AACE INTERNATIONAL RECOMMENDED PRACTICE

43R-08

RISK ANALYSIS AND CONTINGENCY DETERMINATION USING PARAMETRIC ESTIMATING - EXAMPLE MODELS AS APPLIED FOR THE PROCESS INDUSTRIES

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TCM Framework: 7.6 – Risk Management

Rev. December 28, 2011

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Disclaimer: The opinions expressed by the authors and contributors to this recommended practice are their own and do not necessarily reflect those of their employers, unless otherwise stated.

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INTRODUCTION

Scope

This recommended practice (RP) is an addendum to the RP 42R-08 titled *Risk Analysis and Contingency Determination Using Parametric Estimating*. It provides three working (Microsoft Excel®) examples of established, empirically-based process industry models of the type covered by the base RP; two for cost and one for construction schedule. The example models are intended as educational and developmental resources; prior to their use for actual risk analysis and contingency estimating, users must study the reference source documentation and calibrate and validate the models against their own experience.

This RP summarizes three landmark empirically-based models; the "Hackney" model first presented in John Hackney's 1965 text *Control and Management of Capital Projects* (later expanded on in 1992, and now an AACE publication-reprinted 2002), and the later two "RAND" models. The RAND cost model is from 1981 research by Edward Merrow *et al*. for which Mr. Hackney was a consultant. The RAND construction schedule model is from 1986 research by Christopher Myers *et al.* building on the 1981 cost research. These models posit plausible causal relationships between cost growth (i.e., contingency usage) and schedule slip and various risk systemic drivers such as the levels of development of process and project scope information and the level of process technology. They present similar empirical and quantitative analysis of the reasons for inaccurate estimates of capital costs and schedule duration and provide tools to improve assessment of the commercial prospects of projects at early stages of scope development and/or using advanced technologies. Prior to these models, the literature on the causes of cost and schedule growth for process plants provided little consensus about the relative contribution of various risk factors. Therefore, the authors of the source documents measured the factors and statistically assessed their relative influence on cost and schedule growth for process plant projects undertaken in North America. The results of their work had a significant impact on the practice of cost engineering and the evolution of project management phase-gate scope development systems (i.e., these studies are a basis of AACE's RP on classification of cost estimates; RP 18R-98).

While this document attempts to summarize the basis of the models, it is highly recommended that users review the source documents before using the tools as a basis for their own study or development. Instructions for using the tools themselves are included in worksheets.

RECOMMENDED PRACTICE

Cautions

Empirical models, until validated with new data or analysis, cannot be assumed directly applicable to projects beyond the scope of those that form their empirical basis. The following describes the general model basis.

Project Types

These models are based on actual project experience on process plant projects undertaken in North America from the 1950s through the 1980s. Process plant projects are characterized by having process mechanical and fabricated equipment at their heart, supported by a variety of structural, piping, electrical, control, and other scope elements. Piping tends to be the most significant cost driver for non-equipment costs. In terms of schedule, major equipment purchases often have long lead times. The model basis projects generally included both the process units as well as supporting outside battery limit and off-site components. The project types are common in the oil and gas, petrochemical, chemicals, hydro-metallurgical, power and other industries. The principles apply, but the actual models will be less applicable for projects with either little process equipment (i.e., buildings and infrastructure) or projects where the equipment or machinery is dominant (e.g., dry processes with little piping, manufacturing, pyro-metallurgy, etc.).

Given that the basic nature of the engineering, procurement and construction business has not changed drastically since the 1980s, it is felt that time has not diminished the value of the models much. **However, users should always validate the models with their own more current data. AACE would appreciate other researchers updating or expanding on the empirical work of these pioneers.**

<u>Data Ranges</u>
There are many variables in these parametric models and the examples show the allowable entry ranges for each. However, users should take great caution in entering most or all of the variable values at their extremes. This would be extrapolating the models outside of the range of the empirical data and extrapolation generally provides poor results. For example, the Hackney model can have a maximum definition rating of 8498; however, it would have been rare for a project to have an overall rating of over 5000. Similarly, if all the variables in the RAND cost and schedule models are entered at their best possible defined rating, the outcome will be negative contingency and slip which is generally not a recommended outcome (unless the base estimate and schedule are biased on the conservative side; an important consideration that is not addressed in the model).

