Integrated Cost-Schedule Risk Analysis Improves Cost Contingency Calculation

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Summary

- Purpose of the Quantitative Risk Analysis
- Model uncertainty for duration and cost
- Model project-specific risks using Risk Drivers
- Compare P-80 for cost and schedule to the Joint Confidence Level (JCL-80) as promise dates and costs
- Prioritize the risks @ P-80 and days saved
- Mitigate risks partially, recording mitigation costs

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Abstract

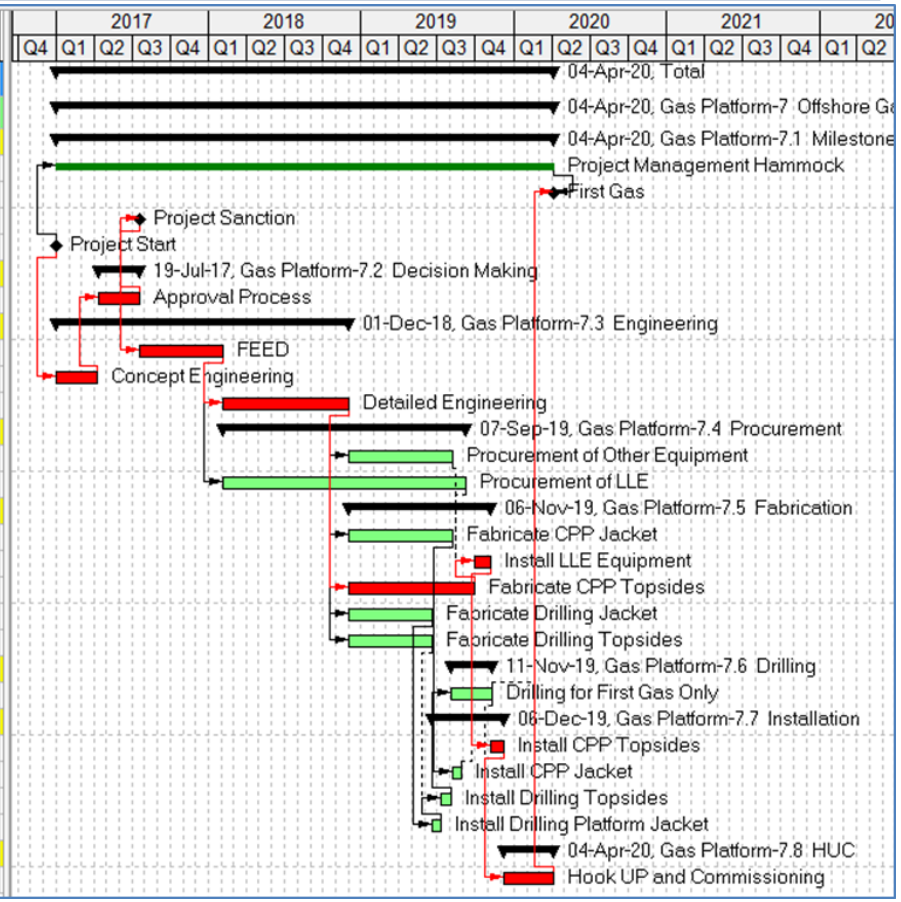
- The main benefits of integrated cost-schedule risk analysis are improvement of the estimates of cost contingency and identification of the main risks to cost for mitigation purposes.
- The main focus is on estimating the cost contingency needed and identifying risks to cost, which may be independent of schedule or indirectly due to schedule risk.
- New simulation software including iterative risk prioritization will be used to illustrate these points.

Purpose of Quantitative Risk Analysis

- Answer 3 questions:
  - How likely is the project to meet its schedule and cost goals on the current plan?
  - How much schedule and cost contingency is needed to achieve the a desired level of certainty of hitting both schedule and cost targets
  - Which risks are causing potential overrun of schedule and cost, including indirect schedule-driven cost, and are thus high priority for risk mitigation?

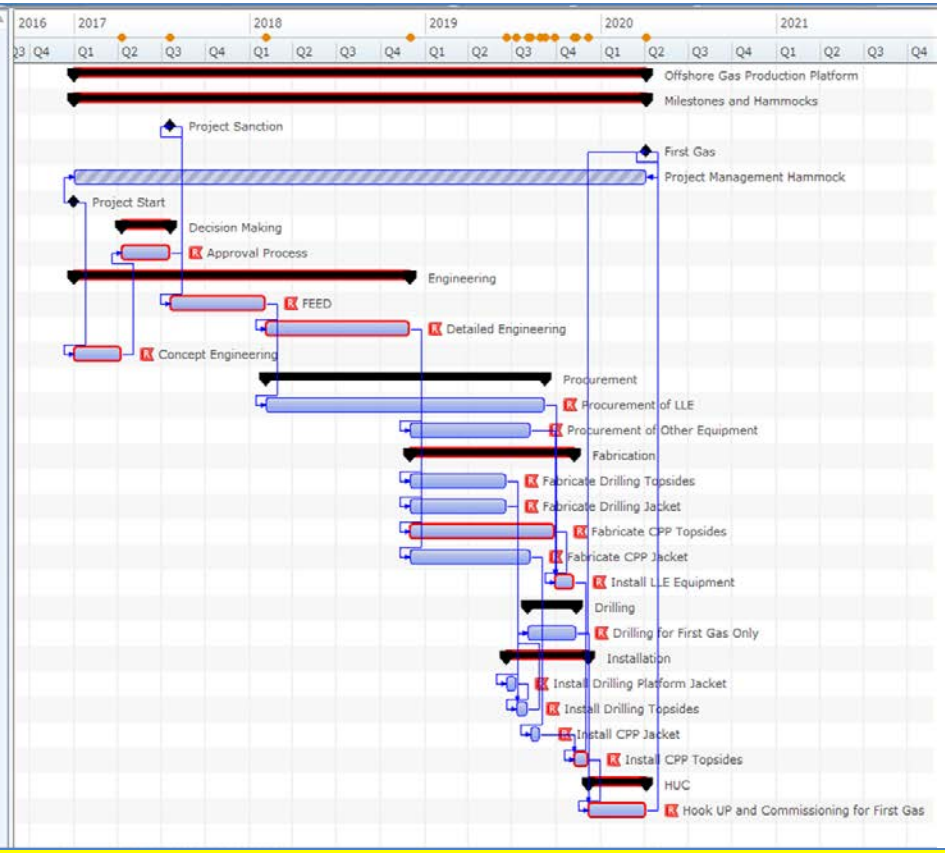
Example Schedule: Offshore Gas Production Platform Project

Activity ID	Activity Name	Original Duration	Start	Finish
Total		1190d	01-Jan-17	04-Apr-20
Gas Platform-7 Offshore Gas Pr		1190d	01-Jan-17	04-Apr-20
Gas Platform-7.1 Milestones and Ham		1190d	01-Jan-17	04-Apr-20
A1030	Project Management Hammock	1190d	01-Jan-17	04-Apr-20
A1020	First Gas	0d		04-Apr-20
A1010	Project Sanction	0d		19-Jul-17
A1000	Project Start	0d	01-Jan-17*	
Gas Platform-7.2 Decision Making		100d	11-Apr-17	19-Jul-17
B1000	Approval Process	100d	11-Apr-17	19-Jul-17
Gas Platform-7.3 Engineering		700d	01-Jan-17	01-Dec-18
C950	FEED	200d	20-Jul-17	04-Feb-18
C900	Concept Engineering	100d	01-Jan-17	10-Apr-17
C1010	Detailed Engineering	300d	05-Feb-18	01-Dec-18
Gas Platform-7.4 Procurement		580d	05-Feb-18	07-Sep-19
D1010	Procurement of Other Equipment	250d	02-Dec-18	08-Aug-19
D1000	Procurement of LLE	580d	05-Feb-18	07-Sep-19
Gas Platform-7.5 Fabrication		340d	02-Dec-18	06-Nov-19
E1030	Fabricate CPP Jacket	250d	02-Dec-18	08-Aug-19
E1025	Install LLE Equipment	40d	28-Sep-19	06-Nov-19
E1020	Fabricate CPP Topsides	300d	02-Dec-18	27-Sep-19
E1010	Fabricate Drilling Jacket	200d	02-Dec-18	19-Jun-19
E1000	Fabricate Drilling Topsides	200d	02-Dec-18	19-Jun-19
Gas Platform-7.6 Drilling		100d	04-Aug-19	11-Nov-19
F1000	Drilling for First Gas Only	100d	04-Aug-19	11-Nov-19
Gas Platform-7.7 Installation		170d	20-Jun-19	06-Dec-19
G1030	Install CPP Topsides	30d	07-Nov-19	06-Dec-19
G1020	Install CPP Jacket	20d	09-Aug-19	28-Aug-19
G1010	Install Drilling Topsides	25d	10-Jul-19	03-Aug-19
G1000	Install Drilling Platform Jacket	20d	20-Jun-19	09-Jul-19
Gas Platform-7.8 HUC		120d	07-Dec-19	04-Apr-20
H1000	Hook UP and Commissioning	120d	07-Dec-19	04-Apr-20



Import to Integrated Cost-Schedule Risk Analysis Software

UID	Task	Start Date	End Date	Duration	Cost
Gas Pla	▼ Offshore Gas Production Platfor	01/01/2017	04/04/2020	1,190	$1.697M
Gas Pla	▼ Milestones and Hammocks	01/01/2017	04/04/2020	1,190	$80,000
A1010	Project Sanction		07/19/2017	0	$0
A1020	First Gas		04/04/2020	0	$0
A1030	Project Management Ham	01/01/2017	04/04/2020	1,190	$80,000
A1000	Project Start	01/01/2017		0	$0
Gas Pla	▼ Decision Making	04/11/2017	07/19/2017	100	$8,000
B1000	Approval Process	04/11/2017	07/19/2017	100	$8,000
Gas Pla	▼ Engineering	01/01/2017	12/01/2018	700	$256,000
C950	FEED	07/20/2017	02/04/2018	200	$80,000
C1010	Detailed Engineering	02/05/2018	12/01/2018	300	$160,000
C900	Concept Engineering	01/01/2017	04/10/2017	100	$16,000
Gas Pla	▼ Procurement	02/05/2018	09/07/2019	580	$350,000
D1000	Procurement of LLE	02/05/2018	09/07/2019	580	$250,000
D1010	Procurement of Other Equ	12/02/2018	08/08/2019	250	$100,000
Gas Pla	▼ Fabrication	12/02/2018	11/06/2019	340	$836,000
E1000	Fabricate Drilling Topsides	12/02/2018	06/19/2019	200	$180,000
E1010	Fabricate Drilling Jacket	12/02/2018	06/19/2019	200	$140,000
E1020	Fabricate CPP Topsides	12/02/2018	09/27/2019	300	$320,000
E1030	Fabricate CPP Jacket	12/02/2018	08/08/2019	250	$164,000
E1025	Install LLE Equipment	09/28/2019	11/06/2019	40	$32,000
Gas Pla	▼ Drilling	08/04/2019	11/11/2019	100	$80,000
F1000	Drilling for First Gas Only	08/04/2019	11/11/2019	100	$80,000
Gas Pla	▼ Installation	06/20/2019	12/06/2019	170	$47,200
G1000	Install Drilling Platform Ja	06/20/2019	07/09/2019	20	$8,000
G1010	Install Drilling Topsides	07/10/2019	08/03/2019	25	$13,600
G1020	Install CPP Jacket	08/09/2019	08/28/2019	20	$9,600
G1030	Install CPP Topsides	11/07/2019	12/06/2019	30	$16,000
Gas Pla	▼ HUC	12/07/2019	04/04/2020	120	$40,000
H1000	Hook UP and Commission	12/07/2019	04/04/2020	120	$40,000



