INTEGRATED COST AND SCHEDULE RISK ANALYSIS USING MONTE CARLO SIMULATION OF A CPM MODEL
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TCM Framework: 7.6 – Risk Management

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Contributors:

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.

Dr. David T. Hulett (Author)               John K. Hollmann, PE CCE CEP
Christopher P. Caddell, PE CCE           Donald F. McDonald Jr., PE CCE PSP
Tommy Clarke                            Oscar A. Mignone
Dr. Ovidiu Cretu, PE                   Stephen P. Warhoe, PE CCE CFCC
Kevin M. Curran                         Robert F. Wells, CEP
Michael W. Curran                       Dr. Trefor P. Williams
Patrick B. Egger                        Ronald M. Winter, PSP
Ricardo Garcia da Roza                  David C. Wolfson
John M. Hale                            Rashad Z. Zein, PSP
Dennis R. Hanks, PE CCE
This recommended practice (RP) of AACE International defines the integrated analysis of schedule and cost risk to estimate the appropriate level of cost and schedule contingency reserve on projects. The main contribution of this RP is to include the impact of schedule risk on cost risk and hence on the need for cost contingency reserves. Additional benefits include the prioritizing of the risks to cost, some of which are risks to schedule, so that risk mitigation may be conducted in a cost-effective way, scatter diagrams of time-cost pairs for developing joint targets of time and cost, and probabilistic cash flow which shows cash flow at different levels of certainty.

The methods presented in the RP are based on integrating the cost estimate with the project schedule by resource-loading and costing the schedule’s activities. The probability and impact of risks/uncertainties are specified and the risks/uncertainties are linked to the activities and costs that they affect. Using Monte Carlo techniques one can simulate both time and cost, permitting the impacts of schedule risk on cost risk to be calculated.

These methods can be used both by the contractor and the owner. The contractor usually has a more detailed schedule and understanding of resource allocations used to put the costs into the schedule. The owner may use a more summary schedule and summary notion of resources, but still is able to put the costs into the schedule at a summary level. In fact there are many risks to the owner that do not affect the contractor as risks. Also, the contractor will not know about some of the owner’s risks, such as having insufficient resources. In the case of joint venture owners the JV is often a marriage of convenience of disparate organizations with risks arising from different goals and methods.

This RP is consistent with the Total Cost Management (TCM) Framework Section 7.6 Risk Management. In particular, the entry in the TCM Section 7.6.2.2 Identify and Assess Risk Factors, highlights the fundamental “risk factors (or drivers) are events and conditions that may influence or drive uncertainty (i.e., either opportunities or threats) in asset or project performance.” This RP uses the same approach, starting with the RP section Simulating Using Risks as Drivers and illustrating the method in the case study.

This RP is intended to provide guidelines (not a standard) for integrated cost and schedule risk analysis which is generally considered to be good.

It is based on the recognition that some resources such as labor, rented equipment (e.g., drill rigs, cranes) and level-of-effort (LOE) support (e.g., project management team or quality/safety staff) will respond to risks to schedule because they cost more if they are engaged on the project longer than planned because of schedule delays. This method has been applied to cost and schedule risk in many industries and in commercial as well as governmental projects, so it is generic. One finds in applications of integrated cost-schedule risk analysis that some of the most important cost risks are actually viewed by project participants primarily as risks to the schedule that indirectly extend the use of resources. Applying the methods described in this recommended practice will highlight the identity and mechanism by which risks to schedule might cause cost risk.

This recommended practice describes an improvement in cost risk analysis over the traditional methods that address cost risk without explicit reference or, indeed, any reference at all to the project schedule and its risk. In this analysis the interaction between schedule risk and cost risk is modeled explicitly to develop several results; (1) the schedule contingency reserve, (2) the cost contingency reserve, (3) the joint probability distribution of project...
cost and schedule, (4) the priority risks leading to the need for these reserves of time and budget, and (5) prioritization of project risk, which can lead to efficient actions to mitigate both time and cost risk.

The platform of this analysis is a cost-loaded project schedule. One may use a summary schedule that is complete and integrated with logic end-to-end or a detailed project schedule. The budget (estimates made without padding for risk) is assigned to the activities using resources that may be summary in nature (e.g., construction, detailed engineering or procurement) or detailed. An analysis of the effect of schedule uncertainty on the impact of cost inflation may or may not be required.