<u>Risk Ranges</u>
These models are limited to assessing *systemic* risks or those risks which are driven by characteristics of the company's' practices, the plant processes, the project system, and so on. Risks that are "project-specific" and have less commonality in occurrence or impact are not amenable to regression analysis. At early stages of scope definition (e.g., Class 5 or 4 estimates), systemic risks are the dominant drivers of cost growth and schedule slip. When definition is well defined (Class 3 or better), project-specific risks become more dominant and other contingency analysis methods such as range estimating or expected-value approaches are more appropriate. Note that for this RP, risk is defined as *the net impact or effect of uncertainty (threats – opportunities)*.

RAND COST MODEL (1981)

<u>Background</u>
The 1981 RAND cost growth model resulted from research done under contract with the US Department of Energy (DOE) to study the cost and performance problems on pioneer process plants. The RAND study authors used cost engineering knowledge of the day (such as documented in the Hackney model with its focus on the level of scope definition and the level of technology as major drivers of cost growth) and RAND client input as a starting point for their work. Being more current than the Hackney work and reflecting a more robust statistical sampling and analysis approach, the RAND model is summarized here first.

The RAND cost study collected planning and cost performance information on actual completed pioneer process plants in North America and used regression analysis techniques to find causal drivers of cost growth. A dataset of 106 estimates from 40 plants were used in the final model. The RAND report presents several models that were statistically significant. The study found that the following project and estimate characteristics were most significantly related to cost growth:

<u>Level of New Technology</u>
It had been observed in industry that unforeseen design, engineering, construction or start up problems occurred when a process plant used commercially unproven technologies. These project problems often require extensive

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redesign or repair during project execution. The "newness" of technology was conceived in the study as a continuum, ranging from completely standard technologies being commercially replicated processes, to scale up of a process only demonstrated in a pilot or research facility. The RAND study tested various quantitative measures of this continuum of technology as cost growth drivers. They found that the relative proportion of the total plant cost invested in process steps using commercially unproven technologies had the highest correlation with cost growth. This variable was called PCTNEW.

Impurities

Another industry observation was that the level of technical difficulty encountered during research and development (R&D) and early process development appeared to be correlated with problems experienced in later project design, construction and startup. In particular, cost growth showed an ascending relation with the presence of IMPURITIES (associated with buildups and corrosion) in the feedstocks or process streams, particularly for processes that involve catalysts or extensive recycle.

Project Definition

The amount and quality of project information used as a basis of the estimate was shown to be strongly correlated with cost growth. The measure found to have the best correlation was a combination of the level of engineering definition accomplished prior to the estimate and the average degree of definition of the following four site information elements: on-site and off-site unit configurations (plot plans), soils/hydrology data, environmental, and HSE requirements. A composite variable called PROJECT DEFINITION was constructed by rating the definition of each on a 4 point scale, computing the average value of the four site information variables, and adding level of engineering rating to that average.

Other Variables

While the above variables were dominant, other cost growth drivers were identified and included in the model. These included:

PLANT COMPLEXITY: a count of the number of continuously linked process steps or block units in the plant. When there are more linked process steps, there is more chance of overlooking process issues and problems which tend to cascade and sometimes compound through the process flow.

INCLUSIVENESS: if the base estimate excludes certain costs that tend to happen, more cost growth can be expected. The variable used in the model is the percentage of three commonly needed, but excluded, elements in the base cost estimate, each scored as 1 if included and 0 if not: (e.g., if 1 of 3 items is included, variable is 33.3 percent)

- land purchase/leases/property rentals,
- initial plant inventory/warehouse parts/catalysts,
- pre-operating personnel costs.

R&D: The interaction of the status of process R&D and project definition was found to have a compounding affect on cost growth. This effect was captured by using a different coefficient for the PROJECT DEFINITION variable if the process technology was still in R&D phases at the time of the estimate.

Overall

Each variable had an independent and statistically significant effect on the cost growth, could rationally be considered causal, and together accounted for 83 percent of the total variance in the sample dataset cost growth (project-specific risks likely explain much of the residual). The final model takes the following form: