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Improving Cost Estimation with Quantitative Risk Analysis

Be More Precise by Employing Uncertainty

by Gregory Nolder, Vose Consulting

Introduction

Traditional cost estimation methods provide no insight to possible AND probable outcomes

We have all heard about the many large publicly funded infrastructure projects that have gone far over budget and as a consequence have drawn great levels of negative attention. The reality is that not only do large public projects go over budget but the majority of large public, as well as private, capital projects are likely to end up over budget.

For executives, managers and their teams responsible for project cost estimation, it is a difficult challenge to produce an accurate project cost estimate that takes into account the risks and uncertainties capable of causing costs overruns. This whitepaper will introduce and discuss cost estimation techniques based on quantitative risk analysis[1] that can improve the estimation of a project's budget, including contingency and escalation costs, by taking into account risks and uncertainties. If applied correctly, quantitative risk analysis will allow a cost estimation team to not only forecast the range of possible costs but also the probability of those costs. In addition, this paper will discuss several of the hidden pitfalls that must be avoided when using quantitative risk analysis for cost estimation.

Traditional Cost Estimation

The following is a simplified and concise overview of the traditional cost estimation process:

- Based on the current level of a project's scope and design, historical data and courtesy quotes from sub-contractors and other vendors are used to get starting point estimates at the system, sub-system or line-item level.
- These starting numbers are adjusted based on current or recent levels of material, labor, equipment and other cost items. This becomes a base-case estimate for the total costs of the project.
- An additional escalation amount is added to each cost item to allow for inflation of labor, material and equipment costs.
- Also, an additional contingency amount (often a % that is based on the 'maturity' of the project scope) is added to the overall project to allow for other costs which may be uncertain and/or are beyond control such as regulatory, scope creep, etc.
- The resulting budget is composed of a single-point base-case estimate plus single-point escalation and contingency estimates. This total is often considered the 'upper estimate' for the total project cost.

One study indicates that the accuracy of cost estimation for large projects has not materially improved over the last 70+ years

Historical Perspective

There are many examples of spectacular cost overruns in large public projects:

- **Boston's Big Dig:** *The Boston Globe* has reported that this project will end up costing almost $22 Billion which is a little under 1000% higher than originally estimated[2].
- **Denver international Airport:** The original cost estimate was $1.7 Billion but the actual cost was more than $4.2 Billion according to *The Denver Post*[3].
- **Channel Tunnel:** Construction cost overruns of 80% and financing cost overruns of 140%[4].
- Many more

In fact, one study of transportation infrastructure projects suggests that as many as 9 out of 10 have exceeded their initial cost estimates[5]. In addition, the same study indicates that the accuracy of cost estimation for projects has not materially improved over the last 70+ years.

- Understanding this 'any other possible cost' can certainly be useful. However we gain no insight on how probable it is that the most-likely or upper-estimate might occur. We also have no understanding of the "opportunity" that the project may end up below budget and what factors are most influencial in driving the project's risk.

Clearly there is opportunity for improving upon currently used contingency/escalation cost estimation techniques.

Root Causes

Let's first consider and review some of the root causes for cost overruns:

- **Technical:** Cost estimation is in essence attempting to predict the future which is by nature difficult, if not impossible, because even the best forecasting techniques are inherently imperfect. There are a number of technical factors, financial and otherwise, which are intrinsically uncertain. Examples might be interest rates, commodity prices, supply/demand for sub-contractor resources, regulatory environment, the economic cycle, project duration and many more internal as well as external factors.
- **Economic/Political:** It may be that there are project stakeholders with economic or political reasons for underestimating the costs of a project. Individuals or groups often have an interest in the approval of a particular project – job creation, business success, political influence, etc – and therefore strive to make a project appear financially more attractive to decision makers or the public.
- **Psychological:** It is just human nature that most project planners simply tend to underestimate the potential for unexpected cost increases. This is known as "optimism bias"[6].

Cost overruns are often caused by ignoring the uncertainties and risks inherent in the project

While the above list is not inclusive, it illustrates that the actual costs of a project are often greatly affected by unknowns and risks. Ignoring such uncertainties and risks in the estimation process therefore often causes projects to overrun their budgets.

What is Quantitative Risk Analysis and How Can it Help You?

