(RISK.03)
Integrated Cost and Schedule Risk Analysis:
A Draft AACE Recommended Practice

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at the Atlanta Marriott Marquis

TCM - Cost Engineering on My Mind

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AACE® International’s 54th Annual Meeting
Atlanta, Georgia
• David T. Hulett, Hulett & Associates, LLC

• Degree:
  – Ph.D.

• University:
  – Stanford University

• Years of Experience:
  – 20+

• Professional Field:
  – Project risk analysis and management, project scheduling
Purpose

• The purpose of integrated analysis of schedule and cost risk to estimate the appropriate level of cost contingency reserve on projects

• The main contribution 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 cost risk mitigation may be conducted in a cost-effective way.
Linkage of Schedule and Cost Risk

- Some resources such as labor, rented equipment and level-of-effort support by the project management team will cost more if they are engaged on the project longer than planned because activities take longer than expected.
- Risks to schedule will also be risks to the cost of these resources.
Platform / Risk Model

Resource-Loaded Schedule

• The platform of this analysis is a resource-loaded project schedule
  – One may use a summary schedule or a detailed project schedule

• The budget (without contingency) must be assigned to the activities
  – Using resources that may be summary in nature (e.g., construction, detailed engineering or procurement) or detailed
Monte Carlo Simulation

- Monte Carlo simulation is the standard approach to discovering 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 implication in the same simulation
- The results also produce a list of risks that are prioritized through the risk model, for risk mitigation
Inputs

• A best-practice project schedule, basically a schedule following recommended practice CPM scheduling. A schedule of 300 – 1,000 activities can summarize and represent a large project in this strategic analysis.

• A contingency-free cost estimate, meaning that line items do not have contingency padding built in 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 are characterized by their probability and impact ranges.
Outputs

• 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 of the project management or other stakeholders?
• Which risks are most important to the achievement of the project schedule and cost estimate?
• A unique and useful result is the finding of joint time-cost risk result joint probability distribution, often shown as a scatter diagram of time-cost points showing the possibility of meeting both time and cost objectives jointly.
Best Practice CPM Schedule 1

- All work needed to complete the project must be represented in the schedule. The schedule should relate to the WBS.
- There should not be any “danglers.” This means that each activity needs a predecessor to its start date and a successor from its finish date.
Best Practice CPM Schedule 2

• The schedule should not rely on date constraints or fixed lags between activities
• The schedule should be recently statused
• The schedule should have resources costed and assigned to activities
  – Summary resources are OK
  – The purpose of these resources is to get the costs on the right activities, not to level resources
  – Sometimes we create hammocks and apply summary resources to those
Example of Resources Used

<table>
<thead>
<tr>
<th>ID</th>
<th>Description</th>
<th>Type</th>
<th>Default Loading</th>
</tr>
</thead>
<tbody>
<tr>
<td>COMM</td>
<td>Commissioning</td>
<td>Labor</td>
<td>Normal</td>
</tr>
<tr>
<td>CONS</td>
<td>Construction</td>
<td>Labor</td>
<td>Normal</td>
</tr>
<tr>
<td>ENG</td>
<td>Engineers</td>
<td>Labor</td>
<td>Normal</td>
</tr>
<tr>
<td>ENV</td>
<td>Environmental</td>
<td>Labor</td>
<td>Normal</td>
</tr>
<tr>
<td>MGT</td>
<td>Management</td>
<td>Labor</td>
<td>Normal</td>
</tr>
<tr>
<td>PMT</td>
<td>Project Management Team</td>
<td>Labor</td>
<td>Normal</td>
</tr>
<tr>
<td>PROC</td>
<td>Procurement</td>
<td>Materials</td>
<td>Spread</td>
</tr>
</tbody>
</table>
Risk Data Inputs

- **Risk events** may or may not happen, but if they do happen they will have a positive or negative impact on the cost or schedule or both
  - Risk events’ probabilities are < 100%
  - They have uncertain impacts as well
- **Uncertainties** include ambiguities such as estimating error and uncertainties such as the level of labor productivity or the price of steel.
  - These uncertainties are 100% likely to occur but their impact on the project cost or schedule is uncertain
Collecting Risk Data

• The input risk data are usually collected in risk workshops or interviews.
  – In workshops the people may be influenced by strong personalities or people in higher positions in the organizations.
  – In individual interview sessions, usually protected by promises of confidentiality, people can discuss their concerns and make estimates without feeling the influence of others.
Risk Drivers (aka Risk Factors)

• The risks’ impacts are specified by 3-point estimates
  – In Risk Drivers (Risk Factors) the impacts are **ranges of multiplicative factors**. The 3-point estimate of impact is converted to a triangular distribution

• Risks are applied to activities
  – A schedule risk will multiply the duration of the activity that it is assigned to
  – For any iteration the software selects an impact at random from the distribution and uses that factor for that iteration
Examples of Three Risk Types

<table>
<thead>
<tr>
<th>Description</th>
<th>Likelihood</th>
<th>Dur Min</th>
<th>Dur Likely</th>
<th>Dur Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Schedule is inaccurate, immature</td>
<td>100.00%</td>
<td>95.00%</td>
<td>105.00%</td>
<td>120.00%</td>
</tr>
<tr>
<td>2. Construction Labor Productivity May Vary</td>
<td>100.00%</td>
<td>90.00%</td>
<td>100.00%</td>
<td>115.00%</td>
</tr>
<tr>
<td>3. Quality, key personnel may be unavailable</td>
<td>70.00%</td>
<td>100.00%</td>
<td>105.00%</td>
<td>110.00%</td>
</tr>
</tbody>
</table>

- Schedule duration estimate immaturity is an **ambiguity**. It has 100% probability of occurring and its impact range is both good and bad.
- Construction labor productivity is an **uncertainty** that, compared to the assumption, could be lower or higher.
- The possibility of quality, key personnel unavailability is a **risk event**
  - It may or may not occur
  - In this case its impact is never to the good
Uncertainty and Ambiguity Risks Occur 100% of the time

Schedule inaccuracy operates 100% of the time (all iterations). On a construction activity of 100 days duration the results are triangular. The construction labor productivity risk would look similar to this figure.
Risk Events are Described by their Probability and Impact

- If probability is < 100%, the risk will occur in that percentage of iterations, chosen at random
- On an iteration if the risk occurs, a factor chosen at random from its impact range will multiply the duration of the activities to which it is assigned
- If the risk does not occur the multiplicative factor is 100% with no effect on duration
Risk Events occur with a Probability < 100%

Here a risk event, the possible unavailability of quality key staff, occurs 70% of the time. Hence, in 30% (900) of the 3,000 iterations the original duration of construction, 100 days, is correct. In 70% (2,100) of the iterations, the duration is longer than 100 days as a triangle.
Risk Driver Strategy

• Risks are usually higher-level strategic risks rather than tactical or technical risks
• Data about risks is derived from in-depth interviews
• A risk is usually assigned to several activities
• An activity may have several risks assigned
A Construction Activity with Three Risks Assigned

The interaction of the three risks produces the expected histogram. In traditional 3-point risk estimating, the analyst and interviewees must approximate the result of three risks on duration. The Risk Driver analysis computes the distribution.
In the traditional approach to risk analysis, the correlation coefficient has to be estimated. Risk Drivers model how correlation occurs and the coefficient is a natural result of the model.
Risk Factors Model How Correlation Occurs (2)

**Risk #1**
- P = 50%, Factors .95, 1.05, 1.15
- Activities A and B correlation calculated to be 48%

**Risk #2**
- P = 25%, Factors .8, .95, 1.05

**Risk #3**
- P = 45%, Factors 1.0, 1.1, 1.2

Risk Drivers model correlation as it is caused in the project based on the common (Risk #1) and confounding (Risks #2 and #3) risks affecting pairs of activities.

The correlation coefficient is the result, not the assumption.
Integrating Cost and Schedule Risk using Risk Drivers

• The risks to activity durations will affect
  – Durations and completion dates
  – Costs of labor-type resources
• For each iteration the cost as well as the finish date is calculated
• Enhanced results include
  – Scatter diagrams (joint distributions) of time and cost
  – Probabilistic cash flows by month
Schedule Risk applied to Activity with Labor Resource – Cost/Time Scatter

<table>
<thead>
<tr>
<th>Risk ID</th>
<th>Risk</th>
<th>Probability</th>
<th>Minimum</th>
<th>Most Likely</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Labor Productivity may be Uncertain</td>
<td>100%</td>
<td>95%</td>
<td>105%</td>
<td>120%</td>
</tr>
</tbody>
</table>

![Graph showing Schedule Risk applied to Activity with Labor Resource – Cost/Time Scatter](image)

RP one-path

Entire Plan: Cost

Cumulative Frequency

<table>
<thead>
<tr>
<th>RP one-path</th>
</tr>
</thead>
<tbody>
<tr>
<td>10/09/2012</td>
</tr>
</tbody>
</table>

