Risk Driver Method Applied to

Integrated Cost – Schedule Risk Analysis

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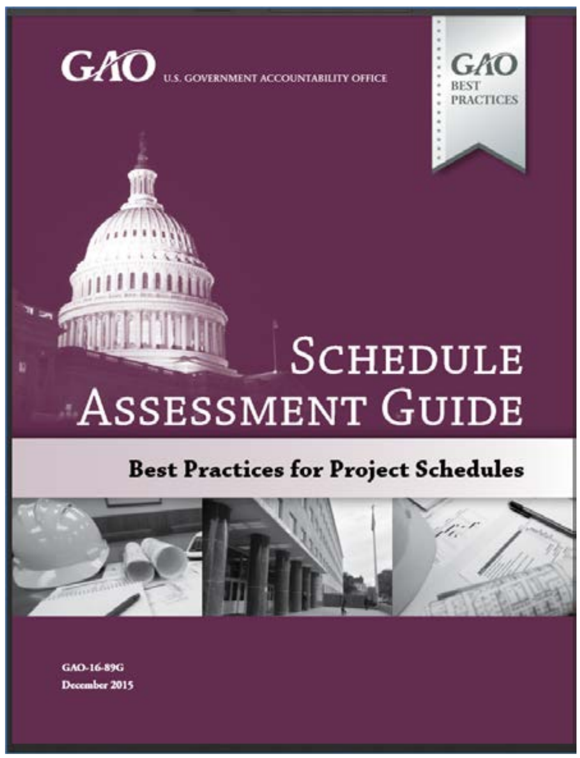
June 2017

Schedule Quality

The first task is to make sure the schedule will react correctly during simulation. We apply the GAO 10-point scheduling best practices and produce a report that highlights what needs to be done with the schedule to bring it up to CPM standards.



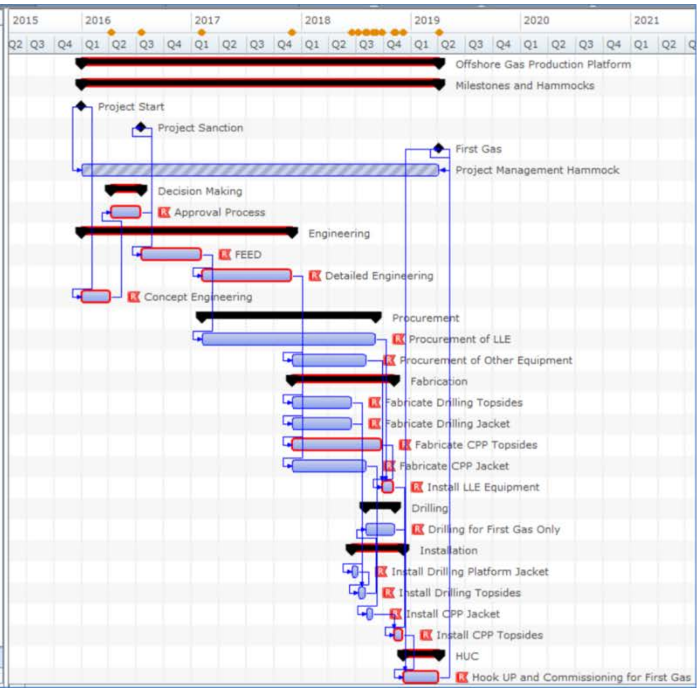
For some of the best practices the use of third-party software such as Acumen FUSE® is required.

Ribbon Analyzer								
Missing Predecessors	Missing Successors	Open Start	Open Finish	Lags	Leads	Hard Constraints	Soft Constraints	Score
1 (5%)	1 (5%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	1 (5%)	0 (0%)	90%

With most projects we recommend the development of a summary "analysis schedule" of 250 – 1,000 activities if the detailed schedule is too large or too difficult to de-bug. A summary schedule can be constructed to comply with scheduling best practices from the outset.

