Using Stochastic Optimization to Improve Risk Prioritization

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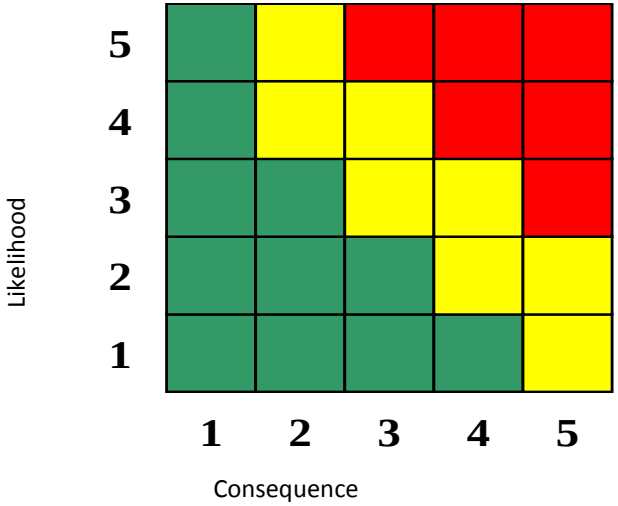
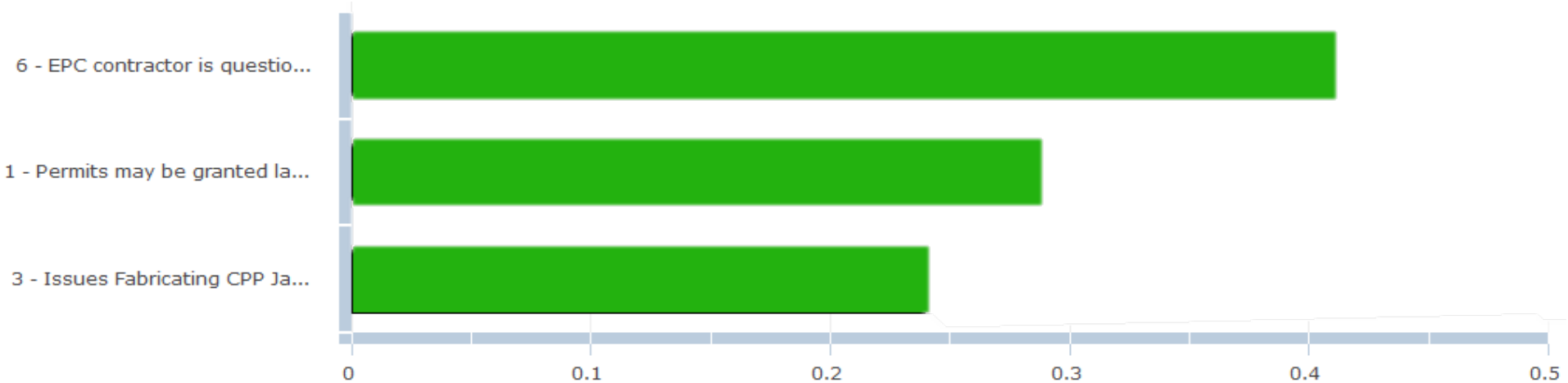
Limitations of the Risk Matrix/Cube Method

- Traditional risk management relies on the risk matrix to develop a probability-weighted metric for ranking risks for mitigation
  - The risk cube uses a combination of the risk's likelihood of occurrence and impact or consequence to categorize the weight



- This method is of limited value due to a couple of shortcomings
  - First, the ranking's usefulness is largely dependent on the quality of the scale used to establish consequence
  - Second, both likelihood and consequence factors are typically developed by subject matter experts focusing only on the area of the project directly impacted by the risk – they ignore the risks downstream impact on cost and schedule
  - These shortcomings mean that, while the risk cube provides a concise quick-look assessment of risk, it should be used to rank risks on only the most simplistic projects

Limitations of Sensitivity Analysis Methods



- To address challenges with the risk cube method, some analysts build simulation models and rank risks using sensitivity analysis metrics
  - Most simulation models capture samples from each distribution for each iteration of the simulation and then correlate these to the final cost and schedule
  - To rank risks, a regression line is drawn across this data and the correlation between the risk occurrence and final cost is calculated and plotted on a bar chart

- This methodology also has limitations
  - Correlation is an unreliable metric for prioritizing discrete events
  - The correlation metric is “unitless” (not measured in dollars or days), and therefore difficult for decision makers to understand
  - Attempts to convert from this unitless metric to tangible metrics ($’s and days) requires an assumption of normality which is explicitly violated when analyzing discrete risks
  - This approach for prioritizing risks ranks them on their impact assuming that none are mitigated, but once the highest correlated risk is removed the risk rankings are almost certain to change

Sensitivity Analysis Results are Inaccurate

Primavera Risk Analysis - [C:\... \Desktop\test-Pre-mitigated.pl

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Review Results

When the analysis is complete, review the results of the risk analysis using the following reports:

- Distribution Graph - determine confidence levels and contingency
- Tornado Graph - identify key schedule, cost, and risk drivers
- Scatter Plot - determine the combined probability of achieving project completion dates and budgets
- Probabilistic Cash Flow - compare the cash flow from the risk analysis to the deterministic project cash flow

After reviewing the results of the analysis, begin your response planning by creating a mitigation scenario in the Risk Register.

- Risk Register - (Mitigation plan)

Once completed, build an Impacted Risk Plan and run the Risk Analysis.

- Build Impacted Risk Plan (Pre- & Post-mitigated)
- Run Risk Analysis

In addition to reviewing the results in the reports listed above, use the Distribution Analyzer to compare risk analysis scenarios using the schedule and cost distribution results.

- Compare Scenarios

ID	Description	Remaining Duration	Minimum Duration	Most Likely	Maximum Duration	Duration Function	Task Existence %	Remaining Cost	Cost Min	Cost Likely	Cost Max
NEWPR	(New Project)	140						$0	$0	$0	$0
A1000	New Activity	100						$0	$0	$0	$0
A100	New Activity	100	100	100	100	Triangle(100;10		$0	$0	$0	$0
A100	1	0	40		80	Uniform(40;80)	50%	$0	$0	$0	$0
A1010	New Activity	100						$0	$0	$0	$0
A101	New Activity	100	100	100	100	Triangle(100;10		$0	$0	$0	$0
A101	2	0	41		81	Uniform(41;81)	99%	$0	$0	$0	$0

