Modern Methods of Schedule Risk Analysis using Monte Carlo Simulations

Presented to the 2017 Large Facilities Workshop
Baton Rouge, LA

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Agenda

• Modern Methods of risk analysis
• Collecting risk data
• Introducing uncertainty to the model
• Introducing risks as Risk Drivers
• Risk drivers model correlation between activity durations
• Risks may be entered in series or in parallel
• Offshore gas production platform project
• Use Categories to apply risks to multiple activities
• Prioritizing risks for management action
• Risk mitigation actions and Results (simple example)
• Probabilistic branching for test failure possibility
MODERN METHODS OF RISK ANALYSIS
Modern Methods of Schedule Risk Analysis (1)

- Earlier methods of quantifying risk analysis using Monte Carlo Simulation (MCS) placed probability distributions directly on activity durations
  - Did not distinguish risks from uncertainty
  - Could not disentangle the relative impacts of several risks on one activity
  - Could not assess the whole impact of a risk that affects more than one activity
  - Therefore, could not prioritize risks for risk mitigation
Modern Methods of Schedule Risk Analysis (2)

• In the last 10 years we have been able to specify risks and use those to directly drive the MCS
  – Distinguish uncertainty from risks
  – Model specific risks including systemic risks from benchmarking data
  – Represent failing a test with probabilistic branches

• This development allows us to model much more specifically and intelligently
  – Apply risks to multiple activities (categories of activities)
  – Apply risks in series and in parallel
  – Model how duration correlation occurs
  – Prioritize risks for focused risk mitigation
COLLECTING RISK DATA
Collecting Risk Data
Using Confidential Interviews

• Data about risk may start with the Risk Register
• During one-on-one confidential interviews we always discover risks not on even well-developed and maintained Risk Registers
• This omission may be because there are some Unknown Knows that are not talked about in workshops
• Collect descriptions of the risk, probability it will occur, impact (multiplicative factors) on the scheduled durations and activities it will affect if it occurs
• Collect data on uncertainty too – 100% likely to occur with some impact
INTRODUCING UNCERTAINTY TO THE MODEL
Add components of Risk - Uncertainty

- Uncertainty is akin to “common cause” variation in the six sigma management
- “Common cause variability is a source of variation caused by unknown factors that result in a steady but random distribution of output around the average of the data. Common cause variation is a measure of the process’s potential, or how well the process can perform when special cause variation is removed. ... Common cause variation is also called random variation, noise, non-controllable variation, within-group variation, or inherent variation.”

https://www.isixsigma.com/dictionary/common-cause-variation/
Uncertainty ranges can be applied to different types of activities “reference ranges” Uncertainty can be correlated, in this case 100% to make overall project uncertainty model what people said during interviews
Scheduled completion is April 4, 2019

With Uncertainty Only the P-80 completion is October 19, 2019, an addition of 6 ½ months

With Uncertainty only the likelihood of meeting the scheduled date is 14%

“P-80” means the date that the project will finish on or earlier than in 80% of the iterations
INTRODUCING RISKS AS RISK DRIVERS
Adding Project-Specific Risks

• Project Specific Risks are like special cause risk in the Six Sigma world

• “… Special cause variation is caused by known factors that result in a non-random distribution of output...Special cause variation is a shift in output caused by a specific factor such as environmental conditions or process input parameters. It can be accounted for directly and potentially removed…”

https://www.isixsigma.com/dictionary/special-cause-variation/
Root Cause of Variation – Risk Drivers

• Risk Drivers came about nearly 10 years ago as the author and a colleague asked Pertmaster, on behalf of a client, to develop this method
• Risk Drivers’ impacts on scheduled durations are in ranges of multiplicative factors translated into probability distributions
• Risk Drivers can be assigned to many activities so it models how a strategic risk influences the project
• Some activities can have several risk drivers
Introducing the Risk Driver Method for Causing Additional Variation in the Simulation

