., cost or schedule driven)
- Terrain/Site Conditions/Weather
- New Technology or Scale
- System Complexity
- Execution Complexity
- Primary Project Type (e.g., greenfield, revamp, etc.)
- Primary Construction Contract Type
- Owner PM System Maturity
- Aboriginal Stakeholder Engagement/Involvement
- Environmental Sensitivity of ROW

Also, the cost content of each project in terms of percent of cost for procurement, construction, and so on was also captured. To collect the data, the team developed a form that captured the following:

- General project characteristics
- High level "base" cost estimate breakdowns at each AACE Class plus contingency and escalation cost estimates for each
- Actual final cost
- Key planned and actual schedule milestones
- Scope change and risk event information

The actual cost data was normalized to the year of the respective estimate using the mid-point of spending approach (actual project cash flows were not available) [3]. The normalization price index used was derived from the Statistics Canada index for the sell price of non-residential construction projects. Also, cost changes resulting from business scope change were adjusted out (costs resulting from a change to a basic premise of the estimate, such as transmission line voltage, capacity, etc.). None of the projects were observed to have experienced a catastrophic risk event.

The primary variable (risk driver) of interest was the level of scope definition upon which the estimate was based. Not all projects had data for estimates of each AACE Class, as can be seen in the following number of valid observations:

- Class 3: 29 (10 of the 39 were funded based on a Class 4 estimate)
- Class 4: 25 (10 of these were the funding estimate)
- Class 5: 25

Actual/Base Estimate	Class 3	Class 4	Class 5
number of observations	*29*	*25*	*25*
p90	1.64	2.34	2.66
p50	1.08	1.24	1.38
p10	0.81	0.84	0.93

TABLE 1 Dataset Cost Estimate Accuracy Metrics (Actual/Base Estimate)

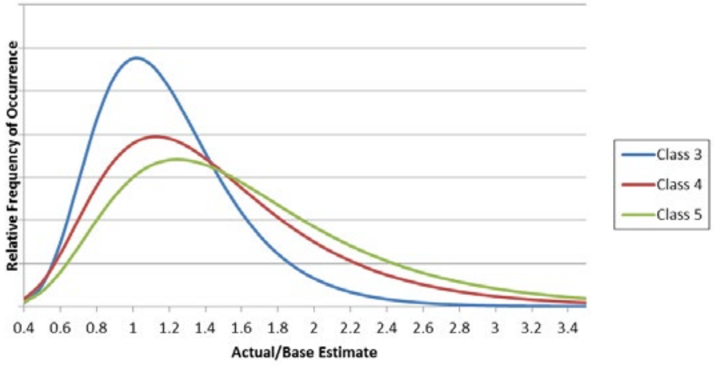

FIGURE 2 Dataset Actual/Base Estimate Metrics Fitted to Lognormal Distributions

Actual/Base Estimate	Class 3		Class 4		Class 5	
	<=20M	>20M	<=20M	>20M	<=20M	>20M
p90	1.32	1.96	1.98	3.79	2.32	3.18
p50	1.01	1.15	1.19	1.37	1.40	1.36
p10	0.82	0.81	0.85	0.83	1.00	0.87

TABLE 2 Dataset Cost Estimate Accuracy (Act/Base Est) by Project Actual Cost Range

This sample size was considered adequate to gain useful insight as to the relationship of accuracy and Class, but not enough to gain deep understanding of the impact on accuracy of any but the most dominant of the other independent variables.

FINDINGS FOR ACCURACY RANGE BY CLASS: DESCRIPTIVE STATISTICS

Table 1 shows the dataset statistics for accuracy. Figure 2 depicts the same data fitted to lognormal distributions. The probability values ("p-value" is the level of confidence expressed as a percentage of values that will be less than that shown) in the table are calculated using the Excel® "Norminv" function applied to the base estimate/actual data, and then converted to the traditional actual/base estimate ratio format (i.e., >1 means the actual cost was more than the base estimate.) This method of inferring the population distribution from a sample is consistent with the method described in AACE RP 42R-08 (Risk Analysis and Contingency Determination Using Parametric Estimating) and supported by process industry research that indicates that estimate/actual data (as opposed to its inverse of actual/estimate) is more or less normally distributed [2].

As an example of how to interpret this, if the ratio for Class 4 at p50 is 1.24, that indicates that 24% contingency would be needed to achieve a 50 percent confidence of underrunning. Note the high side skewing (e.g., the Class 4 p90 of 2.34 is much further from the mean than the p10 value of 0.84). Recall that these values exclude escalation and business scope change.

FINDINGS ON EFFECT OF PROJECT SIZE

The project size in this study's dataset sample was not evenly distributed. There was a group of 20 projects of <=$20 million actual cost (average $8 million) and a group of 19 projects of >$20 million actual cost (average $118 million) (all $2016 $CAN). Industry research indicates that there is a dichotomy between how small versus large projects are managed and estimated [7]. Small projects tend to be managed as a portfolio with project team members having responsibility for multiple projects using less disciplined management procedures. Large projects usually have dedicated teams and more disciplined procedures. The focus of small project funding tends to be on overall portfolio budget predictability which translates to a bias toward over-estimation, while large projects focus more on individual project cost effectiveness which translates to a bias toward under-estimation. These industry findings are consistent with this study's findings.

For example, in Table 2, the p50 value for the Class 3 estimates of small projects (<=$20M) is 1.01 which means the average project actual cost was essentially equal to the average base estimate excluding contingency; i.e., the base estimates appear to have been conservatively biased such that no contingency was needed on average. On the other hand, the large projects (>$20M) had much greater p90 values indicating not only was base estimate bias toward under-estimation, but the project complexity (and longer durations of 35 months versus 27 months from start of execution phase to in-service date) appears to have resulted in greater risk. In particular, several of the largest projects required specific regulatory approval.

COMPARISON OF FINDINGS TO OTHER STUDIES AND AACE RP18R-97

Statistically speaking, considering sample sizes and data quality, this study's accuracy ranges are roughly comparable to those reported for the process industries [5 and 9], as well as infrastructure projects in the CII PDRI-Infrastructure study [4]. However, this study's Class 4 and 5 cost growth ranges were more similar to each other than they were for process plant projects. One hypothesis is that process plant projects usually have outside battery limits and offsite scope elements (i.e., significant scope elements supporting but not part of the process production units) with poor early scope definition causing greater Class 5 underestimates for process plants. Another explanation is that transmission projects are less technically complex; i.e., the main uncertainty is around routing which is similarly defined at Class 4 and 5. Also, the p10 values (significant underruns) of the transmission projects, many of which are fairly small, indicate a bit more bias toward overestimation. Table 3 summarizes the results of these studies.

It was assumed that funding estimates in the Hollmann study [5] were based on scope definition of about Class 4, because general industry front-end planning is assumed to be less defined on average than at the companies in this study and at the clientele of Independent Project Analysis, Inc. (IPA). However, the estimates in the CII study [4] were assumed based on Class 3 estimates given their average PDRI scope of <200 (on a scale of 70 to 1,000 with 70 being best and 200 or less being the CII recommended target level for sanction).

Note that this study's values were adjusted downward from Table 1 to reflect the accuracy relative to the estimate including contingency (i.e., the funded amount) which is typical of the data shown in most published studies. The contingencies added to this study's Class 3, 4 and 5 base estimates were 10%, 12% and 15% respectively which correspond to typical contingencies applied at the time.

This Study	**Class 3**	**Class 4**	**Class 5**
p90	54%	122%	151%
p50	-2%	12%	23%
p10	-29%	-28%	-22%
IPA Inc., Process Industry [3]; p10/p90 approximated from histogram illustration			
p90	40%	70%	200%
p50	1%	5%	38%
p10	-15%	-15%	-15%
Hollmann, Process Industry [4] average of meta-analysis			
p90		70%	
p50		21%	
p10		-9%	
CII Infrastructure PDRI [6] data from Figure 6.6 (mean PDRI <200)			
p90 (assuming normal)	30%		
Mean	6%		
p10 (assuming normal)	-11%		

TABLE 3 Comparison of Accuracy Studies (% Overrun of Estimate Incl. Contingency)

When comparing results in respect to RP 18R-97, one must consider two points of comparison. The first is the bandwidth or span of the range (i.e., p90 minus p10.) The other is the absolute value of a high or low range. Figure 3 shows this study's results superimposed on the RP 18R-97 Figure 1. This study's range spans are somewhat wider (more uncertain) than the worst case spans in the RP. For example, the worst case span for Class 5 in the RP is 150% (100 – <50>) while the span for Class 5 in this study is 173% (151 – <22>.) The high and low absolute range values indicate contingency under-estimation bias (albeit less bias than for hydropower generation projects [6]). Even if only the study's small project range values had been plotted in Figure 3, the Class 3 range at best would be similar to the worst case span of RP 18R-97 (i.e., the RP Figure 1 is optimistic).

COMPARISON OF CONTINGENCY ESTIMATES TO ACTUAL COST GROWTH

The projects in this study allowed only 10 to 15% contingency on average, even for Class 5 estimates. These contingencies appear to reflect a strong industry optimism (under-estimation) bias for large projects, particularly for early estimates. Contingencies (or combinations of contingency and management reserve) of 8, 24 and 38% at p50, excluding business scope change and escalation, are suggested by this study for Class 3, 4, and 5 estimates respectively for transmission projects of average size and risks. However, there is a dichotomy between small and large projects. For small projects (<$20M), the base estimates were more conservatively estimated at Class 3 and 4, such that a contingencies of 0, 20, and 40% at p50 would have sufficed. However, the high p90 values of large projects points to the need for more rigorous risk management to identify and mitigate their greater potential risks.

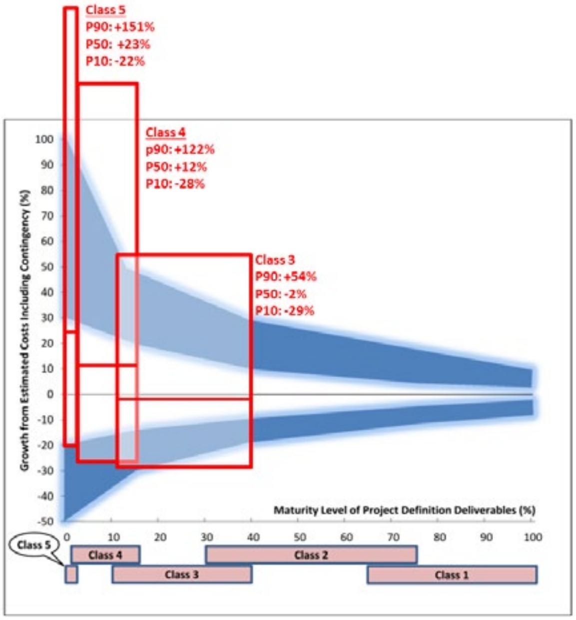

FIGURE 3 Study Accuracy Findings Superimposed on RP 18R-97 Figure 1

If these empirically-valid contingencies, allowing for size bias, had been included in the study projects, their actual range outcome would look similar to but wider than the worst case of RP 18R-97 as shown in Figure 1. The authors are not recommending that these or any other contingency values be assigned arbitrarily; contingency should always be based on risk analyses. However, if a company's risk analyses regularly result in 10 to 15% contingency and narrow ranges with less than ideal scope definition, it is likely that risks and their impacts are not being identified or quantified properly and/or optimism bias is controlling.

REGRESSION ANALYSIS OF OTHER RISK DRIVERS

The study team has also modeled the impacts of systemic risks other than the level of scope definition and project size. To do this, the data from only the Class 3 estimates was examined (Class 3 being the basis for full funding decisions and hence of utmost importance to the business stakeholders). Using multiple linear regression, each independent variable (risk driver) was tested alone and in various combinations. While the findings from the modeling are confidential, a conclusion of the modeling that can be shared was that the level of scope definition is the predominant systemic risk driver for cost growth.

CONCLUSIONS

This study of the variability in accuracy ranges for cost estimates in the Canadian power transmission industry suggests that the actual cost uncertainty is a bit greater than the worst case theoretical depiction of accuracy for the process industries as shown in Figure 1 of AACE RP 18R-97. The study indicates that risks are much greater than being estimated;

contingencies of 8, 24, and 38% percent were indicated for Class 3, 4 and 5 estimates respectively on average. The study also shows that the contingency and reserves estimated were lower than what were required. The study also shows that small projects (<=$20M) appear to have a base estimate bias toward over-estimation at Class 3; however, the contingencies are still underestimated at Class 4 and 5. Finally, large projects (>$20M) have greater risk on the high side (p90) indicating a need for strong risk management. Overall, and in respect to size variations, the Canadian power transmission industry experience is similar to that of other process industry projects, as well as of infrastructure projects studied by CII.

Using the data from the study, the participants have developed a simple parametric risk analysis tool for systemic risks in which the level of scope definition is the dominant risk driver. This emphasizes the importance of doing disciplined Class 3 scope definition prior to full funds authorization if cost predictability is a goal. The Canadian study team will recommend that the AACE Cost Estimating Technical Committee consider this study's findings in development of an RP for classification of estimates in the infrastructure industries. The conclusions are likely applicable to other "vector" oriented infrastructure projects such as pipelines and roads.

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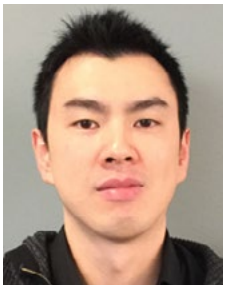

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ConstructConnect's U.S. Construction Starts Summer Forecast Shows **Construction Starts Rose by 1.4% Year-on-Year in Q2 2018**

Civil engineering increased 22.2%, residential construction dropped 2.8%

CINCINNATI – August 6, 2018 – ConstructConnect, a leading provider of construction information and technology solutions in North America, announced today the release of its Fall 2018 Forecast and Quarterly Report. The forecast revealed minor revisions to its total construction starts from what was originally estimated last quarter. Total starts for 2018 over 2017 are now expected to be -0.2%, down slightly from the +0.4% figure previously calculated.

The forecast suggested 2019 total starts will rebound to +7.8% year over year, faster than the +7.1% previously expected. Beyond 2019, the annual growth rate of total starts will settle down into a range of +4.5% to +5.0% out to 2022.

After a one-third increase in the 2017 starts, multi-family residential groundbreakings will ease back in 2018, before resuming upward movement in 2019 and beyond. Single-family homebuilding will provide the major momentum this year and for the next several years.

To learn more about ConstructConnect or to get a free copy of the Forecast Quarterly Report, visit constructconnect.com.