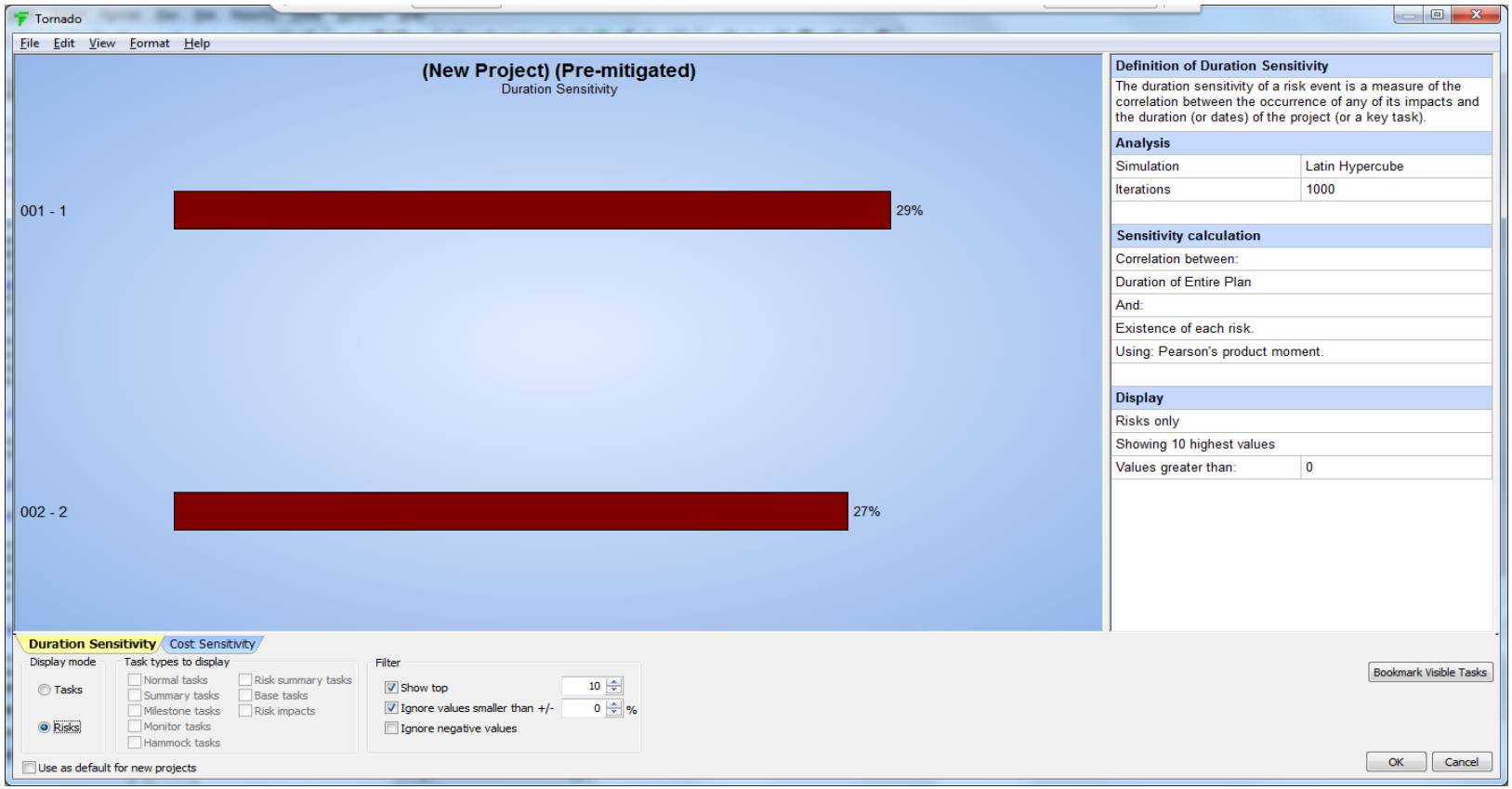
Nov '14: 20, 27, 3, 10, 17, 24 — Dec '14: 1, 8, 15, 22

Primavera Gantt | Logic Trace | Risk Inputs | Risk Outputs | Gantt and Graph | Gantt and Sheet | Import Check

Task Details

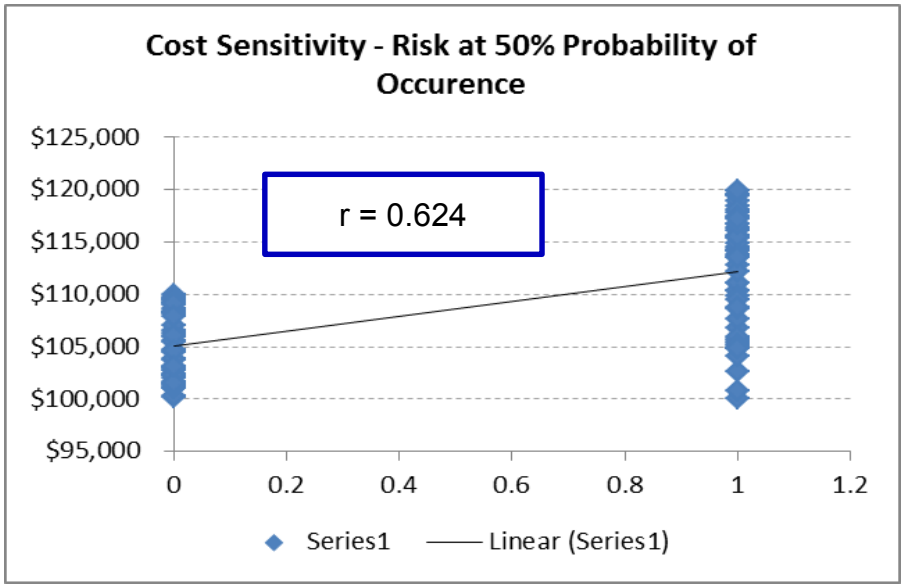
Risk 2 is clearly a stronger driver of schedule risk than Risk 1 – it has both a higher likelihood of occurrence and a higher impact should it occur….

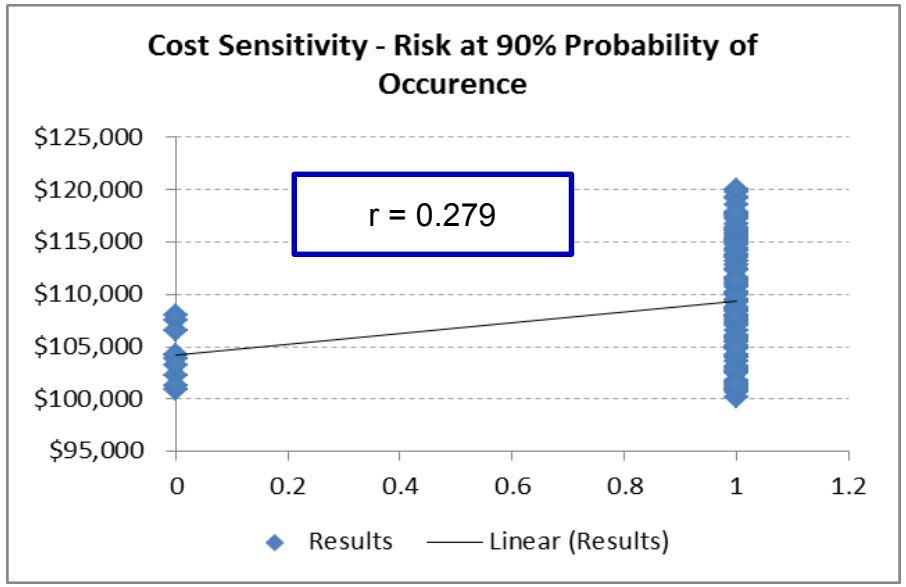
Sensitivity Analysis Results are Inaccurate



…yet in our sensitivity analysis Risk 1 is still identified as the greater risk – let's explore this further