39-month
$1.7 billion
Project

Using Booz Allen Hamilton Polaris©
http://www.boozallen.com/consulting/products/polaris

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Uncertainty

- Inherent variability
- Estimating Error
- Estimating Bias if it exists
- These must be taken into account in the Risk Analysis

Adding Uncertainty to Activity Durations and Resource Quantities by Reference Ranges

- Uncertainty in schedule duration is similar to "common cause" variation related to six sigma process control concepts developed by Walter Shewhart and championed by Edwards Demming
- "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 also called random variation, noise, non-controllable variation … " (http://www.isixsigma.com/dictionary/common-cause-variation/)

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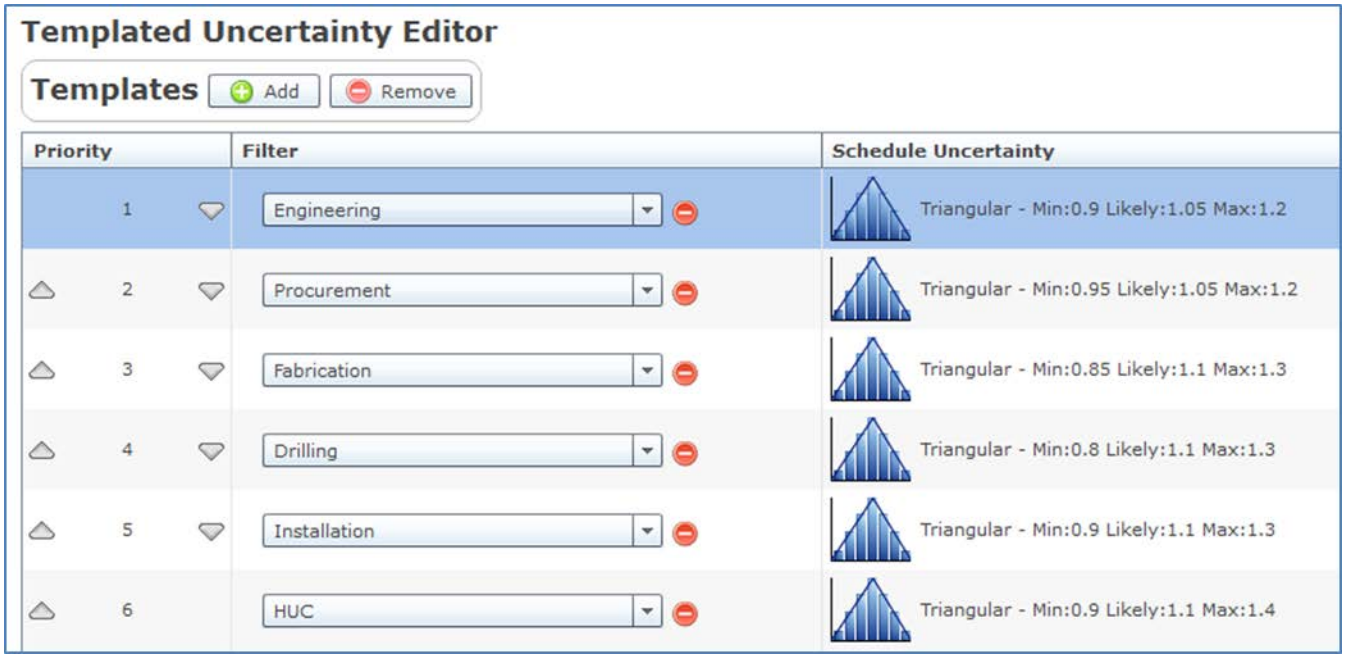
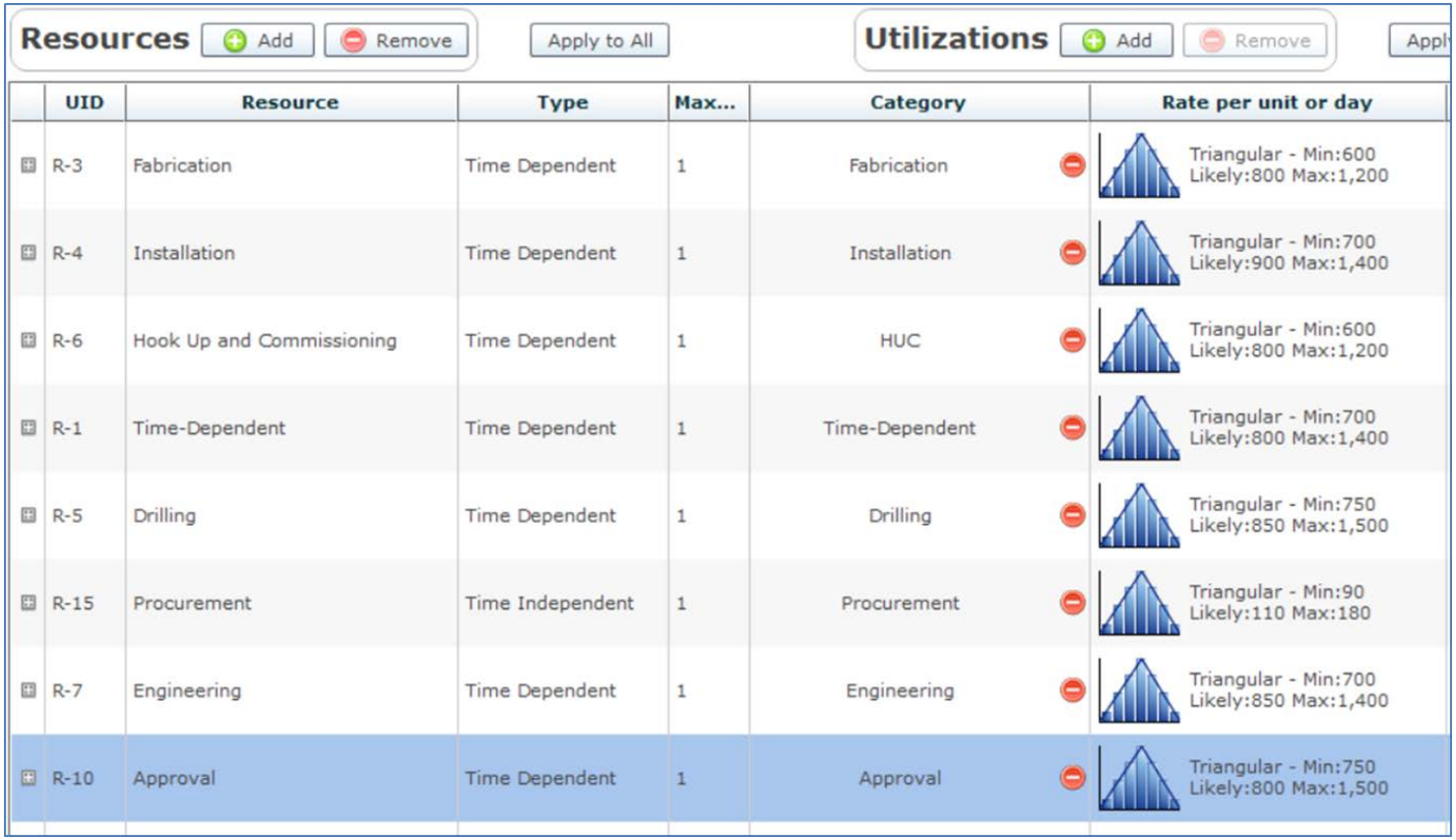
Apply Uncertainty to Activity Durations by Reference Ranges



These represent uncertainty parameters for the entire activity class (engineering, procurement, fabrication…). To achieve that while using the specified ranges on each activity within the class, these uncertainty values must be correlated 100%