Typically, there are a large number of uncertainties involved in the generation of cost estimates for a large project. One way to take into account, understand and possibly manage these uncertainties is through a technique called "Quantitative Risk Analysis". Quantitative risk analysis is a process that identifies and quantifies the uncertainties associated with a project and then develops a 'probabilistic model[7]' to represent the project. The output of this model then provides a view of the risk and uncertainty associated with cost of the overall project as well as the component parts of the project.

For example, the output from a quantitative risk analysis model can answer many questions such as: "What is the probability that the total cost of the project will exceed a specific value?" with the answer in the form of "There is a 20% probability that the total costs will exceed $10 Million."

Uncertainties and risks in a quantitative risk analysis model are usually represented by a probability distribution. For example the costs associated with structural steel are no longer represented in the cost estimate as a single point with an additional allowance for escalation as in traditional estimating. Instead, structural steel costs would now be represented by a range of possible costs, including escalation, along with the probability of each possible cost for structural steel.

Systemic risk drivers should be included in the model

In addition to modeling the costs for particular line items or sub-systems, it is recommended to model the uncertainty associated with potential risks that might affect multiple line items or sub-systems. These risks are often called "Risk Drivers" - examples of such risk drivers might be weather, regulatory permitting, main contractor risks, the level of design completion when the estimate is produced, etc. Risk drivers can also be represented by probability distributions but it important to also identify which specific cost items might be affected by each risk driver and the impact of the risk driver.

Failure to consider the relationships between variable can under estimate the actual risk in the project

When modeling individual cost items as well as risk drivers, it is important to carefully consider the impact of systemic relationships in the project being modeled. One example might be that the labor cost for installing structural steel is directly proportional to the amount of structural steel in the project. As the amount of structural steel increases, so does the amount of structural steel labor. It is critical that this relationship be included in the model as a correlation. The model should not be permitted to estimate the structural steel labor at the low end of its possible range while simultaneously estimating the amount of structural steel at the high end of the range. If this were to happen, the final result of the model would under-estimate the possible range of the overall project cost.

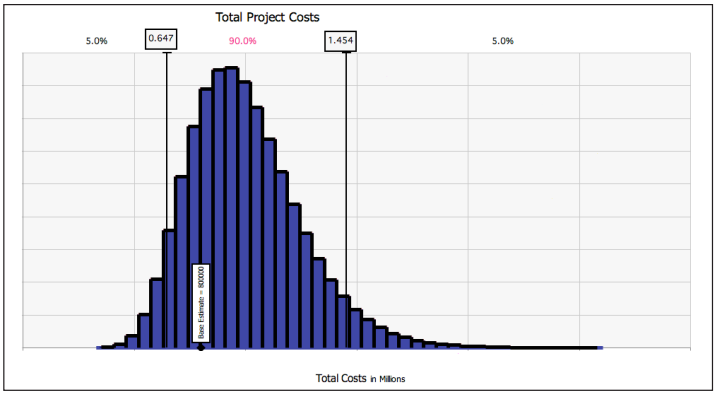
Risk-based cost estimation models are usually solved by Monte Carlo Simulation

The resultant risk-based cost estimation model is now composed of a large number of probability distributions which are being combined based on the project being modeled. It is usually impossible to mathematically calculate a model containing a number of dissimilar probability distributions that may have been modeled with dependencies and correlations. Therefore, in practice, quantitative risk analysis models are usually built and solved using a technique called *Monte Carlo Simulation* [8]. A number of tools exist for implementing Monte Carlo Simulation models with the most widely used being Oracle's Crystal Ball[9], Palisade Corporation's @RISK[10] and Primavera's Pertmaster[11].

Monte Carlo Simulation

Monte Carlo (MC) simulation is a quantitative risk analysis technique in which uncertain inputs in a model (for example an Excel spreadsheet) are represented by probability distributions (instead of by one value such as the most likely value). By letting your computer recalculate your model over and over again (for example 10,000 times) and each time using different randomly selected sets of values from the (input) probability distributions, the computer is using all valid combinations of possible input to simulate all possible outcomes. The results of a MC simulation are distributions of possible outcomes (rather than the one predicted outcome you get from a deterministic model); that is, the range of possible outcomes that could occur and the likelihood of any outcome occurring. This is like running hundreds or thousands of "What-if" analyses on your model, all in one go, but with the added advantage that the 'what-if' scenarios are generated with a frequency proportional to the probability we think they have of occurring.