Pearson's Correlation is Unreliable





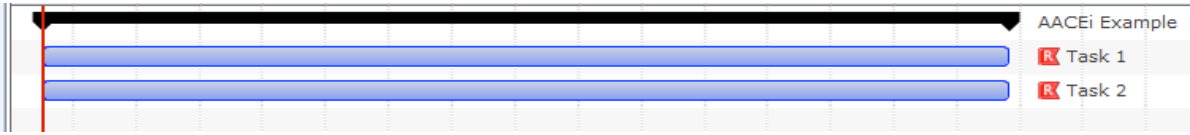
- Pearson's correlation (r) measures the strength of the linear relationship within a data set
- When used to analyze discrete events, r is highly influenced by the probability of occurrence of the event
- Due to this, Pearson's correlation is biased to rank events with probabilities of occurrence closer to 50% as more impactful

A Warning to Analysts

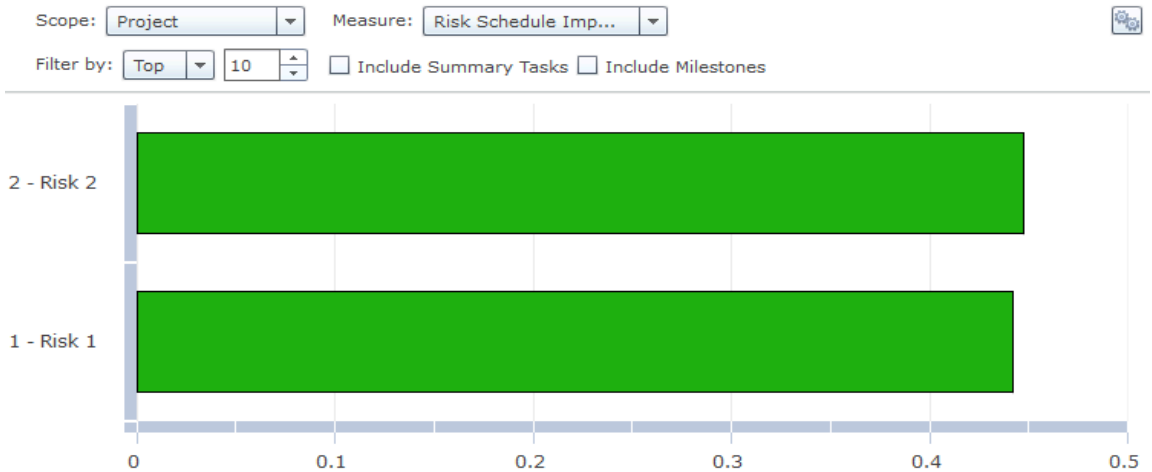
Analysts should beware when using correlation based metrics to prioritize risks

Traditional methods ignore schedule structure

0	▼ AACEi Example	5/19/2014	3/16/2018	1,000	$0
4	Task 1	5/19/2014	3/16/2018	1,000	$0
5	Task 2	5/19/2014	3/16/2018	1,000	$0

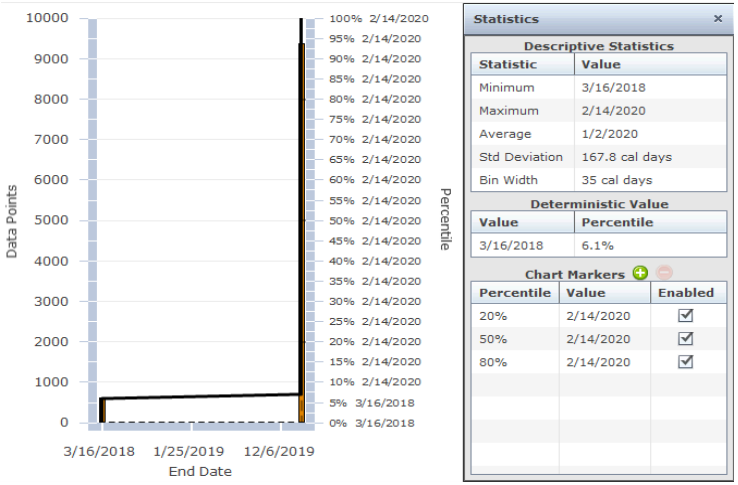


Each risk has a probability of occurrence of 75% with a fixed impact, should the risk occur, of 500 days of schedule growth

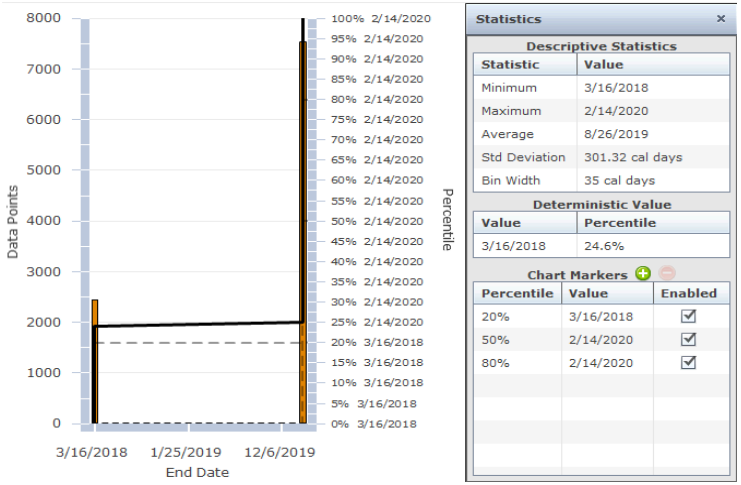


- Neither the risk cube nor correlation-based sensitivity metrics account for the structure of the schedule when mitigating risks
- In the simplistic example above, two risks – with equal probabilities and impacts - are associated with two separate parallel tasks in a schedule with no baseline uncertainty
- Both risks exhibit medium correlation to the finish date of the schedule
- What value does this data provide a decision maker?
  - Which risk should be mitigated?
  - How much time will be saved by mitigating each risk?

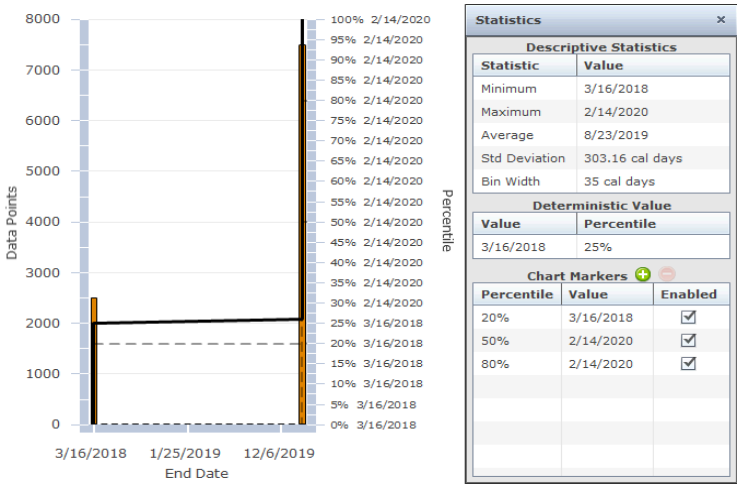
Sensitivity analysis on two parallel risks



