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Variability in Accuracy Ranges: A Case Study in the Canadian Hydropower Industry

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Abstract—This paper presents a case study of the variability in accuracy ranges for cost estimates in the Canadian hydropower industry. The study sought to improve the participants' understanding of risks and estimate accuracy for their hydropower projects of similar scope. The study team also sought to verify the theoretical accuracy curves identified in AACE International's Recommended Practice (RP) 69R-12: "Cost Estimate Classification System – As Applied in Engineering, Procurement, and Construction for the Hydropower Industry". The study team collected and analyzed actual and phased estimate cost data from 24 projects with actual costs from 50 million to 3.6 billion (2012$CAN) completed from 1974 to 2014. Greenfield, brownfield and revamp impoundment and hydropower generation facility projects from across Canada were included (power transmission projects were excluded.) The study found that the range bandwidth (uncertainty) in RP 69R-12 is understated. Further, because actual contingency estimates are biased too low, the actual range curves are biased very high relative to those in RP 69R-12. The accuracy ranges and the underestimation of contingency are similar for hydropower and process industry projects.

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Introduction

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 [1]. This study is such an historical analysis.

Empirical estimate accuracy data has been researched for over 50 years [2]. In particular, the accuracy of process industry project estimates (e.g., oil and gas, chemical, mining, etc.) has been well documented [3]. Other studies have highlighted industry bias and misperceptions of the reality of estimate accuracy [4]. However, there has been a relative void in accuracy studies for hydropower projects with the notable exception of studies of World Bank funded projects; mostly in developing countries [5,6]. This study of the accuracy of estimates for the well developed Canadian hydropower industry will help fill a gap in our understanding of the hydropower industry.

In addition, this study was needed to help verify the applicability of the theoretical accuracy depiction presented in Figure 1 of AACE International's new Recommended Practice 69R-12: "Cost Estimate Classification System – As Applied in Engineering, Procurement, and Construction for the Hydropower Industry" [7]. The questions in regard to that RP were "does Figure 1 in RP 69R-12 reflect real accuracy ranges?" and if not, "how can we assure that this depiction does not feed bias in stakeholder expectations?" (Figure 1 from RP 69R-12 is reproduced below):

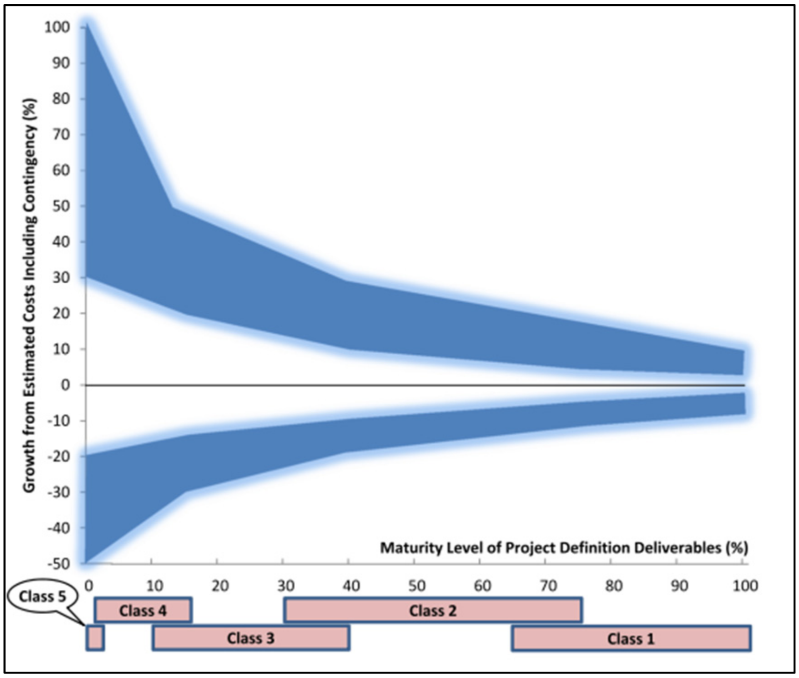

Figure 1 – Example of the Variability in Accuracy Ranges for a Hydropower Industry Estimate (Figure 1 from AACE International RP 69R-12; copied with permission)

Background on the Study

RP 69R-12 referenced above resulted from a multi-year effort led by a team of Canadian hydropower cost experts. The initial RP goal was to document the defining scope deliverables and their expected status to support hydropower project estimates of each Class. After publication of the RP, the next step was to verify theoretical Figure 1 in the RP. To do this, the Canadian study team performed an empirical analysis. The project scope and cost details of the analysis are confidential to the team, but it is hoped that the reference information presented here will be useful for AACE International to improve RP 69R-12.

