AACE INTERNATIONAL RECOMMENDED PRACTICE

123R-22

INTEGRATED COST AND SCHEDULE RISK ANALYSIS AND CONTINGENCY DETERMINATION USING ESTIMATE RANGING AND EXPECTED VALUE WITH MONTE CARLO SIMULATION

AACE INTERNATIONAL

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TCM Framework: 7.6 – Risk Management

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Note: As AACE International Recommended Practices evolve over time, please refer to web.aacei.org for the latest revisions.

Any terms found in AACE International Recommended Practice 10S-90, *Cost Engineering Terminology*, supersede terms defined in other AACE work products, including but not limited to, other recommended practices, the *Total Cost Management Framework*, and *Skills & Knowledge of Cost Engineering*.

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1. INTRODUCTION

1.1. Scope

This recommended practice (RP) of AACE® International (AACE) defines general practices and considerations for integrated cost and schedule risk analysis and estimating contingency using a combination or hybrid of estimate ranging and integrated cost and schedule expected value analysis with Monte Carlo simulation methods. R+EV is used as a shorthand designation for this quantitative risk analysis (QRA) combination. The base methods are covered separately in:

- RP 118R-21, *Risk Analysis and Contingency Determination Using Estimate Ranging for Inherent Risk with Monte Carlo Simulation* [1].
- RP 65R-11, *Integrated Cost and Schedule Risk Analysis and Contingency Determination Using Expected Value* [2].
  Note: RP 65R-11, incorporates methods from RP 44R-08, *Risk Analysis and Contingency Determination Using Expected Value* for cost [3].

Those RPs should be reviewed for details of the respective methods; this RP is focused on how to use them in combination. Descriptions of other recommended risk quantification practices can be found in AACE Professional Guidance Document PGD-02, *Guide to Quantitative Risk Analysis* [4].

The R+EV method is a fit-for-use, practical, risk-driven method intended to support management's need for integrated distributions of bottom-line project cost and schedule outcomes. It is intended to support investment or tender decision making for well-defined, relatively simple, low-technology projects at the sanction or tender phase (i.e., Class 3 or better-defined estimates). See Professional Guidance Document PGD-01, *Guide to Cost Estimate Classification* for more information on Classification [5].

This method is <u>not</u> recommended for projects with significant systemic risks including projects at early scope definition phases (Class 10, 5 or 4) or with significant complexity, and/or with significant levels of technology[1]. Complexity can result in non-linear behaviors not usually captured by estimate ranging and can also result in large numbers of minor risk events that together are significant but are not usually quantified in either ranging or expected value methods. This exclusion from usage results from the estimate ranging method's limitations (see: RP 118R-21). For Class 4 or better definition, hybrid methods combined with parametric modeling are recommended when there are significant systemic risks; refer to either:

- RP 113R-20, *Risk Analysis and Contingency Determination Using Combined Parametric and Expected Value* [6] or
- RP 117R-21, *Integrated Cost and Schedule Risk Analysis and Contingency Determination Using a Hybrid Parametric and CPM Method* [7].

For Class 10 or 5 definition, where systemic risks are dominant, the parametric method, used alone, is recommended (i.e., RP 42R-08, *Risk Analysis and Contingency Determination Using Parametric Estimating* [8]).

While this method can provide limited insight of risks to some activities or milestones, this method is <u>not</u> recommended for projects needing to understand schedule risk at a detailed level (i.e., more detailed than Level 1 or just the completion date) such as the impact of risk on specific schedule activities or on intermediate milestones (these projects also tend to be more complex). This exclusion from usage results from expected value method limitations regarding schedule (see: RP 65R-11). For detailed scheduling needs, QRA methods employing the risk-

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[1] For an example method of measuring complexity or technology, see the Rand model in RP 43R-08, *Risk Analysis and Contingency Determination Using Parametric Estimating – Example Models as Applied for the Process Industries* [18]

driven critical path schedule method (CPM) are recommended including:

- RP 57R-09, *Integrated Cost and Schedule Risk Analysis using Risk Drivers and Monte Carlo Simulation of a CPM Model* [9] or
- RP 117R-21, Integrated Cost and Schedule Risk Analysis and Contingency Determination Using a Hybrid Parametric and CPM Method [7].

The method also excludes quantification of escalation risks (see: RP 68R-11, *Escalation Estimating Using Indices and Monte Carlo Simulation* [10]).

1.2. Purpose

This RP is intended to provide guidelines, not a standard, for contingency estimating that most practitioners would consider to be good practices that can be relied on and that they would recommend be considered for use where applicable. There are a variety of useful risk analysis and contingency estimating methodologies; this RP, combined with other QRA RPs outlined in PGD-02, will help guide practitioners in developing or selecting appropriate methods for their situation.