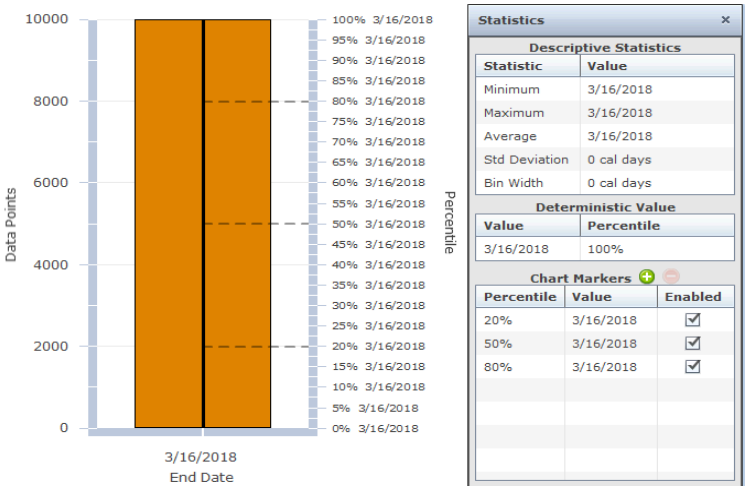
Neither risk mitigated – 94% likelihood of 500 day schedule growth



Risk 2 mitigated – 75% likelihood of 500 day schedule growth



Risk 1 mitigated – 75% likelihood of 500 day schedule growth



Both risks mitigated – 0% likelihood of 500 day schedule growth

Traditional methods ignore schedule structure

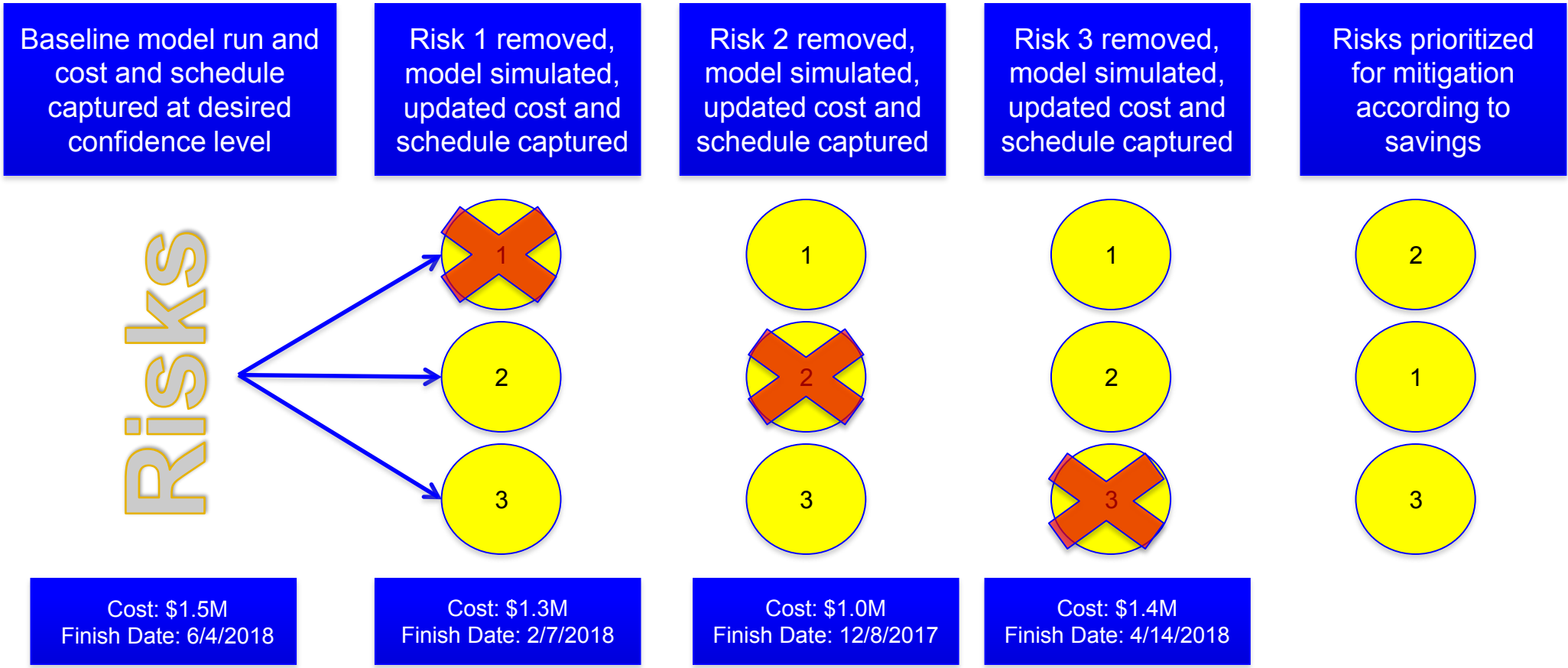
- The previous slide was presented in a simplistic manner to underscore the issue that today's risk prioritization methodologies ignore that the structure of the schedule must be accounted for when risks are ranked for mitigation
  - It is likely that full mitigative impacts won't be realized due to a shift in the critical path
- The aim of this presentation is to present three, increasingly sophisticated, methods for prioritizing risks in a ways more useful to analysts and decision makers
- The goal of the authors was to improve on traditional risk prioritization methods by ensuring the new ranking criteria:
  - Accurately prioritizes risks
  - Accounts for probabilistic aspects of the model including risks, uncertainties, and correlation
  - Is quantified using tangible (day and $) metrics
  - Accounts for where the risk occurs within the structure of the schedule
  - Shows the cost/benefit trade-off of mitigating risks
- The problems addressed in the introduction were related to several ongoing projects the authors participated in
  - Thus, two of the three following methodologies were built into the Polaris tool for integrated cost and schedule risk analysis

Stochastic Optimization Overview

- "Stochastic optimization methods are optimization methods that generate and use random variables"[1]
  - Said another way, stochastic optimization is the practice of trying to find minimum and/or maximum values in a system where the system's rules are represented by random variables rather than deterministic functions
- Since most risk analysis models leverage some type of simulation, any optimization of these models – to find the best risk to mitigate for instance – falls in the field of stochastic optimization
- This paper will present three methods for using stochastic optimization to prioritize risks:
  - Single Pass Prioritization
  - Iterative Prioritization
  - Knapsack Prioritization

