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

TCM Framework: 7.6 – Risk Management

February 22, 2023

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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 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. 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 (i.e., 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-21, *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 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 in regard to schedule (i.e., RP 65R-11). For detailed scheduling needs, QRA methods employing the risk-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 is a range 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, that the term's meaning 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 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).

<u>Inherent Risks-General</u>:
RP 10S-90, *Cost Engineering Terminol*ogy 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 identifiable risks, that is caused by *at least* three commonly-found 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."

<u>Inherent Risks-Duration</u>:
The estimate ranging method in RP 118R-21 quantifies the <u>cost</u> impact of *inherent* risk. However, there is no RP with equivalent detailed mechanisms for deriving <u>duration</u> impact values for inherent risks. No AACE references of any kind were identified for doing this. RP 32R-04 *Determining Activity Durations* [12] speaks of 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 approach; i.e., a 3-point distribution with values derived from workshops, interviews and/or from historical data analysis.

<u>Project-Specific Risks:</u>
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 primarily consist 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 specifically identifiable and commonly included in risk registers.

Systemic Risks (not covered):

As was stated 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 (mostly risk events but also condition uncertainties). The dashed line encompasses risks covered by this RP. Note that if systemic risks are not significant, and the number of minor risk events is insignificant (i.e., 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.

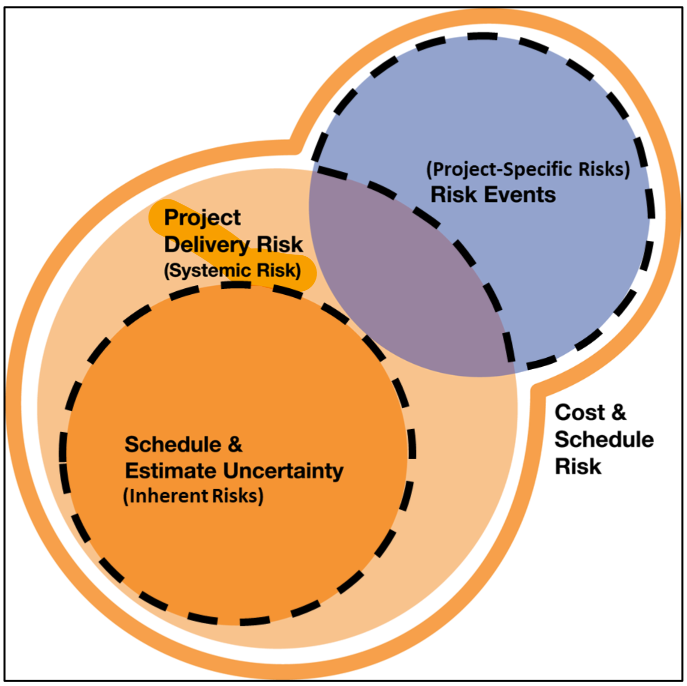

Figure 1 – Inherent and Critical Project-Specific Risks Covered by this RP

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). 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:

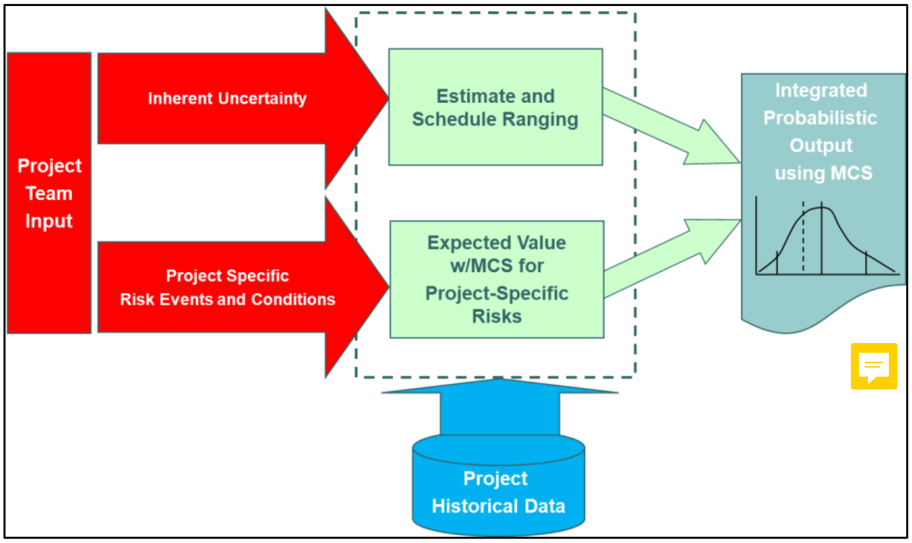

Figure 2 – Hybrid Ranging and EV w/MCS method (R+EV)

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; i.e., the information in a risk register should not be accepted or used verbatim.

Inherent risks by definition are generally not identifiable as to a specific cause; i.e., 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 always subject 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 (re: RP 114-20 *Project Historical Database Development* [13]). Estimate ranging methods (i.e., 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 the facilitator.

The hybrid approach in this RP results in an integrated cost and schedule analysis; i.e., 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. Being integrated, a joint confidence level (JCL) determination can be made.

2. RECOMMENDED PRACTICE

2.1. Hybrid Application Steps

As discussed, RPs 118R-21, 44R-08 and 65R-11 must be reviewed for background and details of each of the underlying methods. 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). This is not a stand-alone RP. The following describes the steps of implementing the R+EV hybrid method.