It is an AACE recommendation that whenever the term *risk* is used the term's meaning should be clearly defined for the purpose of the practice. This hybrid method is intended to quantify two types of risks for cost and schedule: *inherent* and *critical*[2] *project-specific* risks. It is not intended for *systemic* risks when they are significant (i.e., when the systemic risks are much greater than the inherent risks).

1.2.1. Inherent Risks - General

RP 10S-90, *Cost Engineering Terminology* definition of inherent risk is “A risk that exists (but may or may not be identified) due to the very nature of the asset, project, task, element, or situation being considered [11]. A similar 10S-90 term that could be said to apply is *background risks* which is defined as “A set of non-event risks specific to the risk quantification method which cause variability for which probability of occurrence is 100%. When using a particular method, the limited specific uncertainty must be communicated”. For specificity then, a third definition in 10S-90 for *background variability* may be most applicable (this is found as one of three alternate definitions for the general term *uncertainty*). That definition states that background variability is uncertainty that is “distinct from the variation caused by identified risks, that is caused by at least three common factors in projects; (a) inherent variability of the work not caused by identified risks, (b) estimating error and error of prediction, and (c) bias in estimating or prediction.”

1.2.2. Inherent Risks - Duration

The estimate ranging method in RP 118R-21 quantifies the cost impact of *inherent* risk. However, there is no RP with equivalent detailed mechanisms for deriving duration impact values for inherent risks. RP 32R-04, *Determining Activity Durations* [12] speaks of inherent risk duration, and the CPM-based QRA RPs 57R-09 and 117R-21 incorporate inherent risk duration impacts as 3-point ranges. However, the only methods defined for deriving the values of the range are general statements that they can be obtained from workshops, interviews and/or from the analysis of historical data. Therefore, this RP incorporates inherent risk duration impacts using the same general

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[2] Critical project specific risks are those with the potential of creating significant impacts on project success in terms of cost and/or schedule and ultimately profit or other general outcomes. The criteria for a risk being identified as critical are defined in RP 65R-11.

approach, i.e., a 3-point distribution with values derived from workshops, interviews and/or from historical data analysis.

1.2.3. Project-Specific Risks

The expected value method in RP 65R-11 quantifies the cost and schedule impact of *project-specific* risks. The 10S-90 definition of project specific risk is "uncertainties (threats or opportunities) related to events, actions, and other conditions that are specific to the scope of a project. (e.g., weather, soil conditions, etc.). The impacts of project-specific risks are more or less unique to a project." They consist primarily of risk events (i.e., probability of occurrence of less than 100%), but also include project-specific condition uncertainties (probability of occurrence is 100%; such as significant variability in weather impacts or soil conditions). These risks are clearly identifiable and commonly included in risk registers.

1.2.4. Systemic Risks (not covered except Inherent Risks)

This hybrid method is not recommended for projects with significant *systemic* risks. RP 10S-90 defines systemic risk as "uncertainties (threats or opportunities) that are an artifact of an industry, company or project system, culture, strategy, complexity, technology, or similar over-arching characteristics." This encompasses inherent risks but is broader. The historical data analysis used for parametric modeling of systemic risks captures the impacts of a wide spectrum of uncertainties that extend to the overall project system's interaction with external systems, uncertainty causes such as the level of complexity and technology, but also the nominal impacts of minor, non-critical risk events which often fall off the risk management radar.

Figure 1 uses a Venn diagram to illustrate the concepts of inherent risks and *critical* project-specific risks. The dashed lines encompass risks covered by this RP. Note that if systemic risks are not significant, and the number of minor risk events is insignificant (reflecting the limitations for using this RP), then systemic risks become roughly analogous to inherent risk and the dashed inherent and project-specific pieces converge to essentially cover all the risks on these simpler, well-defined projects.