[1]http://en.wikipedia.org/wiki/Stochastic_optimization

Single Pass Prioritization

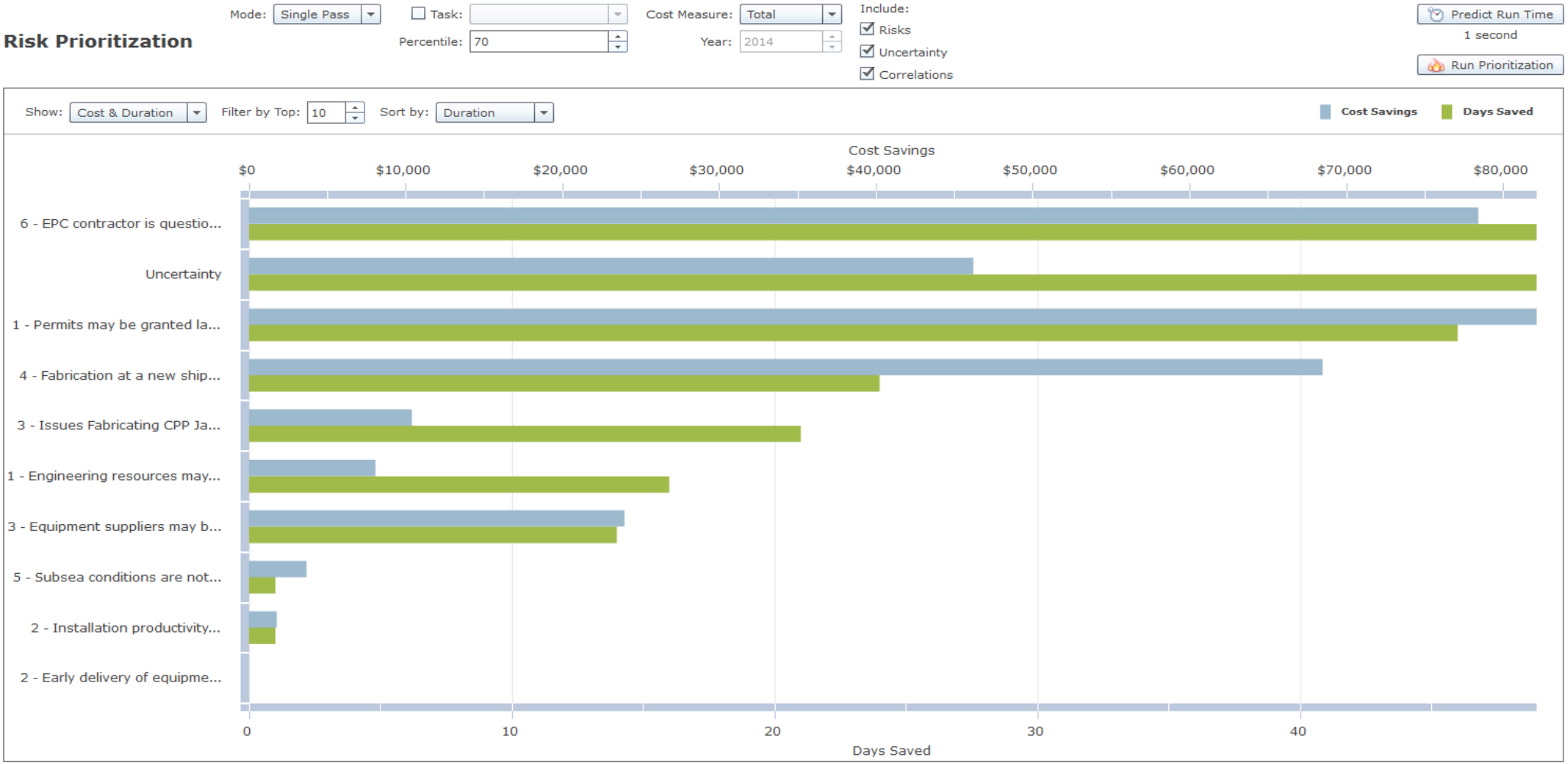


- This method seeks to rank risks based on tangible metrics by iteratively removing them from the model and capturing the resulting cost and schedule savings

Pros and Cons: Single Pass Prioritization

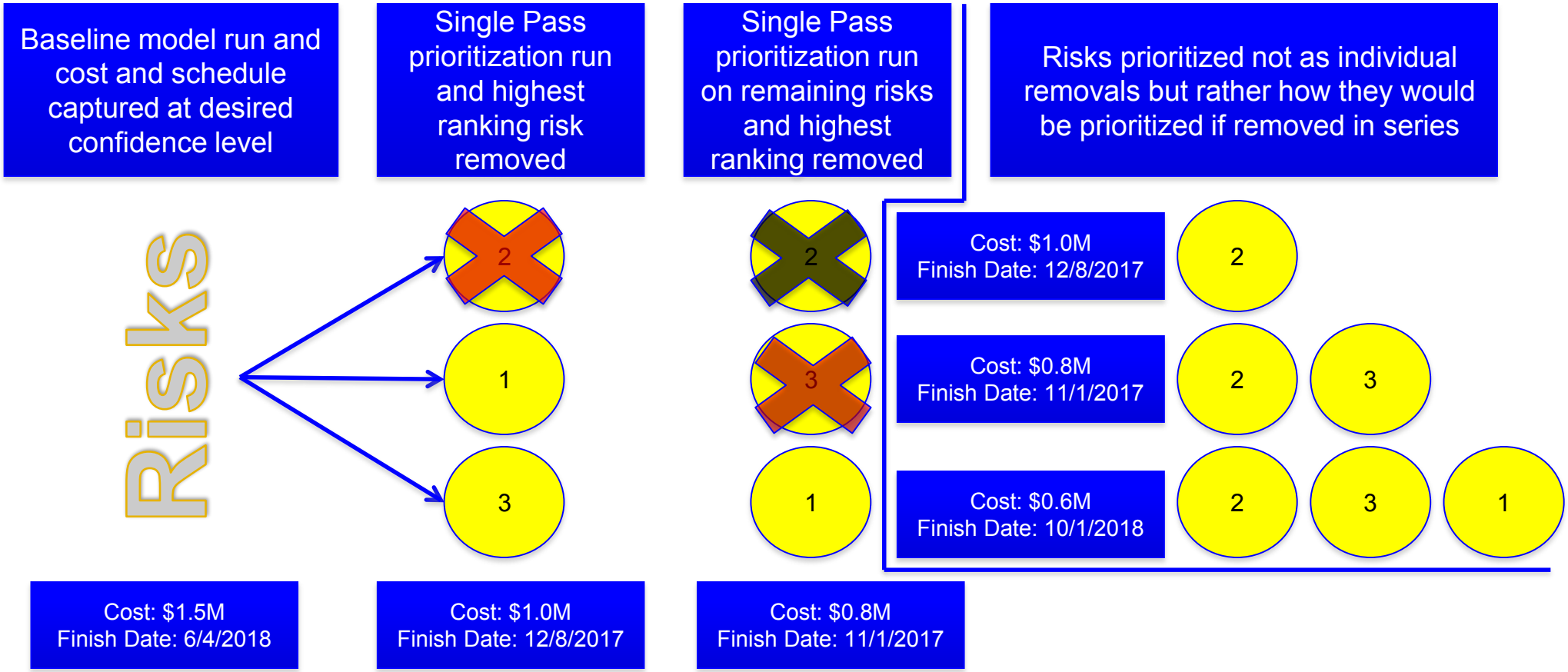
- Pros:
  - Intuitive – the methodology is easy to understand from an analyst and decision maker perspective
  - Tangible – results are provided in day and $ metrics
  - Relatively low number of simulations required to run (# of risks + 1)
- Cons
  - Does not account for how schedule structure impacts removal of multiple risks
  - Tough to do easily do cost/benefit analysis of risk mitigation due to inability to account for multiple risk removals

Implementation of Single Pass in Polaris™



Note addition of correlation and uncertainty factors as well as ability to prioritize based on cost or finish date for a task or year