<u>Precursor-Tools</u>

The steps of this process assume that tools are in place for 1) estimate ranging of inherent risk and 2) for 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, for each risk type and overall, are typically custom Excel-based worksheets 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:

<u>Step 1: Per RP 118R-21; Apply Estimate Ranging Model for Inherent Risk</u>

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 which is 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 per Step 3).

<u>Step 2: Determine Overall Project Duration Distribution for Inherent Risk</u>

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 which is the total duration distribution minus the base duration estimate value. For the hybrid model, only this schedule slip output distribution will be carried forward as an input to the overall MCS model (with correlation to the cost uncertainty per Step 3).

<u>Step 3: Quantify the Inherent Cost and Duration Distributions Correlation</u>

The hybrid model must apply a correlation coefficient(s) between the inherent cost and duration distributions for MCS from Steps 1 and 2. A key driver of inherent risk uncertainty is bias in the base estimate and schedule and the respective biases tend to drive the uncertainty correlation factors. For example, consider the case where a large high range was assigned to the cost distribution to reflect the team's opinion that the quantities are understated for a generally aggressive base estimate. In that case, if an MCS iteration samples the cost distribution at this high end (implying more quantity than estimated), then arguably the MCS sampling of the duration estimate should also lean to its high end (i.e., it takes more time to install additional quantity indicating a strong correlation), especially if the base schedule was also generally aggressive. However, what if the scheduler, working independently, had a conservative bias and padded their base durations? In that case, estimate and schedule development are more independent (not a good practice) and the correlations will be weaker.

Determining correlation coefficients is challenging in the best of circumstances. Typically (as described in RP 118R-21), the inputs about inherent cost and duration correlations will be qualitative (e.g., high, moderate, low correlation) and the analyst will need to translate these into quantitative values for the model. General rules such as 0.75, 0.5 and 0.25 for high, moderate, low correlations may be used (although negative correlations are possible); more scientific methods for inherent risk are usually not justified. The important point is to address correlation through looking at how integrated the estimate and schedule development process was (the more integrated, the more correlated) and their relative biases (the more that the bias is directionally the same, the more correlated). A conservative approach (because more correlation adds more span to outcome distributions) is to start with all correlations being set to 1.00 (i.e., assuming a highly integrated estimating/scheduling process) and then only reducing the correlation when there is a valid reason. Alternatively, when knowledge of the estimating process is less, a correlation coefficient of 0.5 is suggested as a reasonable rule of thumb[1].

Note that there will be a temptation to add a separate time-dependent cost allowance to the duration uncertainty outcome; however, with appropriate correlations, as schedule varies to the high side, so too will costs and vice-versa.

Step 4: Per RP 44R-08; Screen the Risk Register and Identify Critical Risks

Optimally, the risk register will already have categorized each risk by quantification method type to be applied (i.e., create a column in the risk register to identify if the risk is systemic, project-specific, escalation or currency). This categorization can be a challenge because the individual risks in a register are often not well titled or described as to their nature and cause. In general, the more ambiguous, or the more the risk is in the nature of a worry or an issue, the greater the likelihood a risk is inherent or systemic.

Further screen the project-specific risks to develop a list of those that are *critical* and refine the descriptions of their nature and cause. The definition of critical risks is included in RP 44R-08, but in general these are risks that have a material impact on the project economics. Risks are selected based on their post treatment, residual status. Check for any risks that were critical pre-treatment, but non-critical after mitigation; assure that the risk reduction credited to the mitigation is realistic. Post treatment, there should typically be no more than 5 to 15 critical risks, keeping in mind that by definition any one critical risk will put the project success at risk. Having too large a number of truly critical risks implies that the project may not be viable. Note that escalation and currency risks are not covered in this RP (see RP 68R-11).

Step 5: Per RP 44R-08; Quantify the Probabilities of Occurrence

Capture the critical risk titles and clear description in the EV tool (do not link to the risk register; start fresh). Assess and input the percent probability of occurrence for each critical risk (again, this is post-treatment residual risk). Probability can be treated as a distribution depending on the team's confidence in their assessment as discussed in RP 44R-08. Establish any dependencies between the risks (or combine risks if they are similar in nature), again as discussed in RP 44R-08 and/or 65R-11.

Step 6: Per RP 65R-11; Quantify the Burn Rates

The *burn rate* is the approximate spending per month (or other period used) during the anticipated delay duration. This typically includes direct field labor, indirect costs (e.g., temporary facilities, general services), and owner and

[1] The Rand Corporation research referenced in RP 42R-11 found a correlation coefficient of 0.41 between cost growth and schedule slip outcomes [8]

contractor project and construction management. Burn rate can be estimated on a case-by-case basis or pre-determined for project contracts (e.g., site preparation) or phases. These burn rate estimates are generally Class 5 in quality realizing that cash flow can vary widely, some portion of the labor may be productively employed on other activities, and so on. Optionally, the burn rate(s) could be entered as a 3-point distribution in MCS.

Step 7: Per RP 65R-11; Plan the Risk Responses

Determine and document the assumed or planned risk response (i.e., the contingency or contingent plan). Note that this response is the ex-poste action(s) the team will take if and when the risk occurs. It is not a treatment or mitigation (hence the term treatment and response are separate and unique in this methodology). The response in large part defines the scope of the impact estimates. For example, if the project is schedule-driven, money may be no object (within reason) to the business in order to recover the schedule; so, a fast/costly risk response is defined. If management is unsure as to the response, then the impact estimates in the next step will have a correspondingly wide range to cover the various response possibilities.