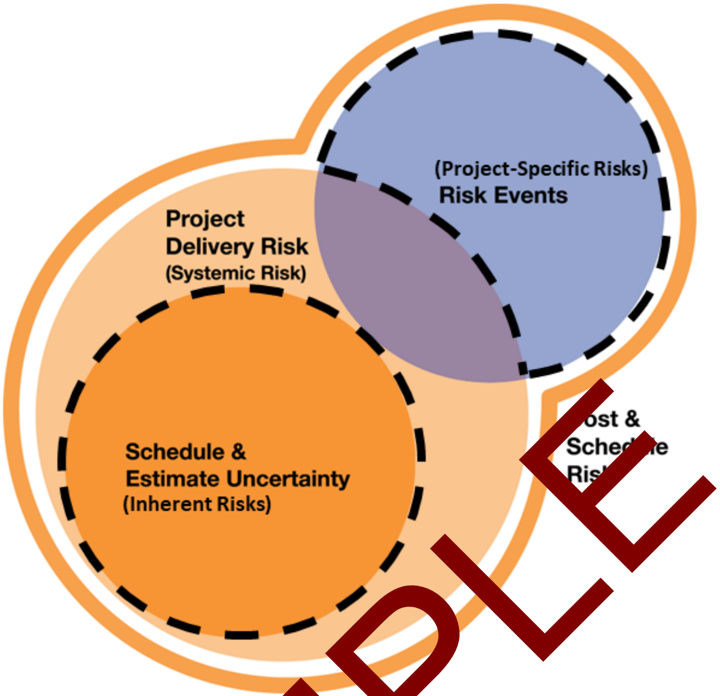

Figure 1 – Inherent and Critical Project-Specific Risks Covered by this RP

1.3. Background

The integrated, hybrid cost and schedule risk quantification method covered by this RP combines estimate and schedule ranging of inherent risks and expected value with Monte Carlo simulation (EV w/MCS) modeling of project-specific risks. R+EV is used as a shorthand designation for the combination. The component methods are addressed in RPs 118R-21 (plus the description of duration ranging herein) and 65R-11 respectively. Two methods are combined because no single method is optimal for quantifying both inherent and project-specific risks when scope is well defined (i.e., Class 3 or better-defined estimates). MCS is used in both the ranging and EV methods and to integrate the analyses results. MCS is needed for the combination because only the mean values of the individual method outputs are additive (e.g., the overall cost or duration, at say P70 confidence level, is not the sum of the separate analyses P70 values). Figure 2 illustrates the hybrid concept:

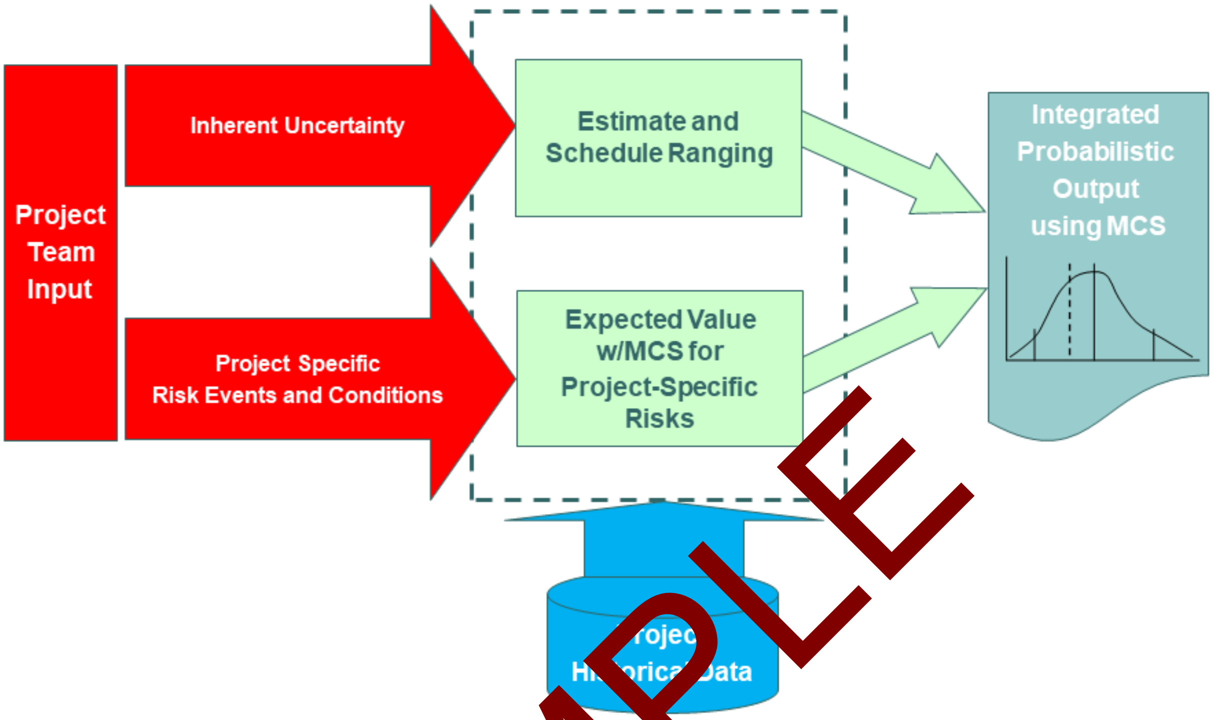

Figure 2 – Hybrid of Ranging and EV w/MCS method (R-EV)

In the EV method as defined in RP 65R-11, only *critical* project-specific risks are quantified, i.e., those with the potential of creating significant impacts on project success in terms of cost and/or schedule and ultimately profit or other general outcomes (the criteria for a risk being identified as critical are defined in RP 65R-11). Most risks in a risk register will not meet these criteria. For these critical risks, the quantitative analysis will first assure that the nature of the risk is well understood (e.g., is the root cause understood, has too much credit been taken for mitigation efficacy, etc.?), and the probability of occurrence and their impact will be reviewed; the information in a risk register should not be accepted and used verbatim.