Deterministic Point

Inside both limits

Outside both limits
Effect on Cost Risk of Adding Burn Rate Uncertainty

<table>
<thead>
<tr>
<th>Risk ID</th>
<th>Risk</th>
<th>Duration Impacts</th>
<th>Cost Impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Probability</td>
<td>Minimum</td>
</tr>
<tr>
<td>1</td>
<td>Labor Productivity may be Uncertain</td>
<td>100%</td>
<td>95%</td>
</tr>
</tbody>
</table>

Distribution Analyzer

Schedule Risk Alone

Schedule, and Burn Rate Risk
Add Uncertainty in Procurement Costs

• Equipment and material costs may be risky but not generally because their activities’ durations are uncertain

• Putting risk factors on material-type resources causes the risk to be applied to the entire cost

<table>
<thead>
<tr>
<th>Risk ID</th>
<th>Risk</th>
<th>Schedule Impact Factors</th>
<th>Cost Impact Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Probability</td>
<td>Minimum</td>
</tr>
<tr>
<td>1</td>
<td>Labor Productivity may be Uncertain</td>
<td>100%</td>
<td>95%</td>
</tr>
<tr>
<td>2</td>
<td>Suppliers may be busy</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>
Impact on Cost Risk of Adding Risk to Material Resources

Schedule Risk Alone

Schedule, Burn Rate and Material Risk

Schedule, and Burn Rate Risk
## Simple Example: Construction Project

<table>
<thead>
<tr>
<th>ID</th>
<th>Description</th>
<th>Remaining Duration</th>
<th>Start</th>
<th>Finish</th>
<th>Total Cost</th>
<th>Resource Loading</th>
<th>Risk Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>0010</td>
<td>Project Start</td>
<td>0</td>
<td>01-Jan-11</td>
<td>01-Jan-11</td>
<td>$0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0015</td>
<td>Approval Process</td>
<td>90</td>
<td>01-Jan-11</td>
<td>31-Mar-11</td>
<td>$2,070</td>
<td>MGT[Normal];PMT[Normal]</td>
<td>1,4,6,7,8</td>
</tr>
<tr>
<td>0017</td>
<td>Project Sanction</td>
<td>0</td>
<td></td>
<td>31-Mar-11</td>
<td>$0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0018</td>
<td>Environmental</td>
<td>180</td>
<td>01-Apr-11</td>
<td>27-Sep-11</td>
<td>$5,400</td>
<td>ENV[Normal];PMT[Normal]</td>
<td>5,8</td>
</tr>
<tr>
<td>0020</td>
<td>Design</td>
<td>200</td>
<td>01-Apr-11</td>
<td>17-Oct-11</td>
<td>$46,000</td>
<td>ENG[Normal];PMT[Normal]</td>
<td>1,6,7,8</td>
</tr>
<tr>
<td>0030</td>
<td>Procurement</td>
<td>360</td>
<td>12-Oct-11</td>
<td>11-Oct-12</td>
<td>$210,800</td>
<td>PROC[Spread];PMT[Normal]</td>
<td>3,6,7</td>
</tr>
<tr>
<td>0070</td>
<td>Install Equipment</td>
<td>90</td>
<td>12-Oct-12</td>
<td>09-Jan-13</td>
<td>$7,650</td>
<td>CONS[Normal];PMT[Normal]</td>
<td>6,7,8</td>
</tr>
<tr>
<td>0040</td>
<td>Construction</td>
<td>460</td>
<td>18-Oct-11</td>
<td>19-Jan-13</td>
<td>$335,800</td>
<td>CONS[Normal];PMT[Normal]</td>
<td>2,4,5,7,8</td>
</tr>
<tr>
<td>0050</td>
<td>Commissioning</td>
<td>100</td>
<td>20-Jan-13</td>
<td>29-Apr-13</td>
<td>$16,500</td>
<td>COMM[Normal];PMT[Normal]</td>
<td>2,3,4,6,7,8</td>
</tr>
<tr>
<td>0060</td>
<td>Project Turnover</td>
<td>0</td>
<td></td>
<td>29-Apr-13</td>
<td>$0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Diagram:
- **Cost**: Cost breakdown for each task.
- **Resources**: Allocation of resources for tasks.
- **Risk Factors**: Identification and management of potential risks.