Step 8: Per RP 65R-11; Quantify the Schedule and Cost Impacts

Estimate and input the schedule and cost impacts of each critical risk. These are typically 3-point estimates with an associated 3-point probability distribution function (PDF). The impact estimates reflect the risk response(s) anticipated, i.e., the risk response largely defines the scope of the impact estimate.

For schedule, the duration impact, considering the risk response, is to the completion milestone. As described in RP 65R-11, team knowledge of what is on or near the critical path and the network's general, dynamic behavior is needed. If confidence is low in understanding of the impact to the completion date, this should be reflected in the range of the 3-point delay estimate.

For cost, the impact is a combination of time-dependent costs for schedule delays plus the non-time driven cost considering the risk response. The time-dependent cost is the schedule delay times the applicable burn rate from Step 6. The non-time dependent cost is the range of potential expenditures considering the risk response.

The EV tool must be set up to perform the calculation of the EV of the cost and of the schedule duration impact of each risk (i.e., probability times impact). In MCS, the simulation results for each risk, or subtotal of several risks, can be captured independently if desired. This subtotal result can be used to assess the impact on intermediate milestones if one or more of the risks drive that milestone (see RP 65R-11).

Step 9: This RP; Integrate the Ranging Outputs into the EV Model (this creates the hybrid)

To integrate the cost and duration ranging results with the EV results, include "inherent risk" and its cost growth and schedule slip output distributions (re: Step 1 to 3) as the first critical risk in the EV w/MCS tool. The probability of occurrence of the inherent risk is 100 percent per the definition of inherent risk. Inherent risks are treated as independent of the project-specific risks for this method.

Step 10: This RP; Run the R+EV MCS Simulation

The R+EV tool must be set up to sum all of the cost (cost growth) and duration (schedule slip) impacts for the inherent and critical project-specific risks. Running the MCS will generate the overall distributions of these risk sums (plus any subtotal that were defined as MCS outputs).

Adding the base cost and duration estimates to the risk outputs will provide the overall cost and schedule distributions. From the total distributions, determine the overall cost and schedule contingency (and reserves if appropriate) based on risk policy or management's risk tolerance. The cost and schedule results are integrated since there is correlation between the inherent cost and duration outcomes and the project-specific risk impacts in the EV method are based on assumed risk responses that consider cost/schedule trading.

Figure 3 summarizes the hybrid R+EV application in flow chart format. Note the input of ranging inherent risks into the EV w/MCS model is shown in the bottom row. Escalation is not included in the R+EV method but is shown here to illustrate that the cost and schedule distributions can be used as inputs to a probabilistic escalation tool (re: RP 68R-11).

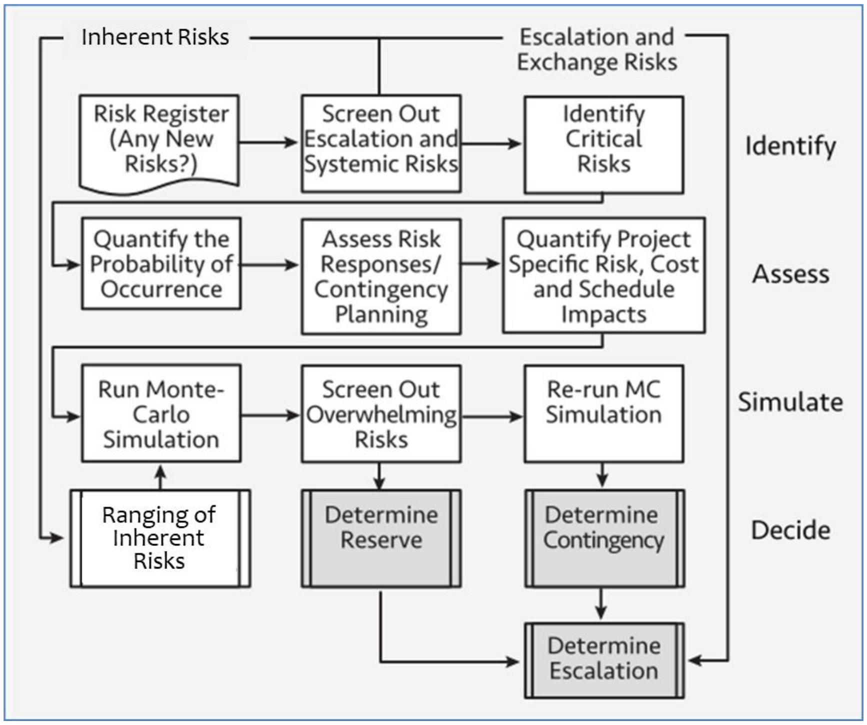

Figure 3 – Hybrid Ranging and EV w/MCS Method Flow Chart [[14]**; with permission]**

2.2. Hybrid Tool Example

This section provides an example of a combined R+EV toolset and illustrates the analysis steps applied in a tool. The toolset shown in the example figures are stylized for the RP, but are based on working tools.

2.2.1. Cost and Duration Estimate Ranging Model

Figure 4 is an example inputs table for an estimate ranging worksheet in Excel®. This is taken from RP 118R-21 (with the addition of duration ranging). This example, and Figure 4, are derived from an engineering, procurement and construction (EPC) contractor analysis of cost and duration estimating inherent uncertainty, used as input to an overall hybrid project QRA that adds analysis of critical project-specific risks.