Inherent risks by definition are generally not identifiable as to a specific cause; it is background variability. For this risk type, estimate and duration ranging are applied. The typical quantitative analysis challenge with ranging is that often there is limited historical data to inform the analysis, putting the onus on subjective team inputs from workshops or interviews. Subjective inputs are prone to bias (optimistic or pessimistic), which, if not effectively managed by the workshop facilitator, can greatly distort outcomes. Optimally, a robust historical database is available to provide applicable range metric information (see: RP 114-20, *Project Historical Database Development* [13]). Estimate ranging methods (see: RP 118R-21) attempt to dissect the sources of estimate variability (e.g., contributions of quantity versus rate uncertainty, etc.) providing some assurance that the range is well understood. Duration ranging has no such documented methods. In either case, the quality of the result is highly dependent on the skills and knowledge of both the facilitator and the team providing the input.

The hybrid approach in this RP results in an integrated cost and schedule analysis; it generates both project cost and overall duration distributions. The cost and duration inherent risk can be correlated in the MCS model, and the EV method correlates cost and schedule impacts based on the risk response(s) assessed for each critical risk. A joint confidence level (JCL) determination can be made based on the integrated analysis.

2. RECOMMENDED PRACTICE

2.1. Hybrid Application Steps

This is not a stand-alone RP. In this hybrid approach, details of each of the underlying methods must be reviewed for background. These methods are described in RPs 118R-21, 44R-08 and 65R-11. In addition, RPs 32R-04, 57R-08 and 117R-21 can be reviewed in respect to their discussions of inherent duration uncertainty ranging (although the treatment is limited). The following describes the steps of implementing the R+EV hybrid method.

2.1.1 Precursor Tools

The steps of this process assume that tools are in place for: 1) estimate ranging of inherent risk; and 2) expected value analysis with MCS for project-specific risks. A tool that pulls these together, and that adds duration ranging of inherent risks will be needed as well. The tools are typically custom Excel-based worksheets[3] using an MCS add-on. It is possible to implement basic MCS in Excel without an add-on, but it tends to be cumbersome and offers limited risk analysis capabilities (e.g., dependencies are difficult to model).

The examples in Section 2.2 provide more information on typical tools. Note that the method described is quantifying the distribution of cost growth and schedule (duration) slip resulting from the risk drivers. These define the contingency contributions. The overall project cost distribution is then the sum of the base cost and duration estimate values and these distributions. With the tools in place, the steps in applying them as a hybrid application are as follows:

Step 1: Apply Estimate Ranging Model for Inherent Risk (See RP 118R-21)
Assess and quantify the cost ranges (usually 3-point distributions at various levels of estimate breakdown) of the estimate elements as appropriate and enter them in the estimate ranging model. Note that the examples in RP 118R-21 model total cost as the final output. For the hybrid model, modify the ranging model output to generate the cost growth (the resulting total cost distribution minus the base cost estimate value). For the hybrid model, only this cost growth output distribution will be carried forward as an input to the overall MCS model (with correlation to the duration uncertainty described in Step 3).

Step 2: Determine Overall Project Duration Distribution for Inherent Risk
Quantify the inherent duration uncertainty for the overall project from the start to the completion milestone. This is typically a 3-point estimate (low, most likely, high or L/ML/H) with an associated 3-point probability distribution function (PDF). The inputs to the distribution will be obtained from a workshop and/or interviews, optimally supported by historical data analysis of duration ranges for similar projects (after adjusting the historical metrics to deduct an allowance for the schedule impact of known critical risk events). The historical data analysis must attempt to isolate the impact of the inherent duration uncertainty; and disregard the schedule impact from known critical risk events.

This distribution entry can be added as a separate element to the bottom of an estimate ranging worksheet in order to support an integrated hybrid application. The L/ML/H duration values can be entered as risk factors (e.g., 0.90, 1.05, 1.20) for which the result, after MCS, will be multiplied times the base duration (e.g., 1.05 times 20 months) or duration uncertainty can be modeled as direct overall duration values (e.g., 18, 21 and 24 months). As with the estimate ranging model, add a calculation to determine the schedule slip (the total duration distribution minus the

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[3] AACE makes no endorsements or recommendations for specific software. Any references to software used in this RP are for illustrative purposes only.