Four risk drivers are specified. The first is a general risk about engineering productivity, which may be under- or over-estimated, with 100% probability. It is applied to the two Design activities.
100% Likely Risk Driver’s Effect on Design Duration

With a 100% likely risk the probability distribution of the activity’s duration looks like a triangle. Not any different from placing a triangle directly on the activity.
Risk Driver with Risk at < 100% likelihood

With this risk, the Construction Contractor may or may not be familiar with the technology, the probability is 40% and the risk impact if it happens is .9, 1.1 and 1.4. It is applied to the two Build activities.
With a 40% Likelihood, the “Spike” in the Distribution Contains 60% of the Probability

Here is where the Risk Driver method gets interesting. It can create distributions that reflect:

• Probability of occurring
• Impact if it does occur

Cannot represent these two factors with simple triangular distributions applied to the durations directly
RISK DRIVERS MODEL CORRELATION BETWEEN ACTIVITY DURATIONS
Model Correlation of Activity Durations

• A common question with schedule (or cost) risk analysis is; “Have you considered correlation?”

• Correlation is defined between pairs of durations. A matrix of correlation coefficients is created
  – Example – Tasks may be long because subcontractor may not be able to provide high productivity
  – Example – Tasks may be long because technology may not be well understood (low TRL)

• People do not do well guessing coefficients

• Using Risk Drivers removes this problem since it models how correlation occurs in projects
Correlation arises when two activities’ durations are influenced by the same external, variable and influential force, a risk.
Correlation of 100% Scatterplot
Introduce Two Confounding Risks

Two risks that affect only one but not the other activity duration drives down the correlation substantially.
Scatterplot with 2 Confounding Risks
RISKS MAY BE ENTERED IN SERIES OR IN PARALLEL
Risks in Series or Parallel

• Some risks, if they happen, will stop progress until the impact is recovered
• Other risks are not that important and their recovery can occur simultaneously with other risks’ recovery
• This matters only on the iterations when the two risks both occur
• An activity can be influenced by both series and parallel risks
Entering Risks in Series or in Parallel

If these two risks cannot be recovered from simultaneously, they are entered *in series*

<table>
<thead>
<tr>
<th>Risk 1</th>
<th>1.2 factor</th>
<th>Risk 2</th>
<th>1.05 factor</th>
</tr>
</thead>
</table>

Use \((1.2 \times 1.05 = 1.26)\) Factor, multiply the two

If recovery from two risks can be accomplished simultaneously, they are entered *in parallel*

<table>
<thead>
<tr>
<th>Risk 1</th>
<th>1.2 factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk 2</td>
<td>1.05 factor</td>
</tr>
</tbody>
</table>

Use 1.2 Factor, the largest factor only
Results with Risks in Parallel or in Series
OFFSHORE GAS PRODUCTION
PLATFORM PROJECT
Offshore Gas Production Platform Project summarized from real projects
39 months duration, $1.7 billion cost
Developed in Primavera Risk Analysis® Simulated in Booz Allen Hamilton Polaris®
Here are 8 project-specific and 3 systemic risks assigned to activities. Most risks are assigned to several activities defined as a “category” for ease of application. Some activities have several risks assigned. The risks are specified by probability and impact, a distribution of multiplicative factors and are called “Risk Drivers.” If they happen on an iteration a factor is chosen at random and multiplies the duration of all activities to which the risk is assigned.
USE CATEGORIES TO APPLY RISKS TO MULTIPLE ACTIVITIES
Use Categories to Enable Assigning Risks to Multiple Activities

Several Filters are created so a risk may be assigned to multiple activities in one keystroke.
Add Project Specific Risks

Adding Project-Specific risks brings the P-80 to 7/15/20, 15+ months after the schedule date.