RP 118R-21 describes this example in more detail including comments on its strengths and weaknesses. However, in summary, the example applies estimate ranging at the summary level of a process plant cost estimate that has been broken down by direct (including labor and material categories) and indirect accounts at a discipline level. Duration is entered as the total number of months. In this example, the approach was to multiply probabilistic "range factors" (in this case 3-point distributions) times various cost elements and summing the products. The same is done for overall duration. Using an MCS add-on, the distributions of each individual factor x cost, the subtotals and the total cost are obtained for reporting. The same is done for the duration distribution (i.e., duration factor x duration).

<u>Cost. Duration and Range Factor Inputs</u>

The table labeled "A" on the left side of Figure 4 shows the estimate summary. This table is all inputs and summations; there are no MCS formulae. The worksheet simply sums the direct cost elements to get the direct line-item totals, and then adds the indirect item costs to get various subtotals and the total cost. The direct cost elements (in color) that will be multiplied by range factors are the Labor, Equipment, Bulk Materials and Sub-Contracts cost entries plus the line-item costs entered in the Indirect Cost section. Note that the columns labeled Quantity, Man-Hours and Labor Rate are not used in the model (they were likely shown to match the estimate basis report).

The table labeled "B" on the right of Figure 4 shows the range factor or multiplier inputs for use in trigen distributions. A range factor of 1.00 (or 100% as shown in Figure 4) has no effect on the cost. Trigen is a 3-point distribution requiring a low, most likely, and high input (L/ML/H). This model uses a multiplier of cost rather than entering cost directly as a 3-point range. Another common approach is to enter high/low +/- percentages of the base estimate with 0% often assumed for most likely (an unbiased base estimate); the percentages are applied as factors so the outcome is the same. Note that in this case, the "most likely" factor used was not always 1.00; implying that the team is recognizing the base estimate is somewhat aggressive. Table B is also all inputs; there are no MCS formulae here.

The table labeled "C" on the bottom of Figure 4 shows the base duration entry (in this case execution duration from sanction through mechanical completion) and the range factor inputs for use in trigen duration distributions. The comments regarding table B ranges also apply here.

A. Cost Estimate Summary Tabulation (Cost Inputs)

Item	UoM	Quantity	Hours	Labor Rate $/Hr	Labor Cost $Thous	Equip. $Thous	Bulk Materials $Thous	Sub-Contracts $Thous	Total $Thous
<u>Direct Cost</u>									
Site Prep	m3	2,361	4,946	80	396	0	87	57	540
Earthworks	m3	94,448	38,475	80	3,078	0	295	4,023	7,395
Civil	m3	6,460	154,506	80	12,360	0	2,976	0	15,336
Architecture	m2	3,413	8,549	80	684	0	84	319	1,087
Structural Steel	ton	886	68,704	100	6,870	0	3,159	0	10,030
Mech Equipment	each	194	92,968	100	9,297	22,805	0	0	32,102
Vessels	ton	210	23,923	100	2,392	569	0	305	3,266
Piping	m	11,205	87,737	100	8,774	0	2,774	122	11,670
Electrical	each	58	7,696	100	770	2,816	0	0	3,586
Cables	m	241,742	71,958	100	7,196	0	2,511	1	9,708
Raceway	m	73,844	86,880	100	8,688	0	1,136	0	9,824
Instrumentation	each	801	16,886	100	1,689	1,519	2,472	595	6,275
Subtotal									110,818

B. Risk Factor (multipliers) Inputs entered as Low/Most Likely/High Ranges

Item	Labor: Hours Low	Labor: Hours ML	Labor: Hours High	Labor: Labor Rate Low	Labor: Labor Rate ML	Labor: Labor Rate High	Equipment, Materials and Subcontra: Quantity Low	Quantity ML	Quantity High	Price Low	Price ML	Price High
Site Prep	100%	121%	144%	90%	100%	105%						
Earthworks	100%	121%	144%	90%	100%	105%	100%	100%	125%	85%	100%	125%
Civil	100%	121%	144%	90%	100%	105%	100%	100%	105%	95%	100%	110%
Architecture	100%	121%	144%	90%	100%	105%						
Structural Steel	100%	121%	144%	90%	100%	105%	100%	105%	110%	90%	100%	110%
Mech Equipment	100%	121%	144%	90%	100%	105%				100%	100%	128%
Vessels	100%	121%	144%	90%	100%	105%						
Piping	100%	121%	144%	90%	100%	105%	95%	100%	110%	95%	100%	115%
Electrical	100%	121%	144%	90%	100%	105%						
Cables	100%	121%	144%	90%	100%	105%	95%	100%	120%	95%	100%	110%
Raceway	100%	121%	144%	90%	100%	105%						
Instrumentation	100%	121%	144%	90%	100%	105%	95%	100%	110%	85%	100%	110%

Item	Total $Thous	Indirects Low	Indirects ML	Indirects High
<u>Indirect Cost</u>				
Construction Equipment	4,101	95%	100%	120%
Field Indirects Construction Contract	11,729	100%	100%	120%
Fee	8,666	95%	100%	115%
Freight	3,664	90%	100%	120%
Vendor Reps	1,802	90%	100%	120%
Spare Parts	1,441	90%	100%	120%
Initial Fills	1,018	90%	100%	120%
Field Distributable cost	2,224	90%	100%	120%
Camp, Catering & Lodging	5,829	95%	100%	115%
Precomm & Comm	382	90%	100%	120%
Subtotal Indirect Cost	40,855			
<u>EPC Services (Home & Field Office)</u>				
Home Office Services	11,087	90%	100%	110%
Field Office Services	8,517	90%	100%	125%
Subtotal EPC Services	19,604			
TOTAL COST	171,276			

C. Duration Inputs and Inherent Risk Low/Most Likely/High Ranges

			Low	ML	High
Execution Duration	21	months	95%	100%	120%

Figure 4 – Example Cost and Duration Model Inputs for Inherent Risks

<u>MCS Distribution Application</u>

Note that this RP (and other QRA RPs involving MCS) expects users to have basic familiarity with applying MCS. The details of defining distributions and dependencies are not covered here. Also, it is difficult to illustrate MCS application, which largely takes place within spreadsheet formulae with software-specific terms, so the example's MCS approach is described narratively.

The general MCS approach as shown in Figure 5 was to multiply probabilistic range factors times the respective cost and duration inputs as were shown in Figure 4. For example, Equipment cost was multiplied by a range factor applied as a trigen distribution with input low, most likely and high factors of 1.00, 1.00 and 1.28. When the MCS simulation is run, the add-on will iteratively sample (e.g., say 10,000 iterations) from this range factor distribution, multiply it by the Equipment cost, and hence derive and store a dataset of resultant products of factors x cost for Equipment. These factor x cost products for various elements are then subtotaled and then finally grand totaled, and each total can also be named, stored and reported as outputs by the MCS application.

Figure 5 also shows at the bottom that duration uncertainty was quantified in a similar manner with the only connection to cost being defined correlation coefficients between the duration and appropriate cost element range factor distributions.

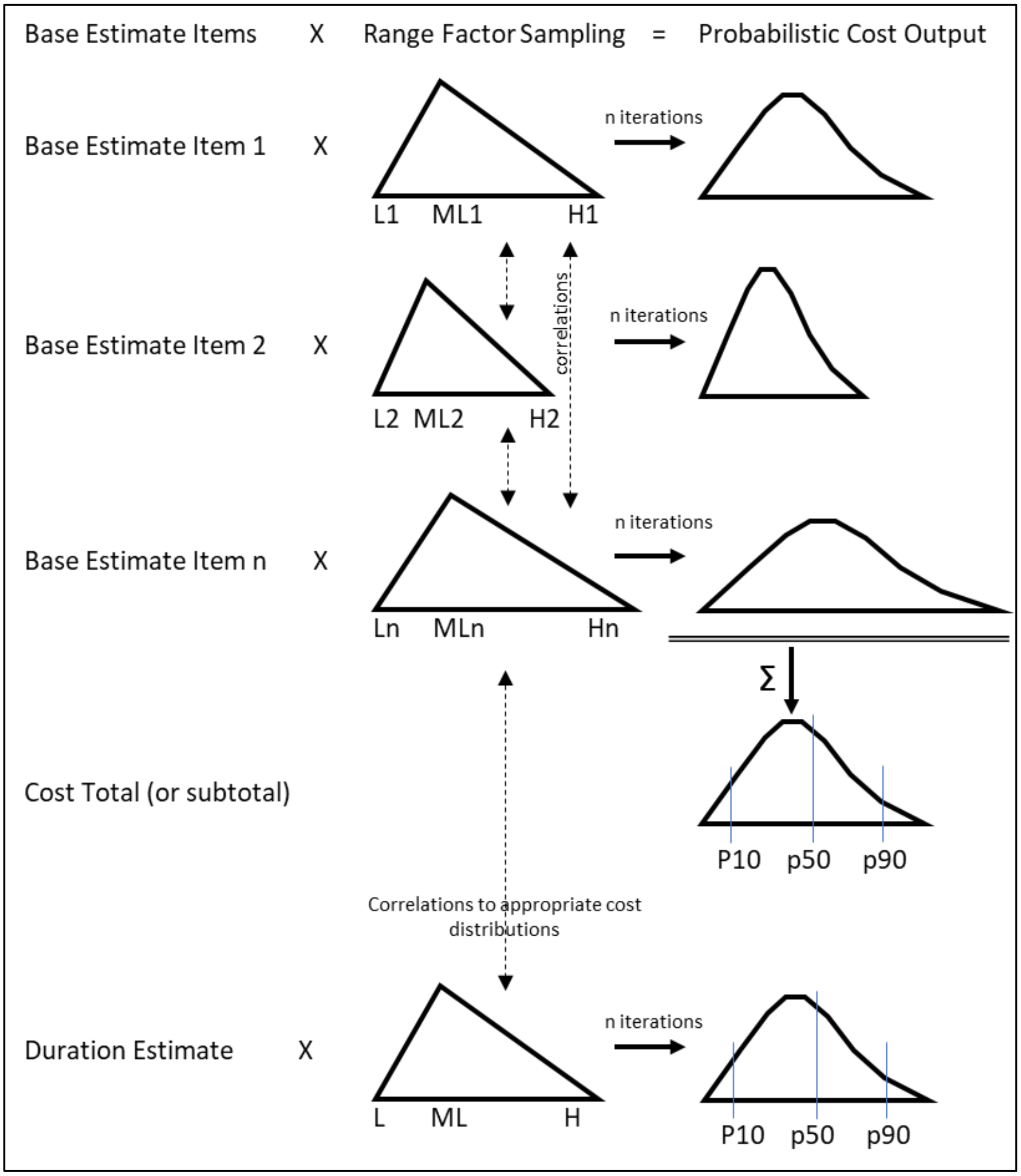

Figure 5. Illustration of the Example MCS Application by Cost Item and for Duration Using Range Factors

The total cost and duration distributions will typically be of most interest to management; it is used to decide on contingency values. For example, if management decides (or if it is company policy) to fund contingency at a 50 percent confidence level of underrun (p50), then that value (and any p-value such as the p10 and p90 for the range) from the total distribution can be displayed using an MCS add-in formulae. The outcome p-values can be presented in tabular form, a frequency diagram (as illustrated in the bottom curve of Figure 5) or cumulative frequency diagram (s-curve).

The example MCS used *trigen* distributions of the low, most likely, and high range factors. The example in Figure 4 assumes that the team's inputs (and/or the facilitator's ability to elicit true lows and highs) were optimistically biased (see RP 66R-11 concerning distributions). [15] The selection of distributions and the various distribution attributes

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applied are assumptions that need to be challenged by the facilitator. Again, this example MCS application is not a recommendation but an illustration of how a variety of MCS approaches is possible.

<u>MCS Dependency Application</u>

MCS best practice requires that correlation be defined between distributions where there is a dependency relationship between them. This is illustrated by the dashed arrows in Figure 5. Correlation can be somewhat addressed outside of MCS math; for example, performing the QRA at the discipline level of costs assumes all detailed items within that discipline behave the same way (i.e., they are 100% correlated). Similarly, the example model combined the productivity & rates (and the quantity & price) for costs through multiplication of their L/ML/H values and only applying the trigen distribution to the resultant L/ML/H product of the multiplication. This multiplication likewise assumes 100% correlation of these drivers. Such base modeling assumptions are often of a questionable nature as they are here. For example, why should all Civil detail items be correlated and why should productivity (hours) and labor rates be correlated?

Correlation can also be addressed through the MCS add-in formulae. The example model assumes that three sets of item distributions are internally correlated; i.e., the labor item distributions, the bulk material and subcontract item distributions, and the indirect item distributions (major equipment price was assumed to be not correlated to anything). The example does not define correlations between these broad cost categories. For example, civil and piping discipline labor cost are assumed correlated, but direct labor and indirect costs are not. It should be obvious to an estimator that the later assumption is questionable (e.g., if direct labor hours increase, so too will field office indirect costs).

The last correlations in Figure 5 are between the duration range factor distribution and the cost range factor distributions as appropriate. In the example which has multiple cost range distributions by element, correlations between the cost estimate quantity and hour inputs and duration make sense (more quantity and hours implies longer duration), but correlation between the rates and prices and duration is not as logical.

2.2.2. R+EV Model

Figure 6 is a snapshot of a simplified R+EV tool model worksheet in Excel®. Note that this is the same tool worksheet as used in the Parametric + EV example in RP 113R-21 with the exception that step 4 carries over the inherent risk from the ranging model rather than the systemic risks from the parametric model. It has been set up to use PDFs and an MCS add-on. In a fully developed tool, there would be more thorough entries, enhanced features such as 3-point probabilities and burn rates, etc. The various user input sections are numbered and described as follows:

1) Enter the base cost estimate and schedule duration.
2) Enter the critical risks (e.g., one risk is entered for a *Mudslide* in Figure 6).and probability of occurrence (re: section 2.1, step 5) This could be enhanced to 3-point entry and PDF application. Note the inherent risk probability is 100%.
3) Enter the burn rates (re: section 2.1, step 6) for respective contract/elements. This would usually be enhanced to contain multiple possible burn rate elements/phase/contracts and so on, and the user could select, for each critical risk, which burn rate applies. It could also be enhanced to 3-point entry and PDF application.
4) This section carries over the cost and duration ranging model outcomes for inherent risks. A trigen PDF has been applied; this is risk #1 in the R+EV tool with MCS.
5) Finally, enter the critical risk responses (re: section 2.1, step 7) and schedule and cost impacts (re: section 2.1, step 8) (only one risk entry area is shown). The mean results of probability x impact are shown. In addition, the sum of the means of all the risks and the total mean project schedule duration and cost are shown.

After running the MCS simulation, the outcome distribution tables at the bottom are populated from which management may determine contingency and reserves values.

1) Base	Cost Estimate	$ 1,000,000					
	Duration (mos)	30					
2) Critical	Critical Risk Entry	Probability					
Risks	Mudslide	20%					
	Example Risk 2	0%					
	Example Risk 3	0%					
	Inherent Risks	100%					
3) Burn Rates		$/month					
	General	$ 10,000					
	Main Contract	$ 30,000	Used below, but can override for each risk				
4) Inherent Risk (carried over from Ranging tool)							
	Duration	Months				Cost %	Cost $
p10	1%	0.3	**3 point percentage outcomes for schedule slip and**			-10%	$ (100,000)
p50	13%	3.9	**cost growth are carried over from the ranging model,**			9%	$ 90,000
p90	28%	8.4	**and multiplied by the base cost and schedule duration**			35%	$ 350,000
	Schedule Months (EV)	**4.3**	< Risk Trigen applied to the 3-point estimates >			Cost (EV)	**$ 120,100**
5) Critical Risks: (only one shown: same work table for each risk					Note: results are probability x impact		
	Risk Response	Mobilize maximum resources to quickly remove mud, build retaining wall, and restore road					
	Schedule Impact	Months	Time Driven $	$/mo	Non-time Driven $		Total Cost
	Low	1.0	General	$ 10,000	Low	$ 100,000	
	Most Likely	1.5	Main	$ 30,000	Most Likely	$ 150,000	
	High	2.0	Burn Rate	$ 40,000	High	$ 250,000	
	Schedule Months (EV)	0.3	Time Driven $EV	$ 12,000	Non-time Driven $EV	$ 31,700	$ 43,700
		Months					Costs
Mean Contingency		4.6	< ∑ of systemic + critical project specific risk impacts >				$ 163,800
TOTAL INCL BASE (mean)		34.6	< ∑ of base values and respective impacts >				$ 1,163,800
OUTPUT Contingency Tables		Total Cost	Contingency	As percent			
COST	10%	$ 950,400	$ (49,600)	-5%			
	20%	$ 1,005,100	$ 5,100	1%			
	30%	$ 1,064,000	$ 64,000	6%			
	40%	$ 1,115,100	$ 115,100	12%			
	50%	$ 1,158,500	$ 158,500	16%			
	60%	$ 1,204,800	$ 204,800	20%			
	70%	$ 1,254,400	$ 254,400	25%			
	80%	$ 1,321,700	$ 321,700	32%			
	90%	$ 1,402,300	$ 402,300	40%			
		Total Duration	Contingency	As percent			
SCHEDULE	10%	30.8	0.8	3%			
	20%	32.0	2.0	7%			
	30%	32.9	2.9	10%			
	40%	33.7	3.7	12%			
	50%	34.4	4.4	15%			
	60%	35.1	5.1	17%			
	70%	36.1	6.1	20%			
	80%	37.2	7.2	24%			
	90%	38.5	8.5	28%			

Figure 6 – Example R+EV Model Integrating Inherent and Project-Specific Risks [[14]; with permission]

3. SPECIAL CONSIDERATIONS FOR HYBRID APPLICATION

The following are considerations for assuring that all critical uncertainties and risks are covered by the combined methods (keeping mind that this tool is not to be used for projects with significant systemic risks) while also assuring there is no redundancy:

Start-up and Commissioning and Other Phasing

The nature of the risk profile for the execution phase often differs from that of the start-up and commissioning (SU&C) phase. The example was focused on the execution phase (sanction through mechanical completion). However, the example for the inherent risk ranging model could be expanded to include a SU&C cost estimate entry. Also, the SU&C duration and risk factors could be added as their own entries with the overall duration outcome being the sum of the sequential execution and SU&C phases. Project-specific risk events during SU&C could then be added to the EV model section. The same approach could be used for other phased risks.

Uncertainties That are Project-Specific

There are risks commonly found in risk registers that are uncertainties (p=100%) but are not inherent risks (i.e., they are identifiable and manageable to some extent). Examples are weather variability and soils condition variability that are not caused by an event (e.g., not a hurricane). The nominal uncertainty from these risk drivers may partly be covered by the team's ranging inputs (e.g., quantity of rock in the soil); however, extreme (critical) condition variability may not be covered in these ranges. For example, assume an analysis was based on 20% of a pipeline trench containing rock; however, the trench may be just one item in a broad civil discipline entry and the trench rock risk may not have received full attention. In this case, the risk that the rock content may range from say 10% to 80% of the trench length could be added as a critical specific condition uncertainty in the EV tool. Note that extreme or critical variation is not an event; i.e., there is 100% probability the rock content will not be exactly 20%. This example risk should be entered as an uncertainty (p = 100%)with a most likely cost impact of 0% (quantity and cost is the same as the base plan) but a low and high reflecting the extreme variability applicable to that right-of-way.

Impacts to Intermediate Milestones

While the EV method cannot examine the impact of risk to the internals of a CPM model, it is capable of assessing impacts to a major intermediate milestone. Perhaps the most common example are projects with seasonality where a harsh winter, monsoons or other condition change puts a premium on completing part of the work prior to the onset of the adverse season (i.e., a phased project). The section on dealing with SU&C describes how the duration uncertainty could be quantified by phase in the ranging model. For risk in the EV model, the phasing approach is described in RP 65R-11. However, in summary, it involves creating a subtotal of the schedule impacts for risk events that occur prior to the seasonal deadline plus that phase's inherent duration risk. This subtotal is made an MCS output that one can review independently of the later phase(s). After running the MCS, a review of this subtotal will provide the distribution of the pre-milestone delay. From that a decision could be made whether to revise the schedule to include an appropriate schedule contingency buffer prior to the intermediate milestone. The R+EV method is quite flexible for addressing various risk analysis situations like this that may arise.

3.1. Note on Joint Confidence Level (JCL) Determination

In 2009, the National Aeronautics and Space Administration (NASA) instituted a policy that certain project budgets were to be based on a "joint cost and schedule probabilistic analysis" with budgets to reflect a "percent probability that the project will be completed at or lower than the estimated amount AND at or before the projected schedule." [16] NASA calls this the joint confidence level or JCL. In NASA practice, the JCL is based on the cost-loaded CPM-based risk analysis method. However, CPM modeling is not required for JCL; the hybrid P+EV method integrates cost and schedule and supports JCL determination. Figure 7 is an example cost and schedule MCS output scatterplot (in this case using Palisade @Risk® software) from the R+EV hybrid method. Note that RP 65R-11 also has an example JCL plot; in that case resulting solely from the project-specific risks.