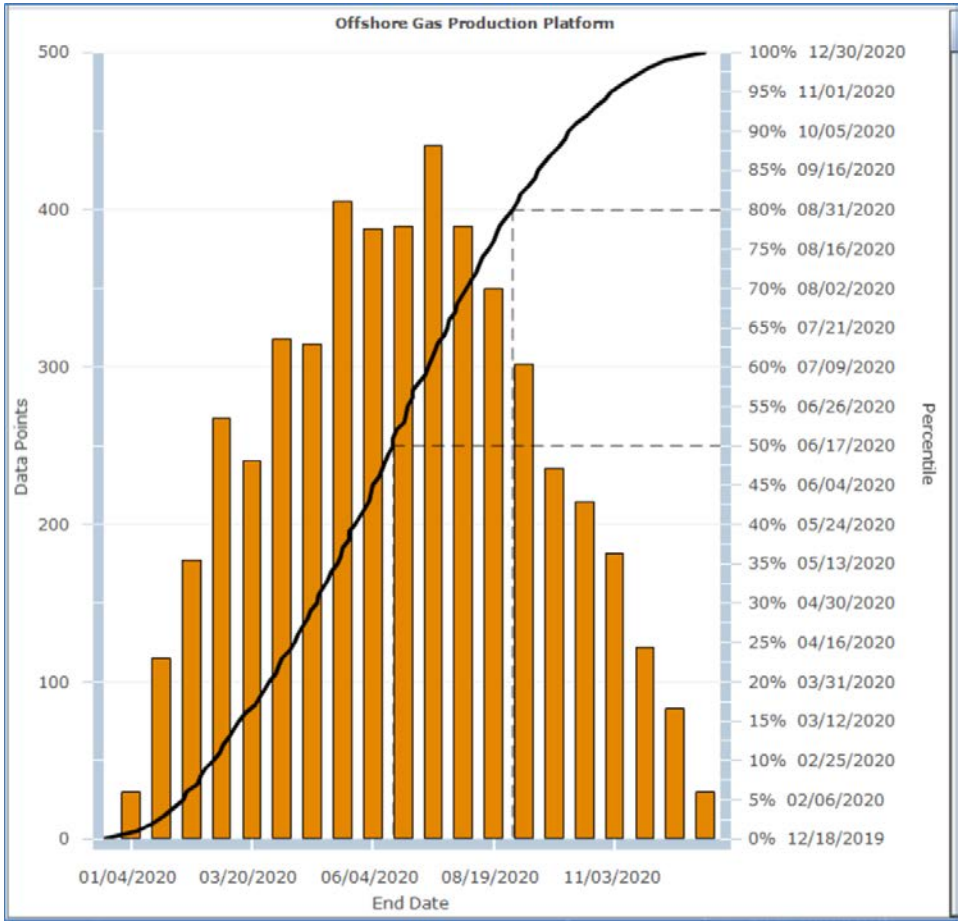
Resource usage Uncertainty Ranges



Resources | Add | Remove | Apply to All | Utilizations | Add | Remove | Appl

UID	Resource	Type	Max...	Category	Rate per unit or day
R-3	Fabrication	Time Dependent	1	Fabrication	Triangular - Min:600 Likely:800 Max:1,200
R-4	Installation	Time Dependent	1	Installation	Triangular - Min:700 Likely:900 Max:1,400
R-6	Hook Up and Commissioning	Time Dependent	1	HUC	Triangular - Min:600 Likely:800 Max:1,200
R-1	Time-Dependent	Time Dependent	1	Time-Dependent	Triangular - Min:700 Likely:800 Max:1,400
R-5	Drilling	Time Dependent	1	Drilling	Triangular - Min:750 Likely:850 Max:1,500
R-15	Procurement	Time Independent	1	Procurement	Triangular - Min:90 Likely:110 Max:180
R-7	Engineering	Time Dependent	1	Engineering	Triangular - Min:700 Likely:850 Max:1,400
R-10	Approval	Time Dependent	1	Approval	Triangular - Min:750 Likely:800 Max:1,500

Effect of Uncertainty on Finish Date

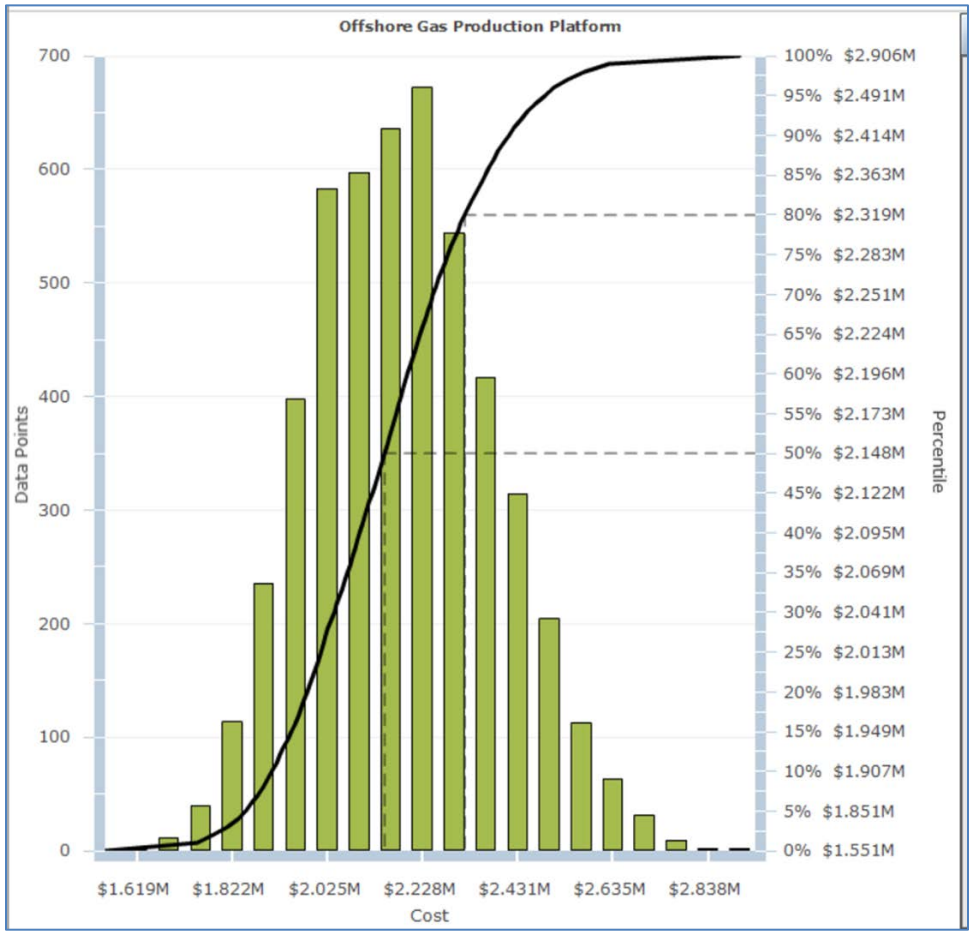


Deterministic Finish Date 4/4/20

P-80 Finish Date 8/31/20

Effect ~ 5 months

Effect of Uncertainty on Project Cost

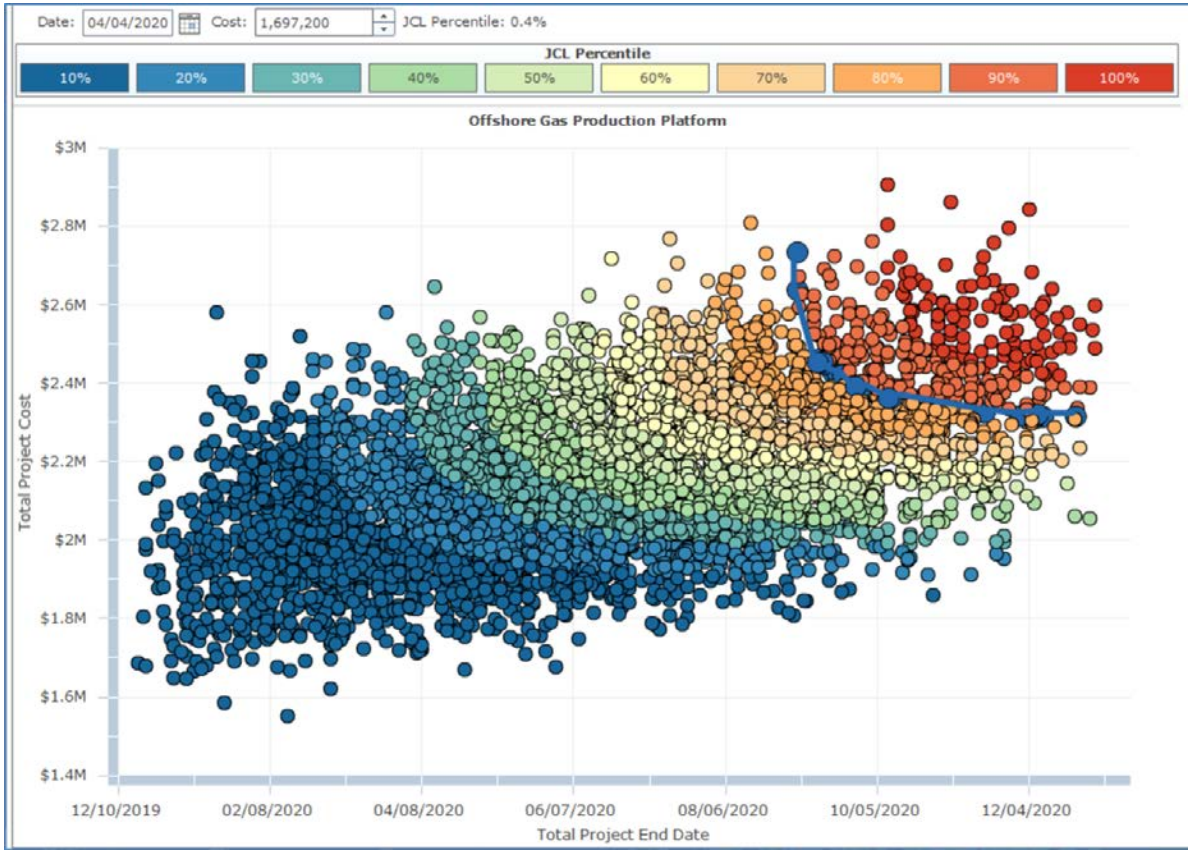


Baseline = $1.69 billion

P-80 cost = $2.32 billion

Over cost = $630 million or 37%

Scatterplot: Effect of Uncertainty on Durations and Resources



Correlation Finish Date – Cost calculated at 49%. Upward slope reflects effect of uncertain durations on cost

Project-Specific Risks

- Risks identified, so potentially mitigated
- Risks quantified with probability, impact, activities affected
- Risk Driver Method of representing these risks

Add Project-Specific Risks

- Risk is similar to "special causes" in six sigma
- "… 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..." (http://www.isixsigma.com/dictionary/variation-special-cause/)
- Hence, pre-mitigated risks are the subject of risk mitigation workshops