An example project schedule is shown below for an offshore gas production platform project[1]:

UID	Task	Start Date	End Date	Duration	Cost
Gas Platfor	▼ Offshore Gas Production Platfor	01/01/2016	04/04/2019	1,190	$1.717M
Gas Platfor	▼ Milestones and Hammocks	01/01/2016	04/04/2019	1,190	$400,000
A1000	Project Start	01/01/2016		0	$0
A1010	Project Sanction		07/18/2016	0	$0
A1020	First Gas		04/04/2019	0	$0
A1030	Project Management Ham	01/01/2016	04/04/2019	1,190	$400,000
Gas Platfor	▼ Decision Making	04/10/2016	07/18/2016	100	$8,000
B1000	Approval Process	04/10/2016	07/18/2016	100	$8,000
Gas Platfor	▼ Engineering	01/01/2016	11/30/2017	700	$256,000
C950	FEED	07/19/2016	02/03/2017	200	$80,000
C1010	Detailed Engineering	02/04/2017	11/30/2017	300	$160,000
C900	Concept Engineering	01/01/2016	04/09/2016	100	$16,000
Gas Platfor	▼ Procurement	02/04/2017	09/06/2018	580	$350,000
D1000	Procurement of LLE	02/04/2017	09/06/2018	580	$250,000
D1010	Procurement of Other Equ	12/01/2017	08/07/2018	250	$100,000
Gas Platfor	▼ Fabrication	12/01/2017	11/05/2018	340	$536,000
E1000	Fabricate Drilling Topsides	12/01/2017	06/18/2018	200	$80,000
E1010	Fabricate Drilling Jacket	12/01/2017	06/18/2018	200	$80,000
E1020	Fabricate CPP Topsides	12/01/2017	09/26/2018	300	$240,000
E1030	Fabricate CPP Jacket	12/01/2017	08/07/2018	250	$104,000
E1025	Install LLE Equipment	09/27/2018	11/05/2018	40	$32,000
Gas Platfor	▼ Drilling	08/03/2018	11/10/2018	100	$80,000
F1000	Drilling for First Gas Only	08/03/2018	11/10/2018	100	$80,000
Gas Platfor	▼ Installation	06/19/2018	12/05/2018	170	$47,200
G1000	Install Drilling Platform Ja	06/19/2018	07/08/2018	20	$8,000
G1010	Install Drilling Topsides	07/09/2018	08/02/2018	25	$13,600
G1020	Install CPP Jacket	08/08/2018	08/27/2018	20	$9,600
G1030	Install CPP Topsides	11/06/2018	12/05/2018	30	$16,000
Gas Platfor	▼ HUC	12/06/2018	04/04/2019	120	$40,000
H1000	Hook UP and Commission	12/06/2018	04/04/2019	120	$40,000



For an integrated cost-schedule risk analysis the costs (without padding for contingency) are fully loaded using time-dependent (labor, rented equipment) and time-independent (materials, purchased equipment) resources.

Risk Data Quality

Collecting high-quality risk and uncertainty data is a success factor for any risk analysis. Risk interviews appear to be better at gathering risk information on the probability, impact (in multiplicative terms, supporting the Risk Driver method) and activities affected should the risk occur. These interviews are conducted one-on-one (or one-on-few if the teams are cohesive and everyone can talk). Confidentiality is guaranteed so interviewees can speak freely. In addition to the standard "unknowns" there are unknown knowns that are often revealed in a confidential setting.[2]

[1] The simulation software used here is Polaris® from Booz Allen Hamilton.

[2] Psychoanalytic philosopher Slavoj Žižek says that beyond these three categories there is a fourth, the unknown known, that which we intentionally refuse to acknowledge that we know: "If Rumsfeld thinks that the main dangers in the confrontation with Iraq were the 'unknown unknowns', that is, the threats from Saddam whose nature we cannot even suspect, then the Abu Ghraib scandal shows that the main dangers lie in the "unknown knowns"—the disavowed beliefs, suppositions and obscene practices we pretend not to know about, even though they form the background of our public values." German sociologists Daase and Kessler (2007) agree with a basic point of Rumsfeld in stating that the cognitive frame for political practice may be determined by the relationship

Selecting the interviewees and reserving enough time to collect the data is important to the quality of the input data.

Uncertainty

During the interviews we collect data about uncertainty and risks. Uncertainty is like "common cause" variability in six sigma terminology.[3] Common cause variability is unlikely to be reduced (mitigated) so forms the limit to which project risk an be mitigated. It includes inherent variability of duration or resource cost because of inherent variability and duration estimating error. Even without discrete risks there is no certainty because people and organizations cannot do the same activity according to a plan, unless the project is performed hundreds of times by the same teams so they can reduce this source of variation. Uncertainty also includes estimating error and, if it is thought to exist in the subject schedule, estimating bias (usually optimism).