The Canadian study team collected estimated and actual project capital cost data from 24 projects with actual costs from $50 million to $3.6 billion (in 2012 $CAN) completed from 1974 to 2012. For each project, estimate data from each scope development phase was captured, resulting in data on 50 estimates. All projects had a Class 3 estimate, but some did not have Class 4 and/or 5. The project scopes included greenfield, brownfield and major revamp impoundment and power generation facilities on rivers across Canada. It excluded power transmission projects. Most of the projects were located in semi-remote areas and included camps, mass excavation, concrete and/or earth-filled impoundments and diversions, intake structures, penstocks, and power houses with turbine generation equipment. 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 and multi-variable linear regression. The accuracy metric described by the statistics and the dependent variable of regression was the ratio of “base estimate/actual costs”. “Base estimates” 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., predict contingency required). The study also examined schedule duration estimate accuracy which is not included in this paper.

The estimate/actual cost ratio was used because it tends to be close to a normal distribution and hence is amenable to linear regression analysis. As will be discussed later, the more commonly considered actual/estimate inverse tends to be biased to the high side which makes regression analysis problematic.

The primary independent variables examined included (drivers of accuracy outcomes):

- Scope definition (i.e., Class)
- Cost content (e.g., % equipment or impoundment)
- Location/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

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 (per 69R-12) 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) [8]. The normalization price index used was derived from Statistics Canada indices for the sell price of non-residential construction projects. Also, cost changes due to business scope change were adjusted out (costs resulting from a change to a basic premise of the estimate such as generation capacity or throughput.) 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. Not all projects had data for estimates of each AACE Class as can be seen in the following number of valid observations:

- Class 3: 21 (a group of 4 projects in a program were combined into one)
- Class 4: 17
- Class 5: 12

Data for 3 projects was excluded because extreme age and/or duration raised questions as to the validity of the normalization. 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. The linear regression was performed using Microsoft Excel® with an add-on package called Analyse-it® that provides additional modeling, diagnostic and graphical capabilities.

Findings for Accuracy Range by Class: Descriptive Statistics

Table 1 shows the dataset statistics for accuracy. Figure 2 depicts the same data fitted to lognorm 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 International RP 42R-08 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 [1].

As an example of how to interpret this, if the ratio for Class 3 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 5 p90 of 3.01 is much further from the mean than the p10 value). Recall that these values exclude escalation and business scope change.

Actual/Base Estimate	Class 3	Class 4	Class 5
number of observations	*21*	*17*	*12*
Mean	1.24	1.40	1.79
p90	1.63	2.09	3.01
p50	1.24	1.40	1.79
p10	0.99	1.06	1.27

Table 1 – Dataset Cost Estimate Accuracy Metrics (Actual/Base Estimate)

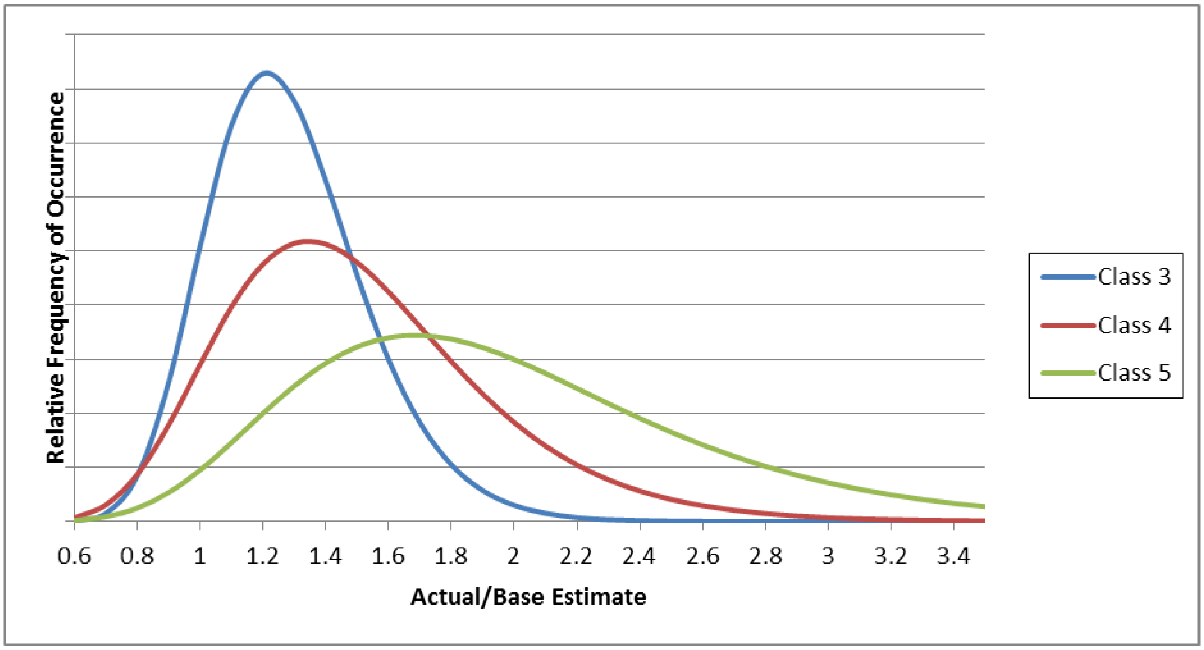

Figure 2 – Dataset Actual/Base Estimate Metrics Fitted to Lognorm Distributions

Comparison of Findings to Other Studies and AACE RP69R-12

Statistically speaking, considering sample sizes and data quality, this study's accuracy ranges are comparable to those reported for the process and infrastructure industries [3 and 4] as well as hydropower projects funded by the World Bank [5]. Table 2 summarizes the results of these studies. It was assumed that funding estimates in studies [4] and [5] were based on about Class 4 scope definition because general industry front-end planning is assumed to be less defined than planning at the companies in this study and at the clientele of Independent Project Analysis, Inc. (IPA). 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 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, Canadian Hydro	**Class 3**	**Class 4**	**Class 5**
p90	53%	97%	186%
p50	14%	28%	64%
p10	-11%	-6%	12%
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%	
Merrow, Hydro [5] Mean & Std Dev Reported; Normal distribution assumed below)			
p90 (assuming normal)		65%	
Mean		24%	
p10 (assuming normal)		-17%	

Table 2 – Comparison of Accuracy Studies (% Overrun of Estimate Including Contingency)

When comparing results in respect to RP 69R-12, 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 69R-12 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 174% (186 – 12.) The high and low absolute range values indicate strong contingency under-estimation bias. Note that all the projects in the study were greater than $50 million (in 2012 $CAN); the findings may not apply to small projects where estimating practices often differ. [4]