The scheduled date is now only 2% likely.
Adding 3 Systemic Risks

Three systemic risks often associated with large, complex projects:
- Interdependency
- Coordination
- Excessive schedule pressure

Adding these make the P-80 = 5/15/21 or about 25 + months late
Comparing Results with Uncertainty and Risks

- Uncertainty Only
- Add 3 systemic risks
- Add 8 project-specific risks

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PRIORITIZING RISKS FOR MANAGEMENT ACTION
Typical Risk Prioritization Method

• Typical tornado diagrams have limitations:
  – Report correlation coefficients, but management does not know how to turn these into actionable metrics
  – Correlation centers on the means of the distributions, but management cares about other targets, e.g., P-80
  – Usually report on activities, not risks, whereas management looks to mitigate risks
  – Even when they show correlation of risks with the finish date, the algorithm can show incorrect correlation leading to incorrect conclusions
## Preferred Prioritization Method

Iterative Approach to Prioritizing Risks (Days Saved at P-80)

<table>
<thead>
<tr>
<th>Risk #</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Priority Level (Iteration #)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abusive Bids</td>
<td>Offshore design firm</td>
<td>Suppliers Busy</td>
<td>Fab productivity</td>
<td>Geology unknown</td>
<td>Coordinating during Installation</td>
<td>Problems at HUC</td>
<td>Resources may go to other projects</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>2</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>3</td>
<td>X</td>
<td>3</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>4</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>X</td>
<td>5</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>X</td>
<td>6</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>7</td>
<td>7</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>8</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

Iterative prioritization method requires many simulations to order the risks correctly @ P-80 in Days Saved
Risk Prioritization Results

Risks, not Activities

Days Saved @ P-80, not correlation coefficients
## Risk Prioritization Table for Risk Mitigation Workshop

### Risks Prioritized by their Contribution to P-80 Finish Date

<table>
<thead>
<tr>
<th>UID</th>
<th>Name</th>
<th>Days Saved</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>Megaproject may have excessive schedule pressure</td>
<td>133</td>
</tr>
<tr>
<td>6</td>
<td>The organization has other priority projects so personnel and funding may be unavailable</td>
<td>129</td>
</tr>
<tr>
<td>9</td>
<td>Megaproject may have interdependency problems</td>
<td>117</td>
</tr>
<tr>
<td>2</td>
<td>Engineering may be complicated by using offshore design firm</td>
<td>77</td>
</tr>
<tr>
<td>10</td>
<td>Megaproject may have coordination problems offshore sourcing</td>
<td>42</td>
</tr>
<tr>
<td>4</td>
<td>Fabrication yards may experience different Productivity than planned</td>
<td>31</td>
</tr>
<tr>
<td>7</td>
<td>Fabrication and installation problems may be revealed during HUC</td>
<td>17</td>
</tr>
<tr>
<td>12</td>
<td>Installation may be more complex than planned</td>
<td>10</td>
</tr>
<tr>
<td>1</td>
<td>Bids may be Abusive leading to delayed approval</td>
<td>9</td>
</tr>
<tr>
<td>3</td>
<td>Suppliers of installed equipment may be busy</td>
<td>9</td>
</tr>
<tr>
<td>5</td>
<td>The subsea geological conditions may be different than expected</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td><strong>Days saved by Completely Mitigating the Risks</strong></td>
<td>574</td>
</tr>
<tr>
<td></td>
<td><strong>Days Contributed to the Schedule Margin by Uncertainty</strong></td>
<td>198</td>
</tr>
<tr>
<td></td>
<td><strong>Total Pre-Mitigated Schedule Contingency</strong></td>
<td>772</td>
</tr>
</tbody>
</table>
RISK MITIGATION ACTIONS AND RESULTS (SIMPLE EXAMPLE)
Mitigation Workshop

• Owner and Contractor meet separately with the same prioritized list of risks
• Propose their own risk mitigations with cost of the actions, owners of the actions and improvement in the risk parameters
• Mitigation must be new, not continued practices from before
• Joint Owner / Contractor meeting to agree
• Must commit to the mitigations to get credit
# Risk Mitigation Workshop Forms

<table>
<thead>
<tr>
<th>Risk ID</th>
<th>Risk Description: Given the quantity of piping in the project, scope may be underestimated</th>
<th>Probability</th>
<th>Optimistic Impact Factor</th>
<th>Most Likely Impact Factor</th>
<th>Pessimistic Impact Factor</th>
<th>Optimistic Impact Factor</th>
<th>Most Likely Impact Factor</th>
<th>Pessimistic Impact Factor</th>
<th>Activities Affected</th>
</tr>
</thead>
<tbody>
<tr>
<td>26b</td>
<td></td>
<td>30%</td>
<td>110%</td>
<td>130%</td>
<td>170%</td>
<td>110%</td>
<td>120%</td>
<td>130%</td>
<td>Name Contains Piping</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mitigations Proposed</th>
<th>[Cost Estimate, total all mitigations proposed]</th>
</tr>
</thead>
<tbody>
<tr>
<td>26b.1</td>
<td>$20 million</td>
</tr>
<tr>
<td>26b.2</td>
<td>Responsible person/persons</td>
</tr>
<tr>
<td>26b.3</td>
<td>Smith</td>
</tr>
<tr>
<td>26b.4</td>
<td>Jones</td>
</tr>
<tr>
<td>26b.5</td>
<td></td>
</tr>
</tbody>
</table>

Fill out mitigation actions proposed, cost (ROM) for all actions as a group, risk owners, and parameters after mitigation

<table>
<thead>
<tr>
<th>Parameters After Mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>26 b</td>
</tr>
<tr>
<td>Given the quantity of piping in the project, scope may be underestimated</td>
</tr>
<tr>
<td>15%</td>
</tr>
</tbody>
</table>
Risk Mitigation Simple Example

• Probability reduced by half for each risk
• Duration impact ranges reduced – mostly schedule risk mitigation
• No change for cost impact ranges
• Cost of mitigation actions range from $10 million to $40 million in Cash (resource) paid at front end
• Mitigation costs in this example total $220 million
Schedule and Cost Risk Post-Mitigated

POST-MITIGATED

PRE-MITIGATED
PROBABILISTIC BRANCHING FOR TEST FAILURE POSSIBILITY
Probabilistic Branch with Test Failure

• Projects have many tests. Each of these is done because the system may fail, with consequences
• Seldom does the schedule include recovery activities, but is usually “success oriented”
• There is a probability of failure with consequences of added activities:
  – Root Cause Analysis of the Failure
  – Determining what to do
  – Doing what is planned
  – Retesting
Failing the Test may lead to Multiple Activities that are Not In the Schedule

• If fail the test all of these activities are needed
• If pass the test none is needed
• These 4 activities constitute a probabilistic branch, since the possibility of doing them is probabilistic
• There is a probability that the instrument or system will not pass the test
  – This probability is often underestimated
Set up the Probabilistic Branch

Add 4 activities:
• Root Cause Analysis
• Plan the recovery
• Execute the Plan
• Retest

Notice that they all have a remaining duration of 0 working days – they will not affect the schedule unless they occur

Using Booz Allen Hamilton Polaris®
Activity A1030 Test 1 is the node from which the project either finishes or fails and goes down the branch.
Set the Test Failure Branch as Probabilistic

Make the branch 40% if it is 40% likely to Fail the Test first time
Give the New Activities Ranges of Impact, if they Happen

> Highlight the new activities in turn and give them uncertainties:
  - Root Cause Analysis 20d – 40d – 60d
  - Design the Fix - 10d – 20d – 40d
  - Fix the Product - 10d- 30d- 50d
  - Retest the Product - 20d – 30d – 50d
With the Probabilistic Branch in Place, Results may show Bi-modal Distribution

Probabilistic branch develops a shoulder at 60%

There can be more than one probabilistic outcome from a node. The probabilities need to sum to \((40\% + 60\%) \, 100\%\).

Probabilistic branch can represent more planning than can be shown with a single probabilistic activity.
Review

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