### Legend:
- MGT: Management
- ENG: Engineering
- ENV: Environmental
- PROC: Procurement
- CONS: Construction
- COMM: Communication
- PMT: Project Management

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AACE International's 54th Annual Meeting
We have Created and Assigned Eight Risk Factors

<table>
<thead>
<tr>
<th>Description</th>
<th>Dur Min</th>
<th>Dur Likely</th>
<th>Dur Max</th>
<th>Cost Min</th>
<th>Cost Likely</th>
<th>Cost Max</th>
<th>Likelihood</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Design Complexity may Challenge Engineers</td>
<td>90.00%</td>
<td>110.00%</td>
<td>135.00%</td>
<td>100.00%</td>
<td>100.00%</td>
<td>105.00%</td>
<td>40.00%</td>
</tr>
<tr>
<td>2. Site Conditions / Site Access may Slow Logistics</td>
<td>90.00%</td>
<td>110.00%</td>
<td>125.00%</td>
<td>100.00%</td>
<td>100.00%</td>
<td>100.00%</td>
<td>50.00%</td>
</tr>
<tr>
<td>3. Equipment Suppliers may be busy</td>
<td>90.00%</td>
<td>105.00%</td>
<td>130.00%</td>
<td>100.00%</td>
<td>105.00%</td>
<td>110.00%</td>
<td>60.00%</td>
</tr>
<tr>
<td>4. Capable Management may not be Assigned</td>
<td>90.00%</td>
<td>105.00%</td>
<td>125.00%</td>
<td>100.00%</td>
<td>100.00%</td>
<td>100.00%</td>
<td>40.00%</td>
</tr>
<tr>
<td>5. Environmental Agency May be Slow</td>
<td>90.00%</td>
<td>110.00%</td>
<td>125.00%</td>
<td>100.00%</td>
<td>100.00%</td>
<td>100.00%</td>
<td>50.00%</td>
</tr>
<tr>
<td>6. Activity Duration Estimates is Inaccurate</td>
<td>90.00%</td>
<td>110.00%</td>
<td>120.00%</td>
<td>100.00%</td>
<td>100.00%</td>
<td>100.00%</td>
<td>100.00%</td>
</tr>
<tr>
<td>7. Cost Estimate is Inaccurate</td>
<td>100.00%</td>
<td>100.00%</td>
<td>100.00%</td>
<td>95.00%</td>
<td>100.00%</td>
<td>110.00%</td>
<td>100.00%</td>
</tr>
<tr>
<td>8. Key Engineering Personnel may be Unavailable</td>
<td>85.00%</td>
<td>105.00%</td>
<td>120.00%</td>
<td>90.00%</td>
<td>100.00%</td>
<td>110.00%</td>
<td>65.00%</td>
</tr>
</tbody>
</table>
Basic Cost and Schedule Results

P-80 is 16 Dec 2013, a 7-month slip

P80 is $760 million, a 22% reserve
Joint Cost-Schedule Distribution

AACEI Integrated Cost-Schedule Risk

Deterministic Point

Joint C/S Distribution, Cross-hairs at 70% Joint Confidence Level
Probabilistic Cash Flow

Deterministic Cost: $624,220

Cumulative

Deterministic Plan

P-80
# Prioritizing Risks To Cost

## Risks to Cost in Priority Order at the P-80

<table>
<thead>
<tr>
<th>Risk Category</th>
<th>P-80</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALL RISKS IN</td>
<td>760.8</td>
</tr>
<tr>
<td>NO RISK</td>
<td>624.2</td>
</tr>
<tr>
<td>Contingency Reserve at P-80</td>
<td>136.6</td>
</tr>
</tbody>
</table>

## Risks Prioritized for Effect on Cost

<table>
<thead>
<tr>
<th>Risk Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activity Duration Estimates are Inaccurate</td>
<td>39.2</td>
</tr>
<tr>
<td>Site Conditions / Site Access may Slow Logistics</td>
<td>23.2</td>
</tr>
<tr>
<td>Key Engineering Personnel may be Unavailable</td>
<td>18.4</td>
</tr>
<tr>
<td>Cost Estimate is Inaccurate</td>
<td>14.9</td>
</tr>
<tr>
<td>Capable Management may not be Assigned</td>
<td>13.4</td>
</tr>
<tr>
<td>Equipment Suppliers may be busy</td>
<td>9.1</td>
</tr>
<tr>
<td>Design Complexity may Challenge Engineers</td>
<td>3.4</td>
</tr>
<tr>
<td>Environmental Agency may be Slow</td>
<td>0.1</td>
</tr>
<tr>
<td><strong>TOTAL Contingency Accounted For</strong></td>
<td><strong>121.6</strong></td>
</tr>
</tbody>
</table>

Some Interaction Effects are not Captured

Prioritize risk mitigations using this table
QUESTIONS?

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