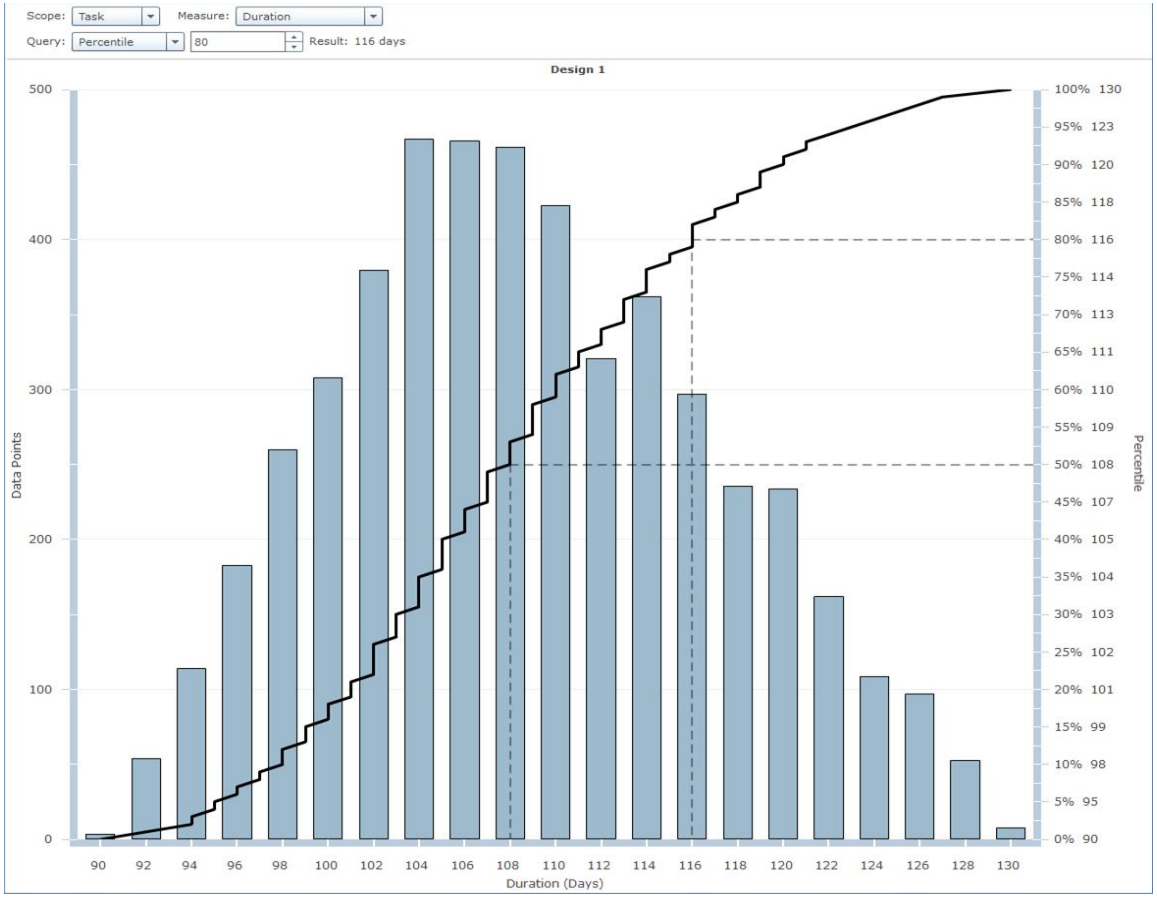
Risk Drivers (1)

- Each identified risk has a probability that it will occur with some effect on time or cost
  - Cost of labor (time-dependent) resources will increase proportionately with the activity duration
- If the risk occurs it affects activities' durations and costs
  - If time-dependent resources (labor, rented equipment) it will vary the daily burn rate
  - If time-independent resources (equipment to be installed, material) it will affect the entire cost directly

Risk Drivers (2)

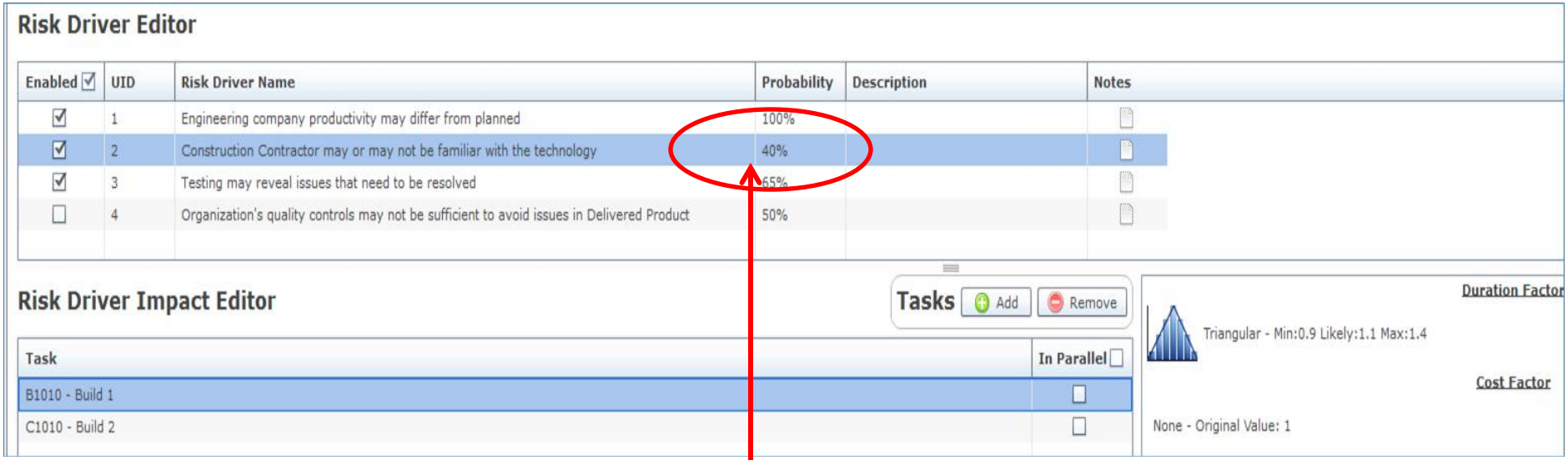
- A risk may affect multiple activities
- Activities may be affected by multiple risks
- If a risk driver occurs it has a multiplicative effect on the durations of the activities it affects
  - Multiplier < 1.0 ➔ shorter duration, opportunity
  - Multiplier > 1.0 ➔ longer duration, threat
- Multiplier for each iteration is chosen at random from input distribution (usually 3-point estimate, triangle)

100% Likely Risk Driver's Effect on Design Duration



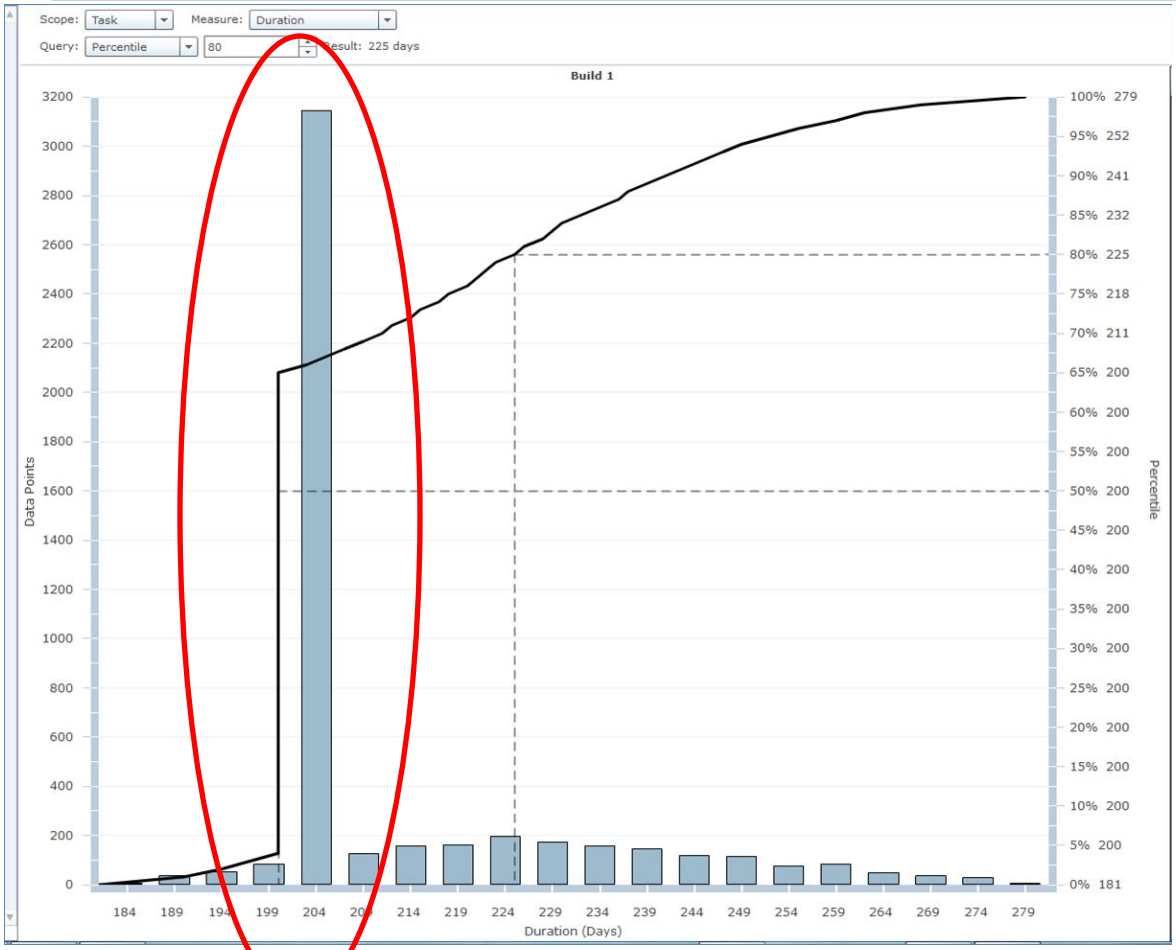
With a 100% likely risk the probability distribution of the activity's duration looks like a triangle. Not any different from placing a triangle directly on the activity