Project-specific and Systemic Risks

Project-specific and systemic risk events are similar to "special causes" in six sigma language.[4] The list of these risks can be based on the Risk Register initially. However, we find the risk register is incomplete, so we ask: "What is bothering you about this project?" and encourage the interviewees to go from there to find out new risks and honest answers about the risks' parameters. Since we are talking about a limited number of specific risks at the strategic level these interviews take on average about 2 hours. If there are data about risks from past projects we incorporate those. These risks are mostly strategic risks, representing technical, external, organizational and even project management risks (use the Risk Breakdown Structure to get interviewees out of their silos).

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between *what we know, what we do not know, what we cannot know*, but Rumsfeld left out *what we do not like to know. https://en.wikipedia.org/wiki/There_are_known_knowns*

[3] Common cause variation is fluctuation caused by unknown factors resulting in a steady but random distribution of output around the average of the data. It is a measure of the process potential, or how well the process can perform when special cause variation removed.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. Therefore, it is a measure of the process technology. Common cause variation is also called random variation, noise, non-controllable variation, within-group variation, or inherent variation. Example: Many X's with a small impact. https://www.isixsigma.com/dictionary/common-cause-variation/

[4] Unlike common cause variability, special cause variation is caused by known factors that result in a non-random distribution of output. Also referred to as "exceptional" or "assignable" variation. Example: Few X's with big impact. 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 and is a measure of process control. https://www.isixsigma.com/dictionary/variation-special-cause/

We introduce systemic risks to the interviewees and usually get responses that derive their values from databases or experiences with similar projects in the past.

Risk Data Consolidation after the Interviews

After the data are gathered we will have different answers about the data for many of the risks, so there is a data-consolidation phase. The different answers for the same risks are consolidated into one set of parameters for each risk. Often the interviewees introduce similar risks that represent the same root causes of variation, and these are consolidated. Usually there has been a second person who knows the participants and was present during the interviews, so we can make informed assessments of which data are more to be relied on than other data.

Risk Modeling using Monte Carlo Simulation

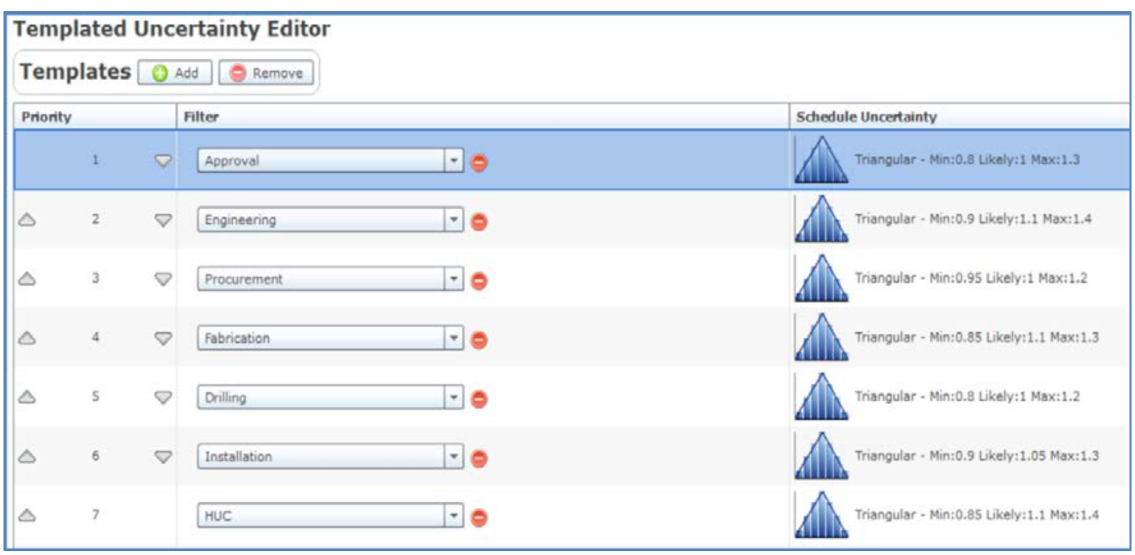
We use Polaris® from Booz Allen Hamilton, a software product that has been used on several project risk analyses (for the Architect of the Capitol, GSA, commercial oil, gas, chemicals and bio-pharmaceutical construction projects) in the last couple of years. We generally use:

- 3-point estimates applied to activity durations and resources for uncertainty
- Risk Drivers with individual risks specified by probability, impact and activities affected for discrete risk events

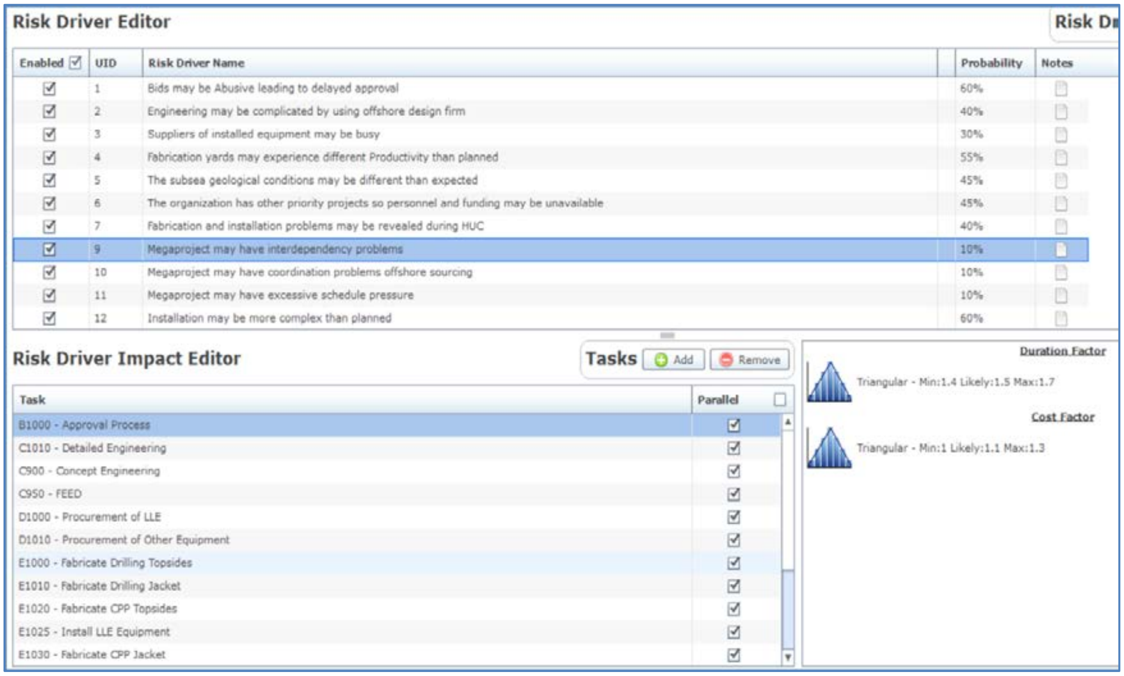
Other constructs can be used to represent non-standard sources of variability, such as:

- Probabilistic branching when the risk causes new activities to be present (e.g., failing a test introduces root cause analysis, plan the recovery, execute the recovery and re-test, activities that are not in the schedule
- Probabilistic calendars if weather affects productivity (e.g., outside scaffolding or steel work in the winter in Washington DC) or even stops some kind of work

Modeling uncertainty in activity durations can be done as shown below:



The modeling of the project-specific and systemic risks into the cost-loaded schedule involves applying some risks to multiple activities. An example of this operation is shown below for the case study project. Highlighted is a systemic risk:



Often the interviewee was talking about strategic risks that affected project phases, and Polaris permits the specification of categories or filters of detailed risks within these phases to allow assignment to many detailed activities at the same time. Also many activities have multiple risks assigned, as in reality several risks affect the durations of different activities, and Polaris allows us to specify those risks to act in series or in parallel.

If costs are involved they are assigned to the activities using resources. The only resources needed for integrated cost-schedule risk analysis are time-dependent (labor, rented equipment) resources and total cost for time-independent (equipment, materials) resources. Loading and risking costs allows a joint review of both time and cost risks.