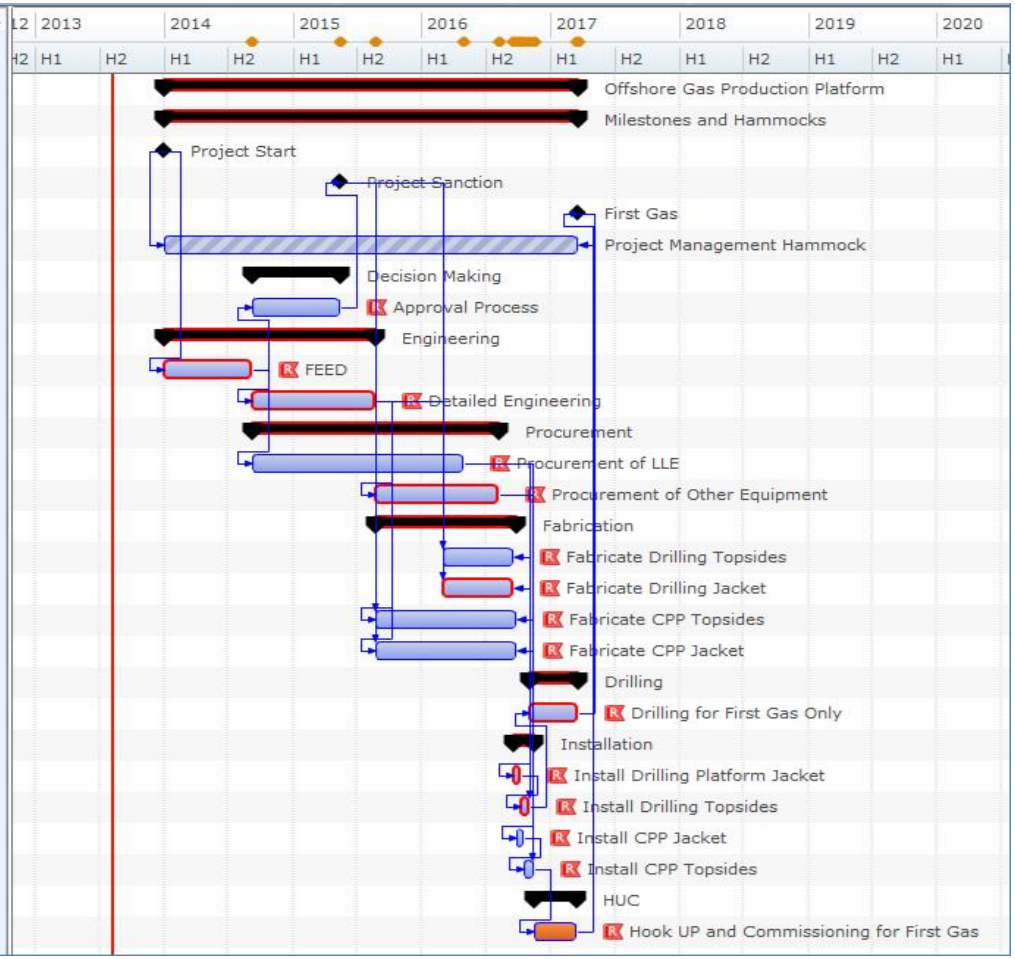
Iterative Prioritization



- This method keeps the tangible metrics of the single-pass prioritization while accounting for schedule structure in removal of multiple risks

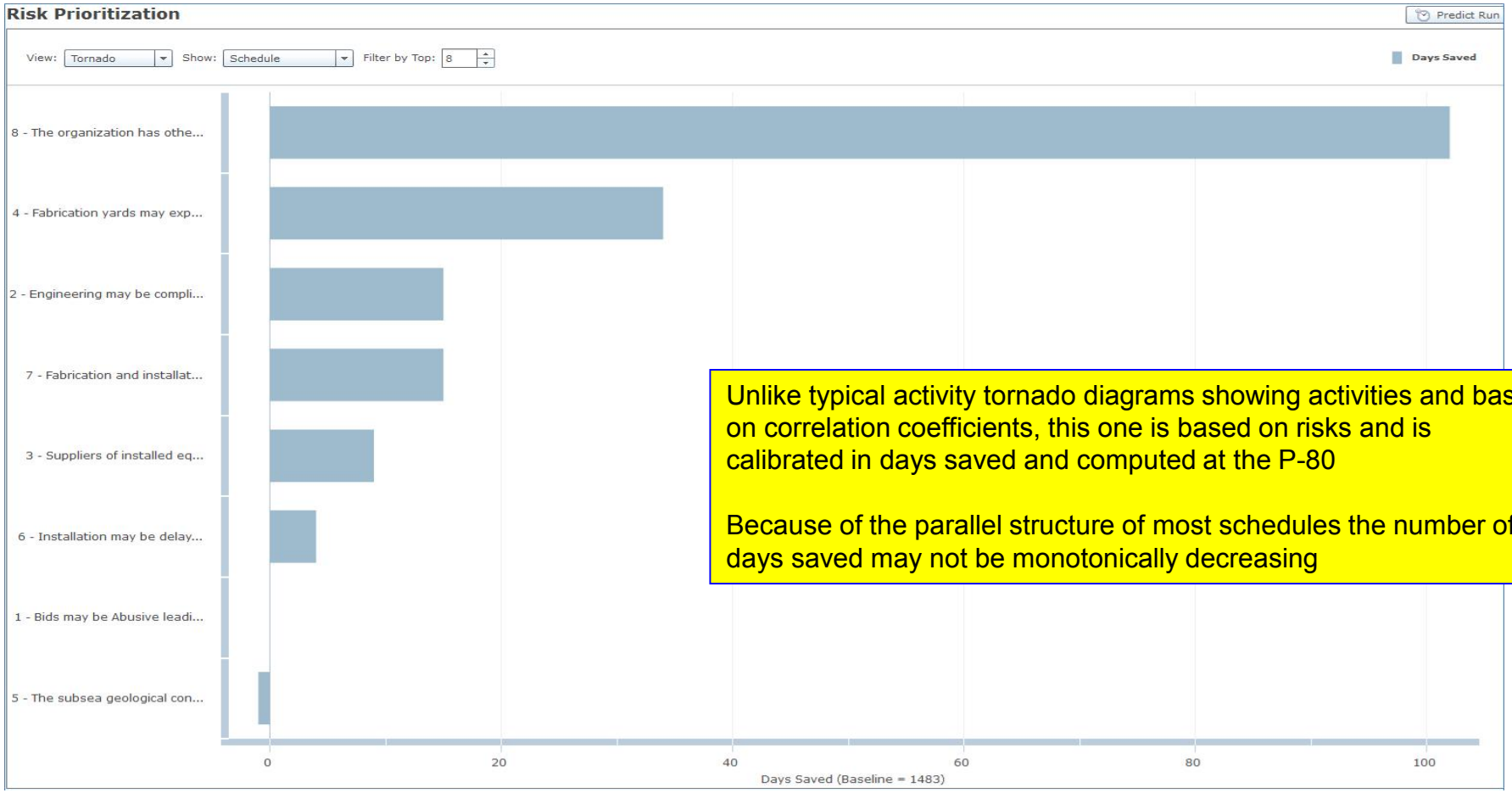
Introducing the Gas Production Platform Schedule