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

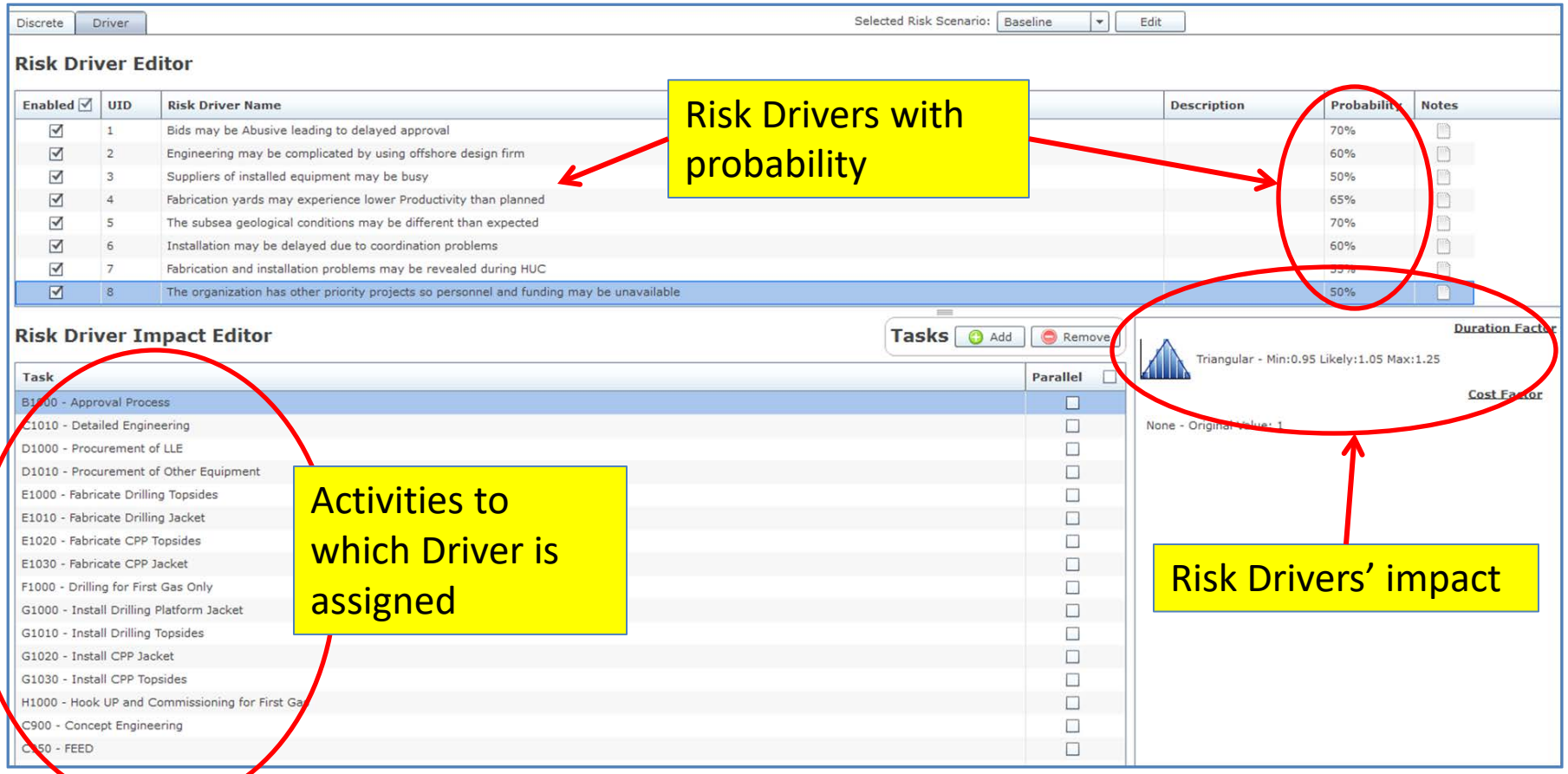


Here is where the Risk Driver method gets interesting. It can create distributions that reflect:

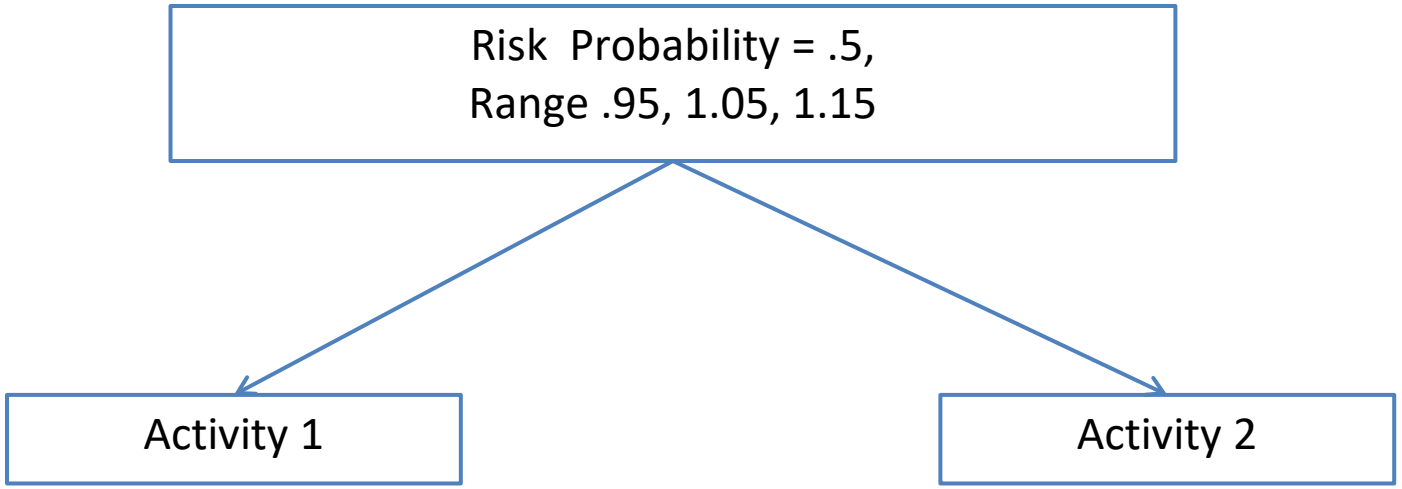
- Probability of occurring
- Impact if it does occur

Cannot represent these two factors with simple triangular distributions applied to the durations directly

Using Risk Drivers Method



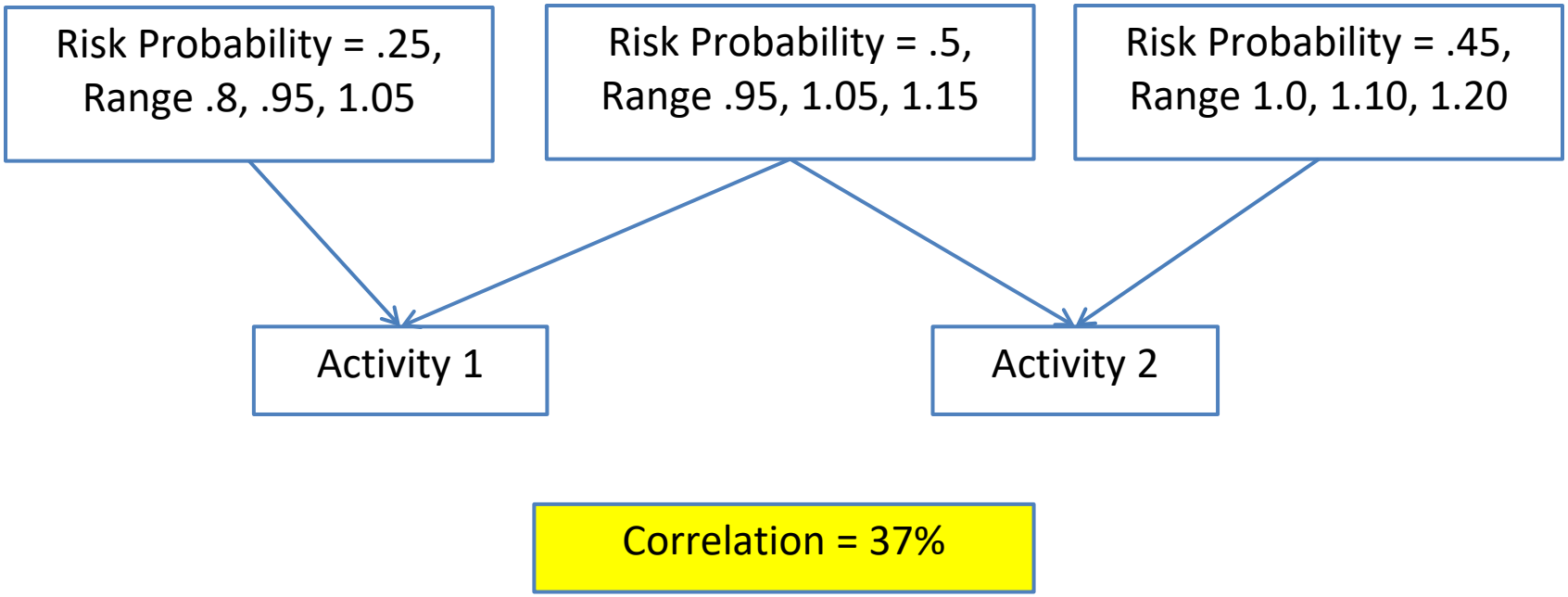
Risk Factors Model How Correlation Occurs Coefficients are Calculated (1)



Correlation = 100%

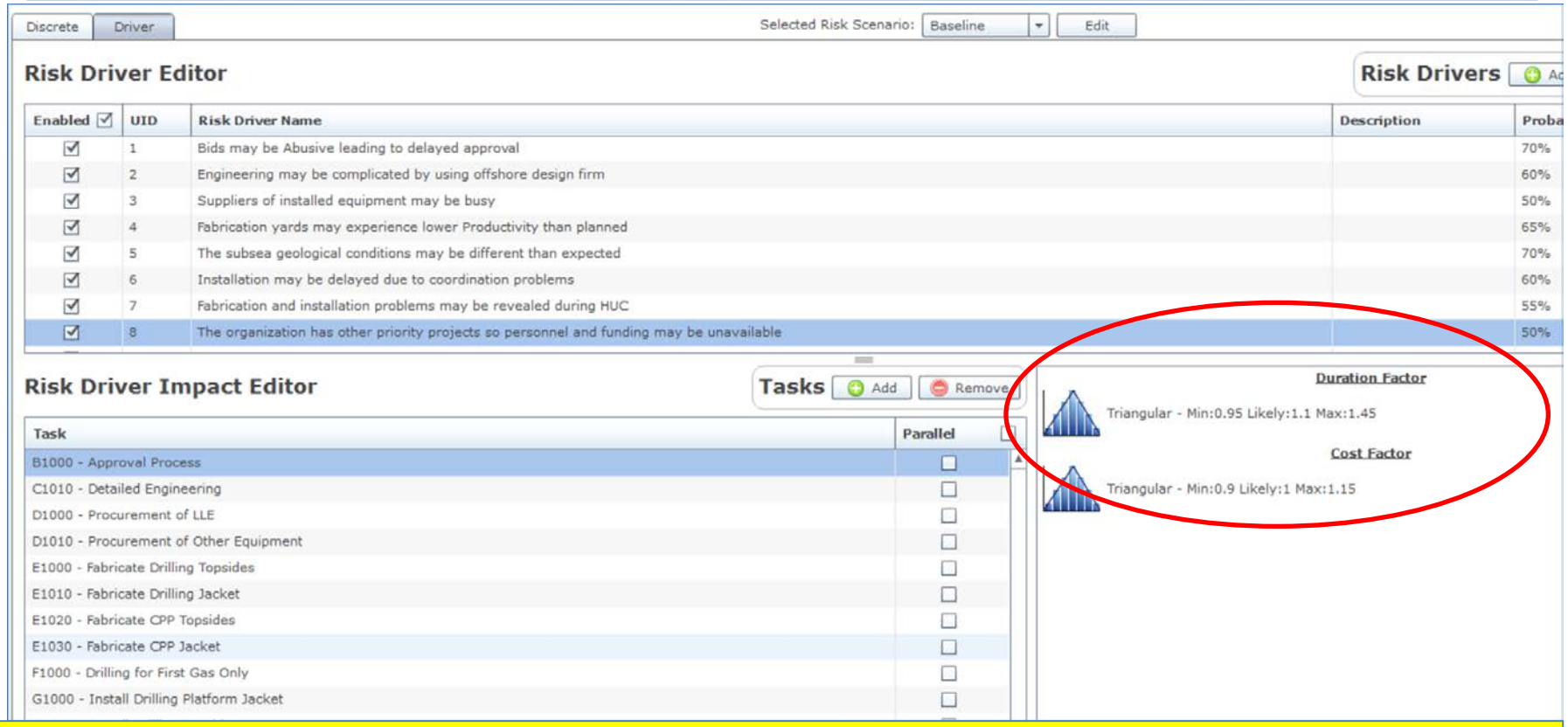
We are very bad at estimating correlation coefficients directly