Example Model Output



Like the input parameters, the results of Monte Carlo Simulation models are also in the form of probability distributions that essentially take into account all uncertainties and risks (see inset). These output distributions provide a range of all possible costs AND an understanding of which outcomes are more probable. In addition, through sensitivity analysis, the model results can provide an understanding of which cost items or risk drivers should be focused on by management to reduce the project's risks.

Advantages of Quantitative Risk Cost Estimation

Using quantitative risk analysis as a basis for cost estimation can provide a number of advantages over traditional methods, including:

- Risk analysis changes the entire paradigm of how the project team thinks about and addresses cost estimation. The process of building a project risk analysis encourages an open discussion about risks and uncertainty. This by itself is an important and often useful exercise resulting in both reduced risk and reduced cost.
- Cost forecasts are not forced into the "pigeon hole" of single point estimates. Instead, risk analysis recognizes that cost estimates are inherently uncertain. Traditional methods ignore or attempt to "average out" the risk and uncertainty.
- The process helps the project team to also identify risk drivers that project management should focus on to reduce the project's costs.
- It allows stakeholders to better understand the project's risks and the probability of the actual costs being above the base-case estimate or the budget.
- Quantitative risk analysis models should be very transparent and have all assumptions clearly documented to encourage acceptance by all stakeholders. This transparency also allows managers to identify areas in the cost estimate where some of the root causes for cost overrun (technical, political, optimism bias) have crept into the model.
- Sensitivity analysis helps identify areas of the project that have the potential for causing the most uncertainty. These are therefore the areas of the project most likely to cause cost overruns and are the areas where the project team would want to concentrate their risk management efforts.

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Who Should Produce the Risk Analysis?

One school of thought is that the cost engineers or managers associated with the project should lead the effort to produce a risk-based cost estimate. What usually happens when this path is chosen is often a scenario similar to the following:

- A Monte Carlo software tool is selected;
- One or several of the cost estimators is given the software and sent to a software training course;
- Those folks are then expected to produce a comprehensive, transparent, easy to use and accurate cost estimation model in (often) a very short period of time.

In many cases this is unfortunately a recipe for failure, for the following reasons.

A cost engineer experienced in traditional estimation techniques will likely not immediately be a good risk analyst. Producing a quality risk-based cost estimate requires a quite different and new set of skills. It requires someone experienced not only with the specific software tools but also with conducting a workshop, expert elicitation, probabilistic mathematics, correlational identification, model building and documentation (all important and needed for producing an accurate and useful quantitative risk analysis).

Quantitative risk analysis requires a different set of skills than traditional cost estimation methods

In addition, it is important to consider time requirements, learning curves and opportunity costs of having an expert cost engineer pulled away from other productive work. It will probably take an inexperienced analyst doing his or her first risk-based cost estimation three to five times as long as an experienced risk analyst to produce a good and useful cost estimation model.

In the long run it is often less expensive to find and hire an expert risk analysis consulting firm experienced with all facets of quantitative risk analysis as it relates to project risk analysis. Such a firm can develop and document a quality risk analysis model based on your specific needs and business processes in a fraction of the time and for a fraction of the total cost of a completely in-house effort. In addition, a good firm will educate and work with the in-house staff so that they become familiar with the tools and techniques required for the analysis. Not only will the project now have a useful risk-based cost estimate, but the users of the model will be prepared to modify and reuse the model without re-engaging the external consultant.

What to Look For in a Risk Analysis Consulting Firm

Locating, choosing and hiring the best consulting firm capable of assisting with the construction of a probabilistic cost estimate can be a challenging experience. To assist in this process, we provide a few key areas that we consider critically important to the selection process:

- **Technical expertise:** Does the consulting firm have staff with the technical expertise to create a robust and functional yet transparent and user friendly Monte Carlo model? Can they demonstrate proof of such expertise?
- **Experience:** What type of experience does the firm's staff have in the area of project and cost risk analysis? What other types of projects have they worked on? An experienced consultant will produce a better outcome in a shorter period of time.
- **Broad background:** There are many statistical, probability and modeling techniques and tools available. Choose a consultant with broad experience (i.e. not just a consultant that knows a certain software package) so that they are familiar with a variety of techniques and can apply the best mix of available methods to your situation.
- **Customer focused and flexible:** It is important for a consultant to pay careful attention to your specific requirements and provide a customized solution tailored to your needs.