UID	Task	Start Date	End Date	Duration	Cost
Gas Pla	▼ Offshore Gas Production Platfor	1/1/2014	3/20/2017	1,175	$1.57M
Gas Pla	▼ Milestones and Hammocks	1/1/2014	3/20/2017	1,175	$200,000
A1000	Project Start	1/1/2014		0	$0
A1010	Project Sanction		5/15/2015	0	$0
A1020	First Gas		3/20/2017	0	$0
A1030	Project Management Ham	1/1/2014	3/20/2017	1,175	$200,000
Gas Pla	▼ Decision Making	9/8/2014	5/15/2015	250	$80,000
B1000	Approval Process	9/8/2014	5/15/2015	250	$80,000
Gas Pla	▼ Engineering	1/1/2014	8/23/2015	600	$96,000
C1000	FEED	1/1/2014	9/7/2014	250	$16,000
C1010	Detailed Engineering	9/8/2014	8/23/2015	350	$80,000
Gas Pla	▼ Procurement	9/8/2014	8/7/2016	700	$425,000
D1000	Procurement of LLE	9/8/2014	4/29/2016	600	$250,000
D1010	Procurement of Other Equ	8/24/2015	8/7/2016	350	$175,000
Gas Pla	▼ Fabrication	8/24/2015	9/26/2016	400	$576,000
E1000	Fabricate Drilling Topsides	3/1/2016	9/16/2016	200	$160,000
E1010	Fabricate Drilling Jacket	3/1/2016	9/16/2016	200	$80,000
E1020	Fabricate CPP Topsides	8/24/2015	9/26/2016	400	$240,000
E1030	Fabricate CPP Jacket	8/24/2015	9/26/2016	400	$96,000
Gas Pla	▼ Drilling	11/1/2016	3/20/2017	140	$80,000
F1000	Drilling for First Gas Only	11/1/2016	3/20/2017	140	$80,000
Gas Pla	▼ Installation	9/17/2016	11/15/2016	60	$47,200
G1000	Install Drilling Platform Ja	9/17/2016	10/6/2016	20	$8,000
G1010	Install Drilling Topsides	10/7/2016	10/31/2016	25	$13,600
G1020	Install CPP Jacket	9/27/2016	10/16/2016	20	$9,600
G1030	Install CPP Topsides	10/17/2016	11/15/2016	30	$16,000
Gas Pla	▼ HUC	11/16/2016	3/15/2017	120	$64,000
H1000	Hook UP and Commission	11/16/2016	3/15/2017	120	$64,000



3+ year schedule costing $1.57 billion

Schedule Risk Tornado with Days Saved



Unlike typical activity tornado diagrams showing activities and based on correlation coefficients, this one is based on risks and is calibrated in days saved and computed at the P-80

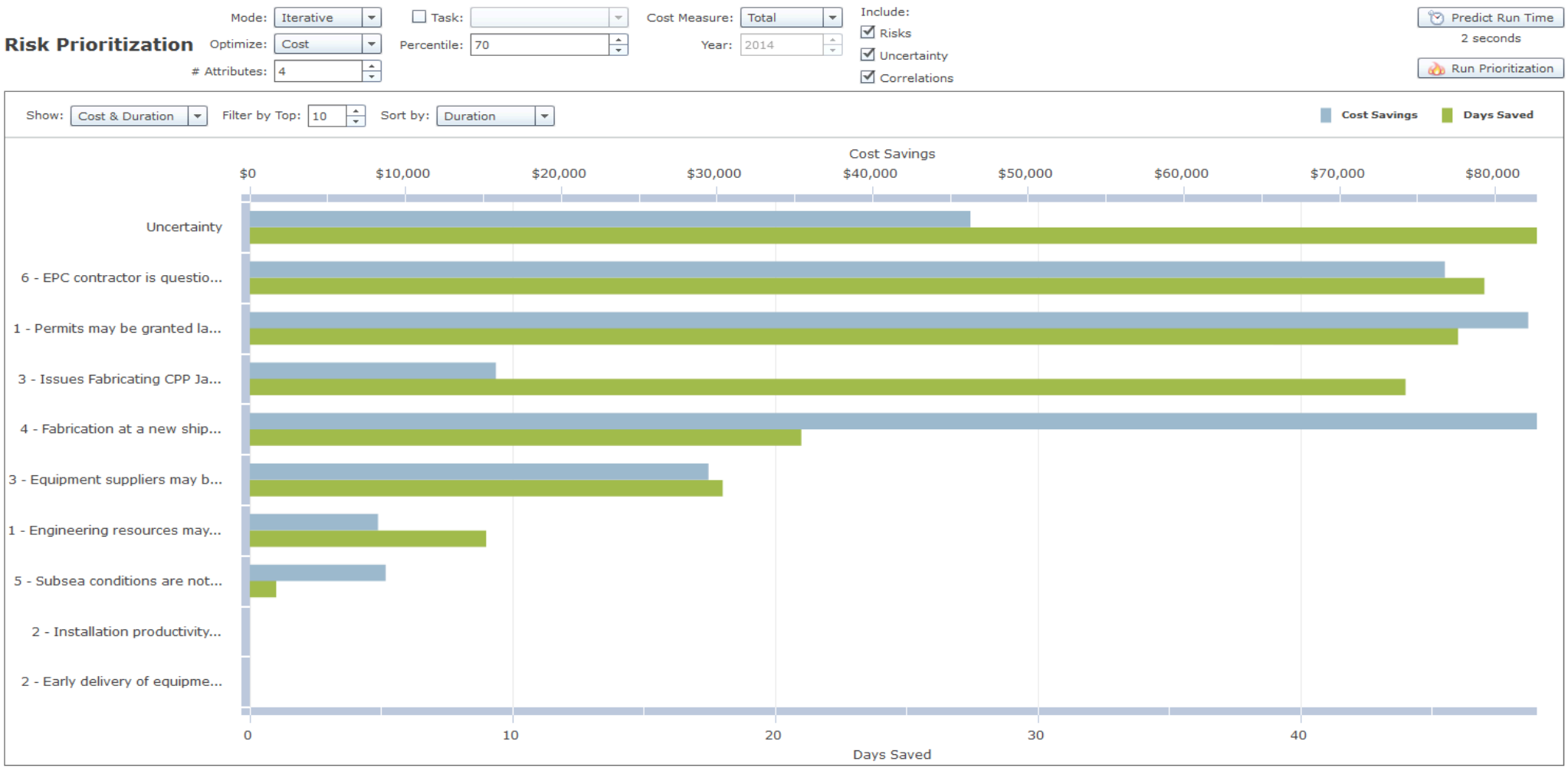
Because of the parallel structure of most schedules the number of days saved may not be monotonically decreasing

Table Showing Risks' Days Saved

Gas Platform-1 - Risk Prioritization (80%)		
UID	Name	Days Saved
8	The organization has other priority projects so personnel and funding may be unavailable	102
4	Fabrication yards may experience lower Productivity than planned	34
2	Engineering may be complicated by using offshore design firm	15
7	Fabrication and installation problems may be revealed during HUC	15
3	Suppliers of installed equipment may be busy	9
6	Installation may be delayed due to coordination problems	4
1	Bids may be Abusive leading to delayed approval	0
5	The subsea geological conditions may be different than expected	-1
	TOTAL DAYS SAVED WITH FULL MITIGATION OF RISKS	**178**
	Uncertainty (inherent, estimating error / bias)	130
	TOTAL CONTINGENCY DAYS WITH UNCERTAINTY & RISKS	**308**