Risk Factors Model How Correlation Occurs Coefficients are Calculated (2)



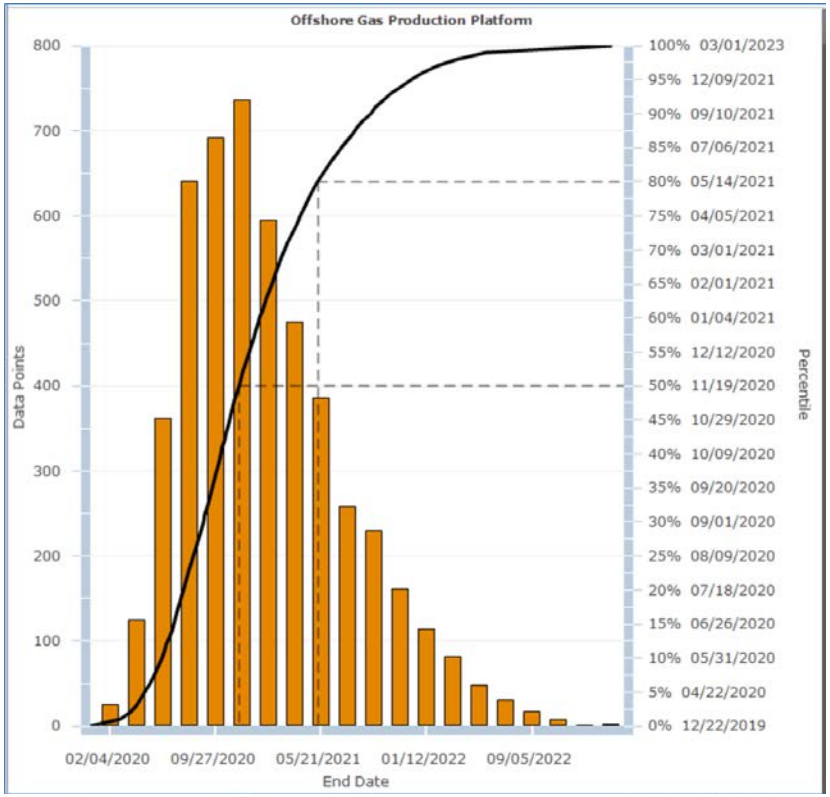
- Correlation is modeled as it is caused in the project
- Correlation coefficients are generated, not guessed
- Correlation drives the results correctly
- By modeling correlation we never get an inconsistent correlation coefficient matrix

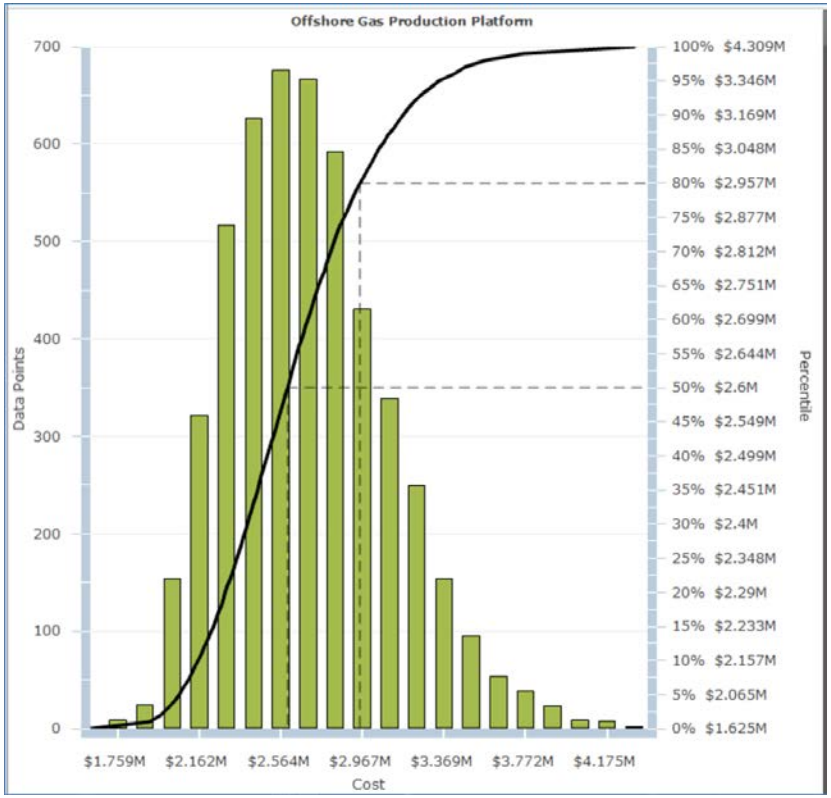
Project-Specific Risks as Risk Drivers that Cause Additional Variation in the Simulation



The highlighted risk driver is an organizational risk that affects all activities' duration as well as daily expenditure rate (for time-dependent labor resources)

What End Date and Cost should be put forward?





P-80 finish date is 5/14/21 adding another 8 ½ months to the project over uncertainty
P-80 cost is $2.96 billion, adding another $638 million to the project from uncertainty.

Use the Time – Cost Scatterplot to Estimate Targets to meet BOTH Objectives

- The histograms / cumulative distribution functions estimate finish date and cost to meet each target individually
- To meet BOTH targets, use the scatterplot
- Meeting both targets requires a more conservative (later date, more cost) estimate
- How much more time and cost depends on their correlation

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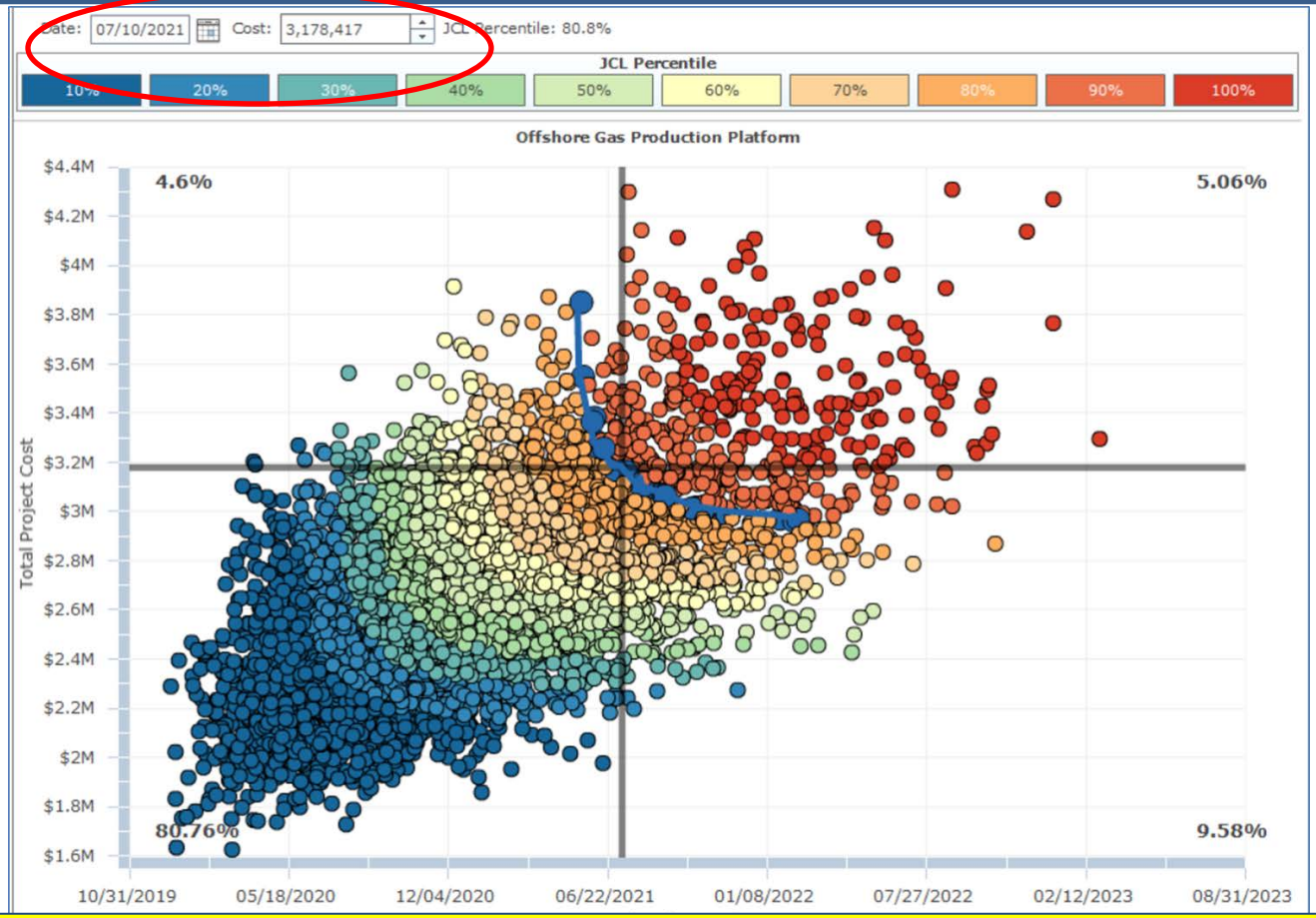
The P-80 Cost and Schedule together do not Provide 80% Joint Success

Approximating the P-80 date and cost as closely as possible with the software yields only abut a 73% probability of joint success

The Joint Confidence Level (JCL-80) values provide 80% Joint Success



Values are approximate since there are many combinations of date and cost that yield a JCL-80 and we cannot just choose where the project will end up. Also, the software is not infinitely calibrated

JCL-80 compared with P-80 Results

P-80 and Joint Confidence Level (JCL-80) Results with Risks and Uncertainty	
Baseline	
Finish Date	4/4/2020
Budgeted Cost (billions)	$1.70
Risk Analysis Results	
Schedule	
P-80	5/14/2021
JCL-80 (point chosen)	8/31/2021
Difference	3.1 Months
Cost	
P-80	2.957
JCL-80 (point chosen)	3.178
Difference	0.221 $Billion

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Difference of JCL-80 and P-80 is because the correlation between cost and schedule is not perfect. Here it is 59%.