Choose a consultant that will not just provide a black box cost model but will also work to increase the risk analysis expertise of your staff

- **Informative and educational:** Work with an outside firm that is truly interested in raising the level of knowledge of your entire team. Also, the solution you receive should be completely transparent and not be a "black box" that only the consultant understands. With increased expertise and a transparent model, your team should be able to modify and reuse the solution without the need for re-hiring the consultant.
- **Personal service:** You should expect personal yet professional service, a high level of responsiveness, complete integrity and independence from a risk analysis consultant. Be sure to ask for and check references, request a proposal outlining what services will be provided as well as complete costs and a timeline.

Next Steps

This paper has only briefly introduced the application of quantitative risk analysis to the field of project cost estimation. If you need help starting, implementing or completing a risk-based cost estimation program, consider contacting Vose Consulting. We offer a wide range of services and have extensive experience including:

- **Facilitating the development of a dedicated internal risk analysis function:** We have helped a number of large corporations design, develop, train and implement an internal risk analysis department.
- **Risk analysis modeling:** We can rapidly design, develop, and validate complex risk analysis models customized to your specific cost estimation and project risk requirements.
- **Model review:** Vose Consulting has reviewed a large number of models built by our clients. We can produce an assessment of your model's soundness, completeness and accuracy as well as provide recommendations for improvement. Many clients have found this to be a very valuable and cost effective service.
- **Training courses:** We offer both public and custom in-house training courses in the area of quantitative risk analysis.
- **Workshops:** Our clients have often found a hands-on custom project risk analysis workshop to be very effective. We meet with the client for approximately one to three days where we provide intense customized training in a specific area of interest as well as develop together a model based on the client's specific needs. At the end of the workshop, the client leaves with a robust functioning model in combination with the knowledge and experience needed to modify and enhance the model on their own.
- **Custom software tools:** Risk analysis models are often built using standard, off-the-shelf software tools and in most cases this is works very well. Sometimes however, if may be necessary or desired to have a custom software tool or application built for specific and unique requirements. Vose Consulting has a team of highly experienced professional software engineers who have built a number of bespoke risk analysis applications for our customers.

Conclusion

We hope this paper has been useful for you. We invite you to let us know your questions, insights, suggestions and ideas at info@voseconsulting.com.

Please contact us at sales@voseconsutling.com to discuss Vose Consulting services, training or software.

Also, please visit our website www.voseconsulting.com to see our client list as well as additional whitepapers, case studies and the list of currently scheduled training courses.

You are also invited to download ModelAssist, a FREE risk analysis training tool from our colleagues at Vose Software – http://www.vosesoftware.com/modelassist.htm.

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[1] Vose, D. (2008). *Risk analysis: A quantitative guide, 3rd Edition.* West Sussex, England: John Wiley & Sons, Ltd. ISBN: 978-0-470-51284-5

[2] http://www.boston.com/news/traffic/bigdig/articles/2008/07/17/big_digs_red_ink_engulfs_state/?page=full

[3] http://docs.newsbank.com/s/InfoWeb/aggdocs/NewsBank/0EAF4448938F99AE/0F1B56E1B179D300

[4] Flyvbjerg, B., Bruzelius, N., & Rothengatter, W. (2003). *Mega Projects and Risk.* Cambridge, UK: Cambridge University Press.

[5] Flyvbjerg, Bent, Mette K. Skamris Holm, and Søren L. Buhl, 2002, "Underestimating Costs in Public Works Projects: Error or Lie?" *Journal of the American Planning Association,* vol. 68, no. 3, 279-295, http://flyvbjerg.plan.aau.dk/JAPAASPUBLISHED.pdf

[6] Flyvbjerg, Bent and Cowi, Procedures for Dealing with Optimism Bias in Transport Planning: Guidance Document (London: UK Department for Transport, June 2004). 61 pp, http://flyvbjerg.plan.aau.dk/0406DfT-UK%20OptBiasASPUBL.pdf

[7] A probabilistic model can basically be seen as a costs estimation that takes into account likelihoods or chances that some risks and uncertainties may or may not happen.

[8] For additional information on Monte Carlo Simulation see our website at: http://www.vosesoftware.com/ModelRiskHelp/index.htm#Monte_Carlo_simulation/Monte_Carlo_Simulation_introduction.htm

[9] http://www.oracle.com/crystalball/index.html

[10] http://www.palisade.com/

[11] http://www.primavera.com/products/pertmaster/index.asp