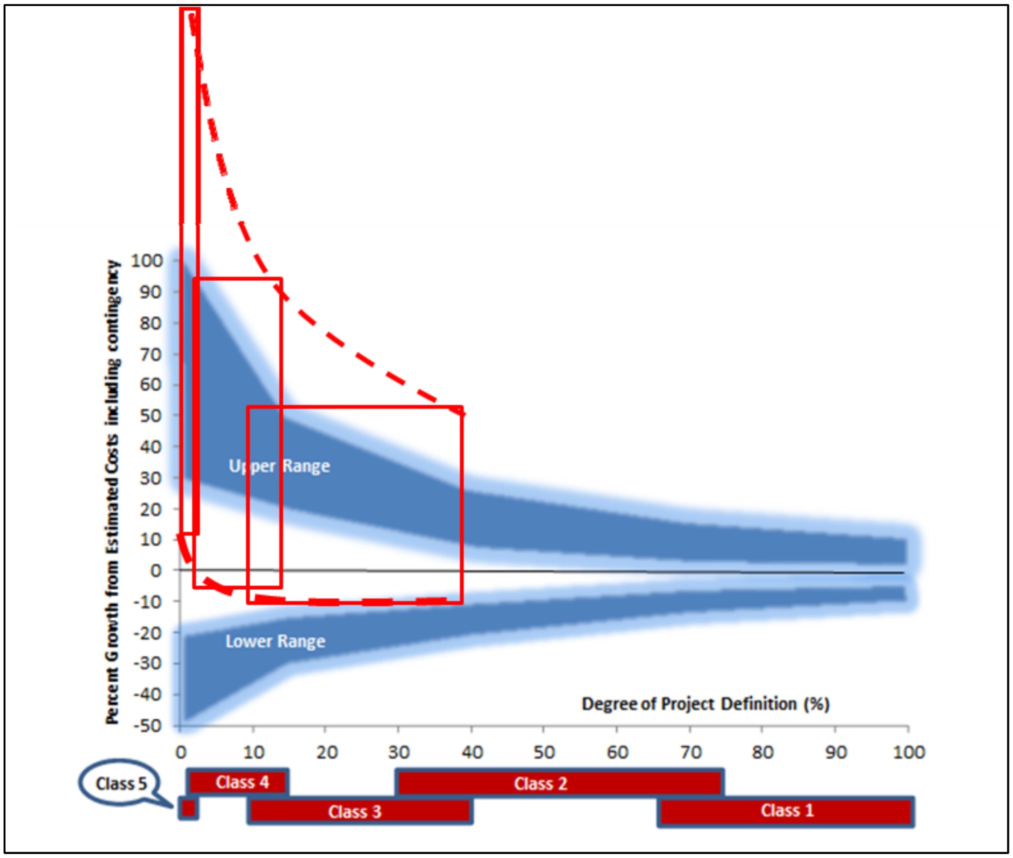

Figure 3 – RP 69R-12 Figure 1 with p10/p90 Study Data Superimposed

Comparison of Contingency Estimates to Actual Cost Growth

The projects in this study allowed only 10-15% contingency on average, even for Class 5 estimates. These contingencies appear to reflect a strong industry optimism bias. For example, a 2012 white paper by the United States Society on Dams, suggested "An overall contingency of *as much as* 50 percent is appropriate" on the conceptual engineer's estimate (i.e., Class 5); however, this *maximum* ("as much as") contingency allowance is much less than this study's *mean* cost growth of 79% at Class 5 [9].

Contingencies (or combinations of contingency and management reserve) of 24, 40 and 79% at p50, excluding business scope change and escalation, are suggested by this study for Class 3, 4 and 5 estimates respectively for projects of average risks. If these contingencies had been included in the study projects, their actual range outcome would look similar to but wider than the worst case of RP 69R-12 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 10-15% contingency and narrow ranges, it is likely that risks and their impacts are not being identified or quantified properly and/or optimism bias is controlling.

Findings for Other Risk Drivers from Regression Analysis

An attempt was made to quantify the impacts of systemic risks other than the level of scope definition. To do this, the data from only the Class 3 estimates was examined. Class 3 is usually the basis for full funding decisions and hence of utmost importance to the stakeholders. Each independent variable (risk driver) was tested alone and in various combinations using Excel with Analyze-it.

A regression model quantifying the cost growth for Class 3 estimates was developed that had an R2 of 0.66. Because the dataset had only 21 observations, the actual model is not shown here to avoid any misuse (findings may not be generally applicable,) but narratively speaking, the following variables appear to be significant systemic risk drivers:

- Proximity: The greater the distance of the project from a large population center, the greater the cost growth. Given the effect of distance on material and labor availability and conditions, this seems rational.
- Size: Larger projects had *less* cost growth. This may be due to larger projects being the sum of parts with highs and lows that balance out, and/or smaller project estimates may be small because of bias towards lowering base costs resulting in greater cost growth.
- Months Execution Duration: Longer projects had more cost growth despite normalizing for escalation. This may reflect the fact that risks often drive both cost and schedule increases rather than a causal correlation. However, the more time that passes, the more chance that there will systemic changes in the social, political, regulatory and other environments.
- % Equipment in Estimate: The greater the proportion of equipment, the less the cost growth. Excluding scope change, most estimators would agree that major equipment is less subject to risk and uncertainty than labor and bulk material costs, particularly for impoundments subject to geologic risks.

The analysis above was repeated with Estimate Class added as an independent variable. This could serve the participant’s as a rudimentary parametric model for systemic risk analysis [1]. While the model is confidential, it can be said that the model coefficients for Class (the level of scope definition) are consistent with the relative range values for each Class in Table 1 and Figure 1. The level of scope definition is clearly the predominant systemic risk driver.

Conclusion

This study of the variability in accuracy ranges for cost estimates in the Canadian hydropower industry suggests that the actual cost uncertainty is a bit greater than the worst case theoretical depiction of accuracy in Figure 1 of RP 69R-12. The study indicated that risks are much greater than being estimated; contingencies of 24, 40 and 79 percent were indicated for Class 3, 4 and 5 estimates respectively on average. Our study shows that the contingency and reserves estimated were lower than what were required. However, the Canadian hydro industry experience is similar to that of other process industry projects, as well as of hydropower projects in other regions funded by the World Bank.

Using the data from the study, the participants developed a simple parametric risk analysis tool for systemic risks in which the level of scope definition as 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 hydro study team will recommend that AACE's Cost Estimating Technical Committee consider improvements to Figure 1 and related content in RP 69R-12 to reflect the findings of this study. The conclusions are applicable to other process related industries, and therefore this paper may encourage improvements in other estimate classification recommended practices.

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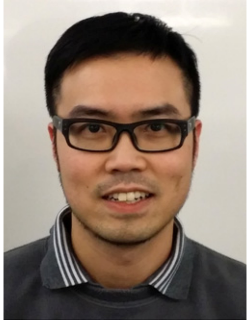

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