Effect of Including Schedule Risk in a Cost Risk Analysis

- Direct impacts on cost risk are from
  - Traditional cost risks (e.g., metrics such as quantities, unit prices…)
  - Affect labor burn rate, material total cost
  - Effect of uncertainty, estimating error, bias
- Indirect impacts on cost risk from schedule combine
  - Schedule uncertainty, estimating error, bias
  - Risks that affect schedule duration of activities with labor-type (e.g., labor, rented equipment…)
  - Indirect costs modeled on schedule hammocks
- Some cost contingency should be held for schedule overruns

In this Example Schedule Risk and Uncertainty Contributes One-Third of the Cost Contingency

Sources of Cost Risk			
Causes of Cost Risk	P-80 Cost ($bill)	Contribution (% of Base)	P-80 End Date
Add Risks on Schedule	2.957	8%	5/14/2021
Add Schedule Uncertainty	2.827	16%	2/15/2021
Traditional Cost Risk Items	2.547	50%	4/4/2020
Base Case (deterministic no Risk)	1.697	100%	
Total Cost Contingency All Risk and Uncertainty		74%	

Iterative Approach to Prioritizing the Risk

- Purpose, discover which risks contribute the most days or total cost at the P-80 level if they were fully mitigated
  - Use Monte Carlo simulation to identify the most important risk, the one that save the most days or dollars at the P-80
  - Continue until all risks contributions have been calculated

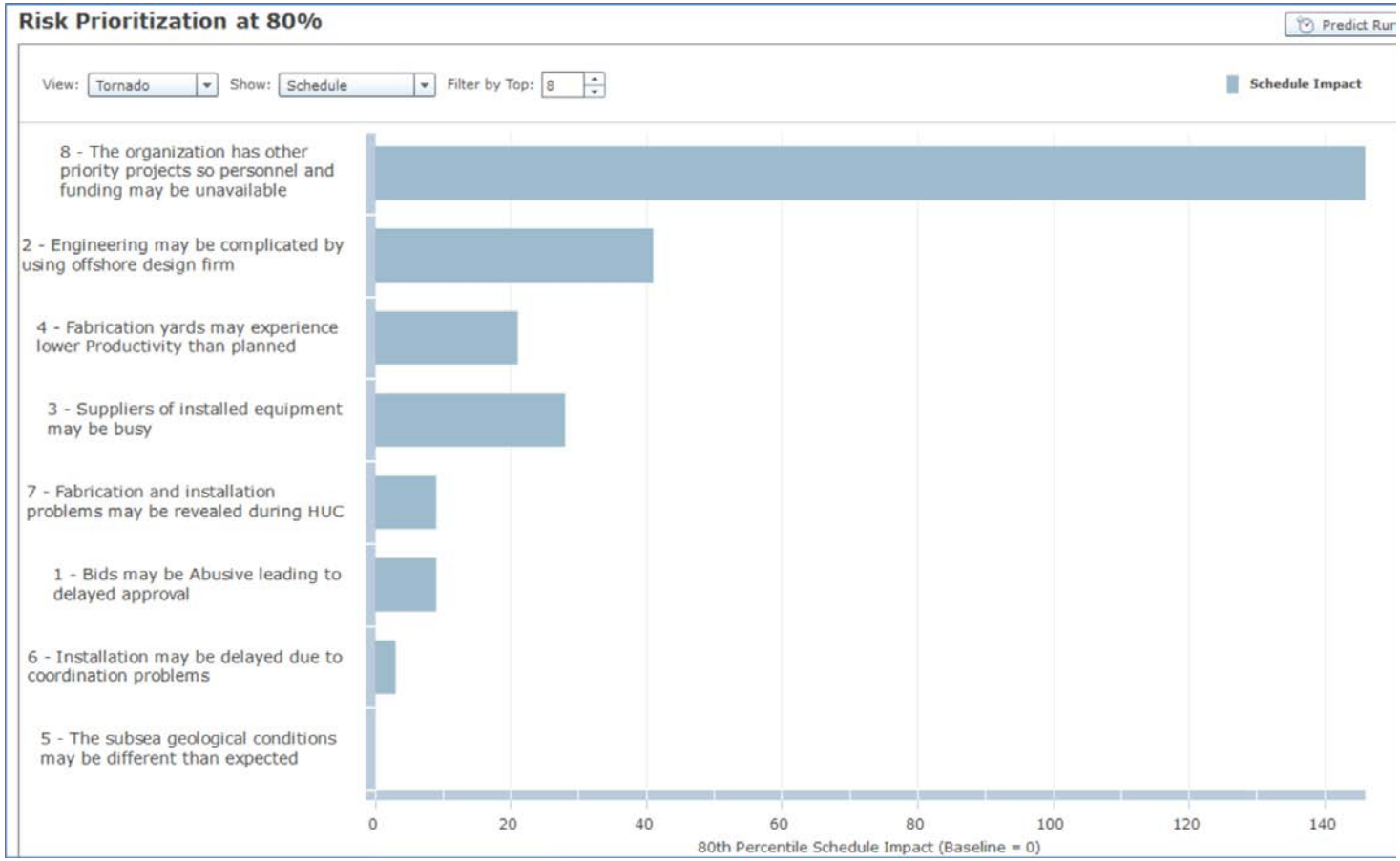
Improve on the Traditional Tornado Sensitivity Approach

- Traditional tornado is usually based on the activities, not the risks
- Even when based on the risk, the traditional tornado is based on correlation but that is a concept at the mean of the distributions and we are at the P-80
- Tornado may provide counterintuitive results if the risk is not 100% likely, as many are not
- The correlation concept cannot be used easily to see if the improvement in schedule or cost is worth the cost of the mitigation
- We use this approach to prioritize risks for mitigation

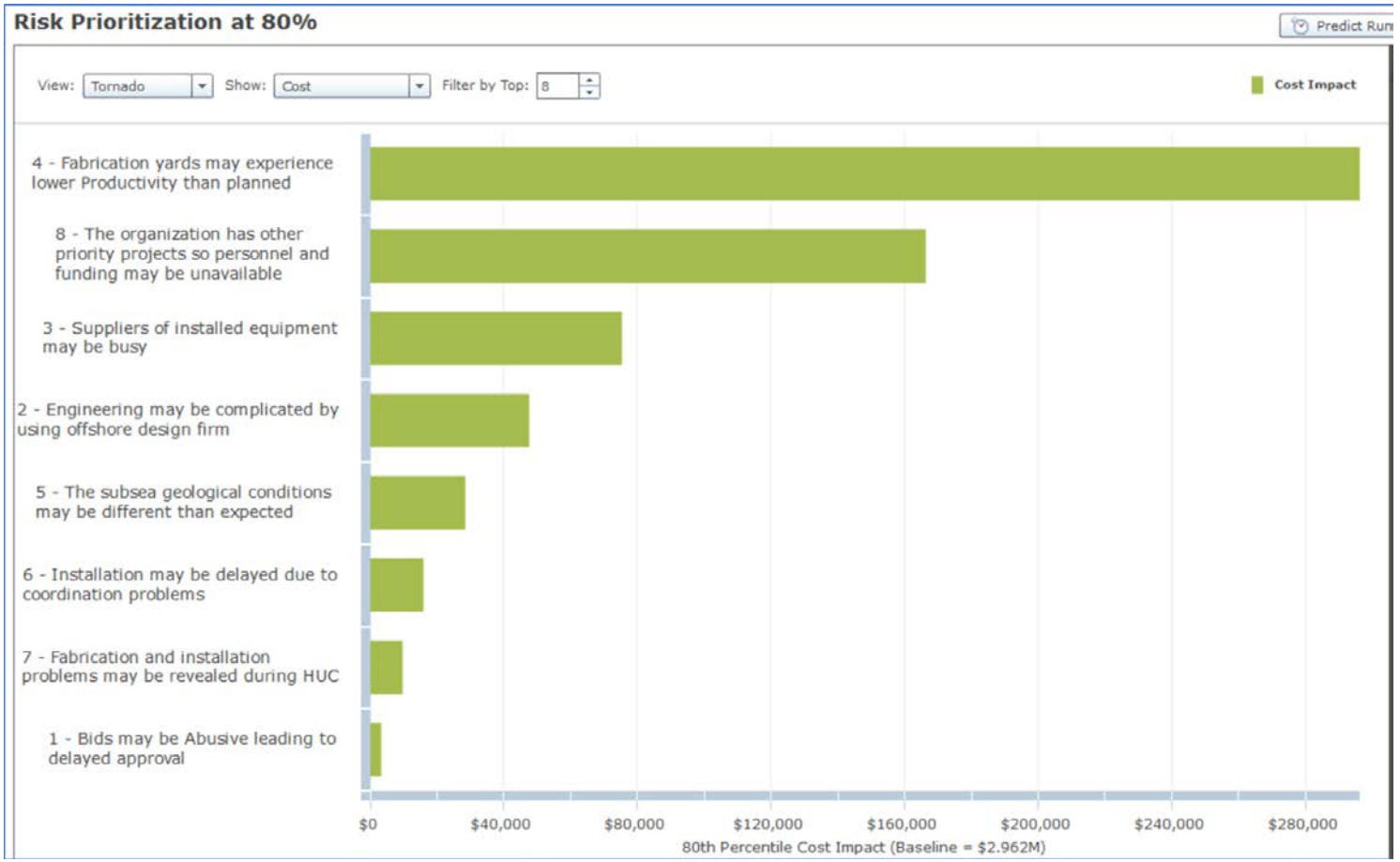
Picture of Prioritized Risks Selected by their Days Saved at P-80