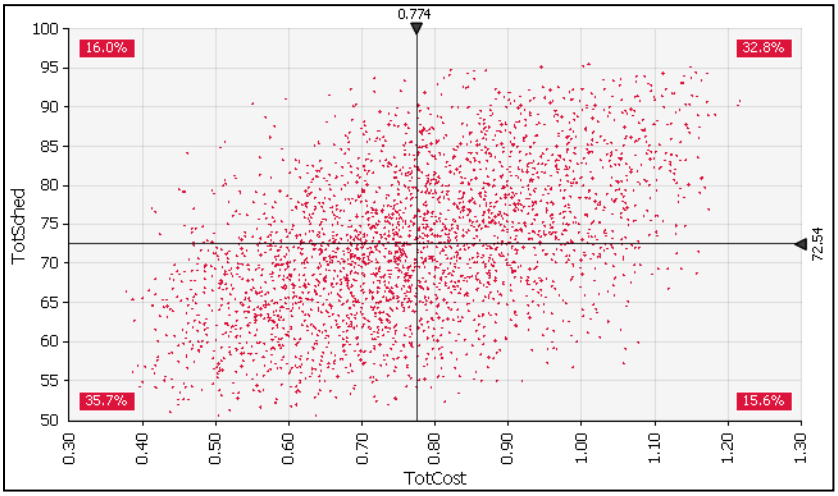

Figure 7 – Example JCL Graph from a R+EV Hybrid Model [using Palisade @Risk® software]

4. COMPARISON OF THE R+EV HYBRID METHOD TO RP 40R-08 PRINCIPLES

RP 40R-08, *Contingency Estimating – General Principles*, provides objective principles against which one can assess the suitability of a contingency estimating method [17]. The following are the RP's general principles that any methodology developed or selected for quantifying risk impact should address:

- Meet client objectives, expectations and requirements.
- Part of and facilitates an effective decision or risk management process (e.g., TCM).
- Fit-for-use.
- Starts with identifying the risk drivers with input from all appropriate parties.
- Methods clearly link risk drivers and cost/schedule outcomes.
- Avoids iatrogenic (self-inflicted) risks.
- Employs empiricism.
- Employs experience/competency.
- Provides probabilistic estimating results in a way the supports effective decision making and risk management.

Table 1 summarizes how the R+EV hybrid method performs in respect to the principles.

First Principles	Hybrid R+EV Method Characteristics
Meets client objectives and requirements	Realistic and practical for projects without significant systemic risks. Can be used for estimates and schedules of any quality at Class 3 or better. It is highly customizable.
Part of a risk and decision management process	The method is risk driven supporting risk management. The EV method is an elaboration of the risk matrix (no conceptual discontinuity between qualitative and quantitative assessment).
Fit-for-use	Can be used on any estimate or schedule of any quality and can be applied using common software (i.e., spreadsheets with MCS add-on) that can be customized.
Starts with identifying risk drivers	It does not address systemic risks well which limits its use to better-defined projects with lower complexity and technology. Elements of inherent uncertainty can be assessed in the ranging method and critical project-specific risks are individually assessed.
Links risk drivers and cost/schedule outcomes	Driver-to-outcome linkages are explicit for project-specific risks and uncertainties (albeit not suitable for high systemic risk projects). The EV method focuses on risk response planning incl. cost/schedule trading. Cost and schedule inherent uncertainty can be correlated. Method supports JCL.
Avoids iatrogenic (self-inflicted) risks	Ranging can be done in a way that minimizes correlation challenges (e.g., range subtotals or similar cost items). The EV method only quantifies critical project-specific risks which also minimizes MCS correlation challenges.
Employs empiricism	While it is optimal to use historical data in the ranging and EV methods, good data is generally not available at most companies. The method is largely dependent on the elicitation skills of the facilitator to assure experiences of the team are brought to the table.
Employs experience /competency	As with all methods, requires experienced risk analysis facilitation. Not using CPM, the EV method requires experienced planner/scheduler input.
Provides probabilistic estimating results	All integrated methods covered by AACE RPs produce probabilistic outcomes. Supports JCL evaluations.

Table 1 – R+EV Hybrid Method versus RP 40R-08 General Principles

Table 2 provides a strength/weakness evaluation of the P+EV hybrid method.

Strengths	Weaknesses
• Integrates cost and schedule analysis • Allows changes to schedule logic due to risks to be included without the complexity of branching in CPM • Ranging leverages team's knowledge of the estimate and schedule basis • Explicit risk-impact linkage for project-specific risks • Fairly simple, flexible and widely used method can be applied in a myriad of ways (e.g., various levels of detail for ranging) • EV method addresses risk response (i.e., cost/schedule trading)	• Ranging is highly subjective and can be prone to team bias • No explicit empirical basis • Does not address significant systemic risks; hence not applicable to early phases (e.g., not for Class 10, 5 or 4) • Not being CPM model based, requires more skilled/intuitive scheduling assessment • The EV method does not encourage the use of quality planning and schedule methods Does not support evaluation of the risks to intermediate schedule milestones as directly as CPM-based methods.

Table 2 – R+EV Hybrid Method Strength and Weaknesses

5. SUMMARY

This RP provides guidance to practitioners in developing or selecting appropriate methods for their situation with the understanding that no one method is best for quantifying all types of risk. This RP integrates cost and schedule risk analysis (and supports JCL) using a hybrid approach. It documents the steps to combine the ranging and expected value methods covered by other RPs in detail. It provides an example using a demonstration toolset. It also documents situations where a hybrid approach requires or may benefit from special considerations.

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