Monte Carlo simulation is the most commonly used approach to analyzing the impact of multiple risks on the overall project schedule or cost risk. Simulating a resource-loaded project schedule derives both schedule risk and the cost risk implications in the same simulation. The main benefit of this RP is to the estimate of cost risk, since the schedule risk analysis in this setting is no different from a schedule risk analysis done without the involvement of resources or costs.

The risk analysis described below is correct only for the current plan, represented by the schedule. The project contingency reserve of time and cost that are the main results of this analysis apply if that plan is to be followed. Of course project managers have the option of re-planning and re-scheduling to the facts of new facts, in part by mitigating risk. This analysis identifies the high-priority risks to cost and to schedule, which assist the project manager in planning further risk mitigation. Some project managers reject the results and argue that they cannot possibly be so late or so overrun. Those project managers may be wasting an opportunity to mitigate risk and get a more favorable outcome.

**BACKGROUND**

Schedule risk has typically been ignored in assessments of cost risk. More recently cost risk analyses have included attempts to represent uncertainty in time, because these analyses occurred outside of the framework of the project schedule.

Only recently have the tools been available to include a full analysis of the impact of schedule uncertainty on the uncertainty in cost. The Monte Carlo tool first calculated labor cost proportional to the duration of activities. This was not a complete assessment of cost risk because it ignored other cost-type risks that are not related to schedule such as risks affecting the labor-type resources’ burn rate per day and the uncertainty in equipment or material cost.

New tools have been developed that allow non-labor resources to vary in cost, as well as modeling uncertain daily rates (burn rates) for labor-type resources. This is not to say that the new software simulation tools are perfect, just that they are at a stage of development that warrants presenting them in an RP.

**RECOMMENDED PRACTICE**

The integrated cost-schedule risk analysis has several inputs, uses specialized Monte Carlo simulation tools, and produces several valuable outputs. A key success factor that should be present is that the organization is “risk-aware,” wants to know the truth about the risks to the project and views the risk analysis as an important input to project success.
Summary of Inputs

Inputs to the analysis include:

- A high quality project schedule, whether a detailed schedule or a summary schedule that represents all of the work, is completely logically linked, does not rely on constraints or lags / leads, has resources loaded, durations are unbiased estimates, and is updated – basically a schedule following recommended practice CPM scheduling.

- A contingency-free cost estimate, meaning that line items do not have padding built in to accommodate risk and there is no below-the-line contingency included.

- Good quality risk data – usually risks that have been identified during a qualitative risk analysis of the project leading to a list of prioritized risks, with probability and impact parameter data collected so that they fully represent the risks and are not biased. Other risk data might include probabilistic risk events that alter the project schedule by adding recovery activities not necessary if the risk does not occur. Without good-quality risk data that is specific to the project being modeled, very little useful information will be derived from this exercise and the conclusions drawn may be incorrect and misleading.

Summary of Tools

The main tool of analysis is a Monte Carlo simulation of the cost-loaded schedule. Monte Carlo simulation is standard practice in quantitative schedule and cost risk applications. Most software packages that simulate project schedules can be used to integrate cost and schedule risk in the same simulations, although some packages are more capable than others.

Other software applications may be developed in this new field of integrated risk analysis. It should be emphasized that this RP is written as the practice is developing rapidly.

Summary of Outputs

Outputs of an integrated cost-schedule risk analysis are:

- How likely are the project plan’s cost and schedule targets to be met given the risk that may affect that plan?

- How much contingency of time and cost needs to be provided to meet the risk threshold or certainty target of the project management or other stakeholders?

- Which risks are most important to the achievement of the project schedule and cost estimate?

- Prioritization of the risk to the schedule and to the cost of the project is an important result. This is a list of prioritized risks results derived from the quantitative analysis and is therefore more accurate than the risk register list that was used as an input to the analysis.

- Risk mitigation actions can be taken based on the prioritized list of risk. These actions can be analyzed using the same risk model that produced the plan contingency reserves of time and cost.

- A unique and useful result is the finding of joint time-cost risk results, often shown as a scatter diagram of time-cost points calculated during the simulation showing the possibility of meeting both time and cost objectives jointly, the so-called joint confidence level (JCL).

- Analyzing the time and cost risk together also leads to a probabilistic cash flow over time that is affected by uncertain costs and uncertain schedules.

INPUTS

Inputs to integrated cost and schedule risk analysis must include the cost estimate where the monetary values are estimated without constraints, a CPM schedule with realistic durations and complete schedule logic that can