Iterative Approach to Prioritizing Risks (Based on Days Saved at P-80)								
Risk #	1	2	3	4	5	6	7	8
Priority Level (Iteration #)	Abusive Bids	Offshore design firm	Suppliers Busy	Fab productivity	Geology unknown	Coordination during Installation	Problems at HUC	Resources may go to other projects
1	X	X	X	X	X	X	X	**1**
2	X	X	X	**2**	X	X	X	
3	X	**3**	X		X	X	X	
4	X		X		X	X	**4**	
5	X		**5**		X	X		
6	X				X	**6**		
7	**7**				X			
8					**8**			

Risks Prioritized to the P-80 Level for Schedule Measured in “Days Saved”



Risks Prioritized to the P-80 Level for Cost Measured in “Cost Saved”



Saving Days will also Reduce Cost Contingency but the Priority Order is not Exactly the Same

Compare The order of Priority for the Risks if the Focus is on Cost or Time						
UID	**Name**	**Days Saved**		**UID**	**Name**	**Cost Saved**
8	The organization has other priority projects so personnel and funding may be unavailable	146		**4**	Fabrication yards may experience lower Productivity than planned	$296,329
2	Engineering may be complicated by using offshore design firm	41		**8**	The organization has other priority projects so personnel and funding may be unavailable	$166,342
4	Fabrication yards may experience lower Productivity than planned	21		**3**	Suppliers of installed equipment may be busy	$75,391
3	Suppliers of installed equipment may be busy	28		**2**	Engineering may be complicated by using offshore design firm	$47,607
7	Fabrication and installation problems may be revealed during HUC	9		**5**	The subsea geological conditions may be different than expected	$28,480
1	Bids may be Abusive leading to delayed approval	9		**6**	Installation may be delayed due to coordination problems	$15,930
6	Installation may be delayed due to coordination problems	3		**7**	Fabrication and installation problems may be revealed during HUC	$9,626
5	The subsea geological conditions may be different than expected	0		**1**	Bids may be Abusive leading to delayed approval	$3,313

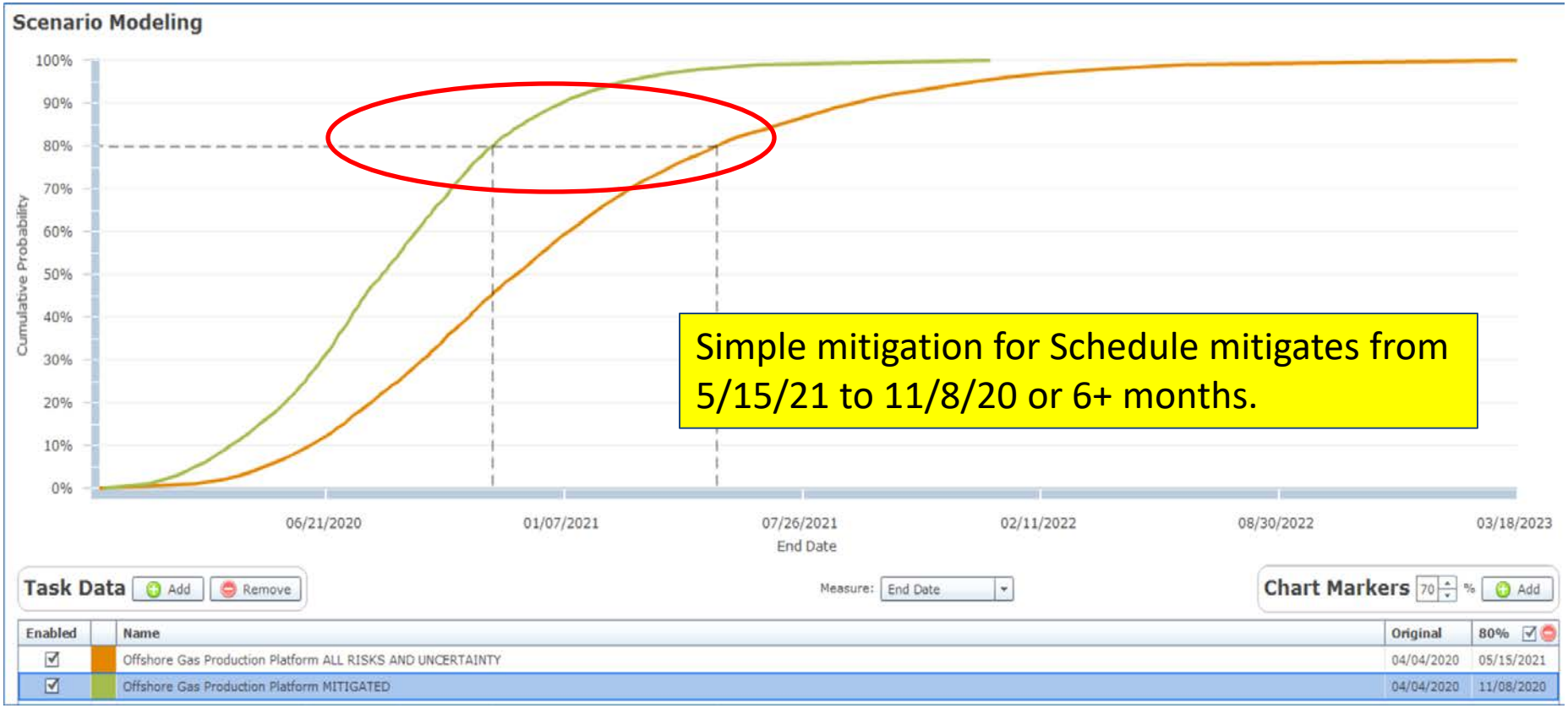
Risk Mitigation Workshop

- Risks can be mitigated but usually not completely
- Mitigation actions are:
  - New, not known to the interviewees, different from yesterday
  - Committed to by management so funded, staffed, monitored and reported on
- Once agreed to, estimate the owner, cost and timing of the mitigation
- Estimate the improvement to risk parameters

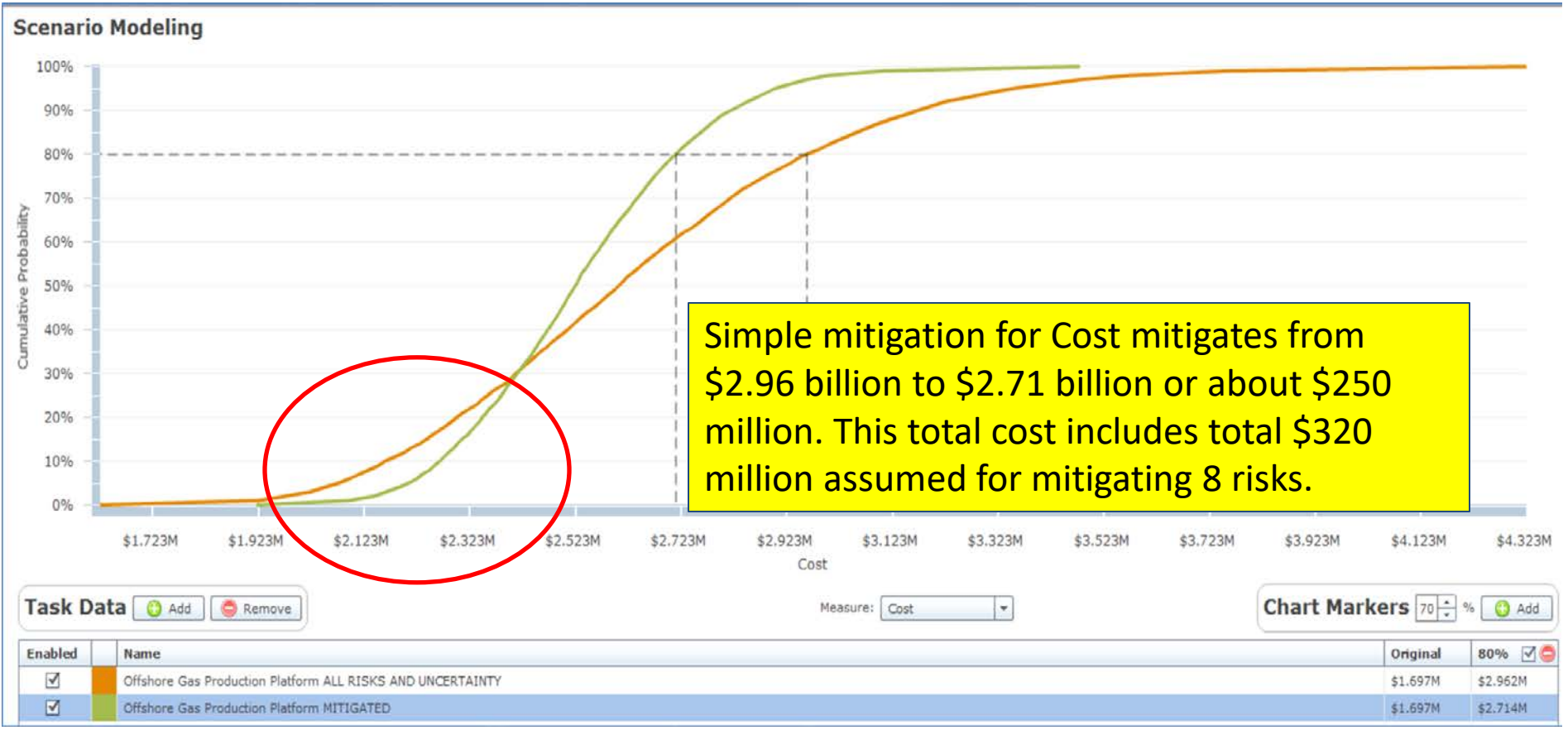
Mitigation Workshop Strategy and Simple Mitigation Scenario

- Prioritize the risks according to days saved
- Recognize that as schedule risk is addressed, the indirect effect on cost risk will be good
- Each risk mitigation has a cost and that cost will be added, so cost risk will represent two conflicting forces
- Simple mitigation scenario,
  - Cut probability for each of the risks in half
  - Add $40 thousand to mitigate each of the 8 project specific risk for a total mitigation cost of $320 million

Compare
Pre- and Post-Mitigation Schedule



Compare
Pre- and Post-Mitigation Cost



Review

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