Target for Mitigations is 178 days. Proceed risk-by-risk

Implementation of Iterative in Polaris™



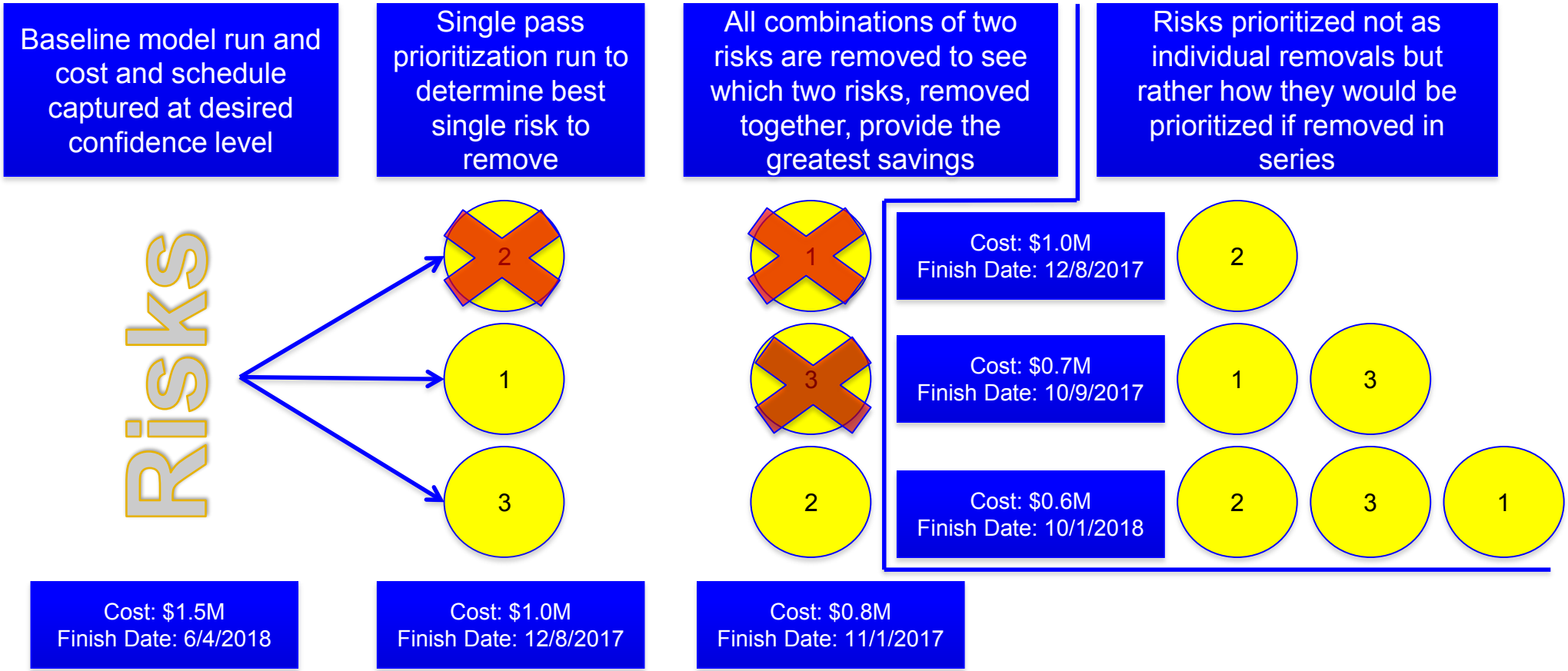
Note different prioritization (value of removing uncertainty drops significantly when compared to single pass) and longer predicted run time

Pros and Cons: Iterative Prioritization

- Pros:
  - Intuitive – the methodology is easy to understand from an analyst and decision maker perspective
  - Tangible – results are provided in day and $ metrics and can be calibrated to a desired level of confidence (P-80)
  - Accounts for how schedule structure impacts removal of multiple risks
  - Easy to perform cost/benefit trade-off analysis to determine value of removing each subsequent risk
- Cons
  - Number of simulations runs required to perform analysis starting to grow - $\sum_{i=n-9}^{n} n$ where n is the number of risks[1]

[1]Assumes only finding the top 10 attributes

Knapsack Prioritization



- This method will produce the 100% optimal set of risks to mitigate, but – as we will show, is too time consuming to be practical as an analysis tool

Pros and Cons: Knapsack Prioritization

- Pros:
  - Tangible – results are provided in day and $ metrics
  - Accounts for how schedule structure impacts removal of multiple risks
  - Easy to perform cost/benefit trade-off analysis to determine value of removing each subsequent risk
- Cons
  - Knapsack optimization is proven to be NP-Hard and unsolvable for anything but the most simple problems
  - Number of simulations required to find top 10 baskets of risk to mitigate $\sum_{i=1}^{10} \frac{n!}{(n-1)}$ where n is the number of risks

Runtime Comparisons Across Methods

Single Pass Prioritization Runtimes

Number of Tasks in Schedule	Run-Time (Minutes)	Risks 10	50	100	150
	100	0	0.2	0.3	0.5
	1000	0.2	0.9	1.9	2.8
	3000	1	4.9	9.7	14.6
	6000	3	15	30	45

Iterative Prioritization Runtimes

Number of Tasks in Schedule	Run-Time (Minutes)	Risks 10	50	100	150
	100	0.2	1.4	2.9	5.7
	1000	1	8.5	17.8	35.6
	3000	5.4	44.3	93	185.4
	6000	16.5	136.5	286.5	571.5

Knapsack Prioritization Runtimes

Number of Tasks in Schedule	Run-Time	Risks 10	50	100	150
	100	0.1 hours	76.7 years	110,821 years	7 million years
	1000	0.3 hours	477.1 years	689,555 years	45 million years
	3000	1.7 hours	2,487.5 years	4 million years	233 million years
	6000	5.1 hours	7,667.1 years	11 million years	718 million years

For context, this is around the time that multicellular life on earth is predicted to die out

[1]Benchmarks calculated based on Polaris™ runtimes using RealTime Analytics™ engine

Conclusions and Future Research

- Traditional risk prioritizations are not providing analysts, project managers, and decision makers the information they need to make informed risk mitigation decisions

- This paper has shown three methods for prioritizing risk that fulfill the following criteria with various levels of success:
  - Account for probabilistic aspects of the model including risks, uncertainties, and correlation
  - Are quantified using tangible (day and $) metrics
  - Account for where the risk occurs within the structure of the schedule
  - Show the cost/benefit trade-off of mitigating risks

- Of the three methods presented, two have reasonable run times for the value provided and have been automated within Booz Allen's Polaris™ tool to enable them to be used by analysts

- We further recommend that at least one of these methods be adopted as a standard practice

- This analysis assumes the complete removal of a risk that is mitigated (0 likelihood of occurrence and 0 impact);
  - As future research the authors intend on applying a gradient allowing partial reduction of risks as this is likely more realistic than wholesale risk removal

Bibliography

1. Smith, C, Herzog, H. (2012). Using Optimization Techniques to Enhance Cost and Schedule Risk Analysis. International Society of Parametric Analysis International Symposium