<u>Schedule Risk and Cost Risk Results using Monte Carlo Simulation</u>

Schedule risk results are shown below. These results are contained in histograms and their associated cumulative distribution functions. The 50th and 80th percentile are highlighted as a matter of convenience, although the project owner can choose a different level of confidence. The 80th percentile, or "P-80" implies that, with the schedule, uncertainties and risks used in the analysis, there is an 80% likelihood that the finish date will be that date <u>or earlier</u>. For cost the P-80 indicates a value for which it is eighty percent likely to meet <u>or be less</u>. Eighty percent is used as a somewhat conservative target of certainty that provides some margin to accommodate risks that are not known at the time of the analysis.

These results reflect the impact of uncertainty and risks defined and assigned as shown above. The scheduled date is 4 April 2019, which is shown to be only 1% likely to occur. This is because of two interacting factors:

- All of the risks and uncertainties were specified to be mostly or completely threats (right-skewed toward overrun of the schedule durations). Even with small probabilities such as the systemic risks exhibit in this example, there is very little opportunity to be had with the way these risks are stated. This is a common finding in risk interviews.
- There are some merge points in the schedule. These are at the Install Long-lead Equipment, Install Central Processing Plant (CPP) Topsides and Hook-up and Commissioning. At each of these activities the two predecessors must both finish on time or earlier for the activity to start on time. This effect, where the successor activity's start is more risky than any of the merging paths, is called the "merge bias," which has been known since the 1960s:[5]

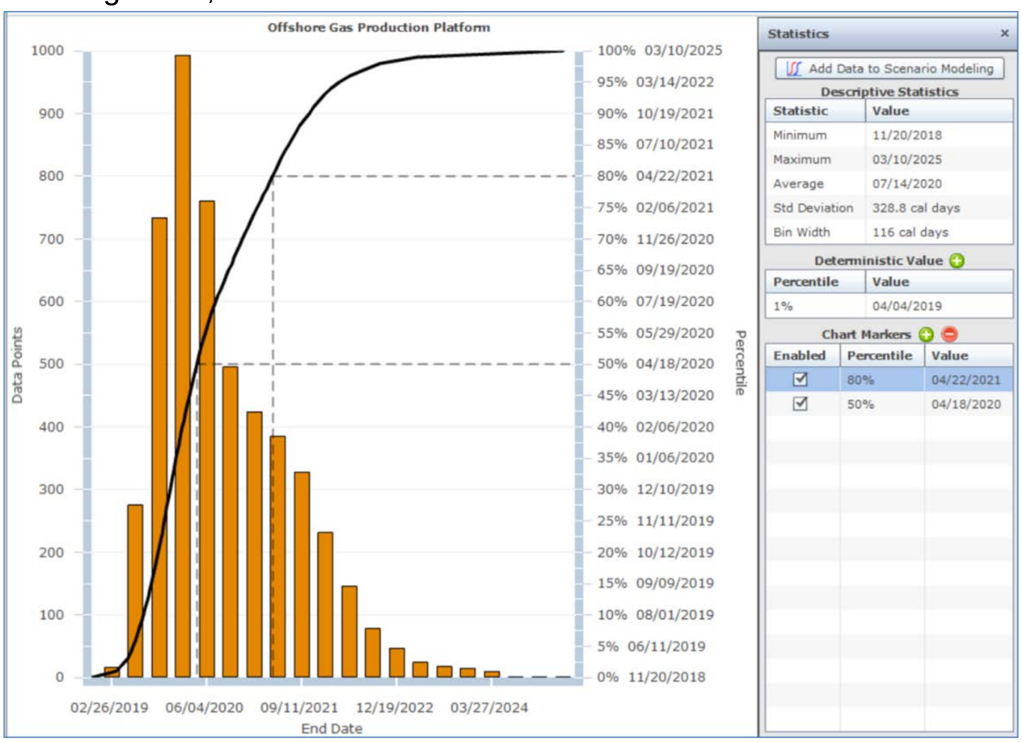


Figure 4 - Standard Schedule Histogram and S-Curve Results

1 [5] MacCrimmon, K., and Ryavec, C., 1962, "An Analytical Study of the PERT Assumptions," Research Memorandum RM-3408-PR, Rand Corporation, Santa Monica CA

The cost risk results from the simulation are shown below: Notice that the estimated cost is $1.7 billion but the P-80 cost is 2.8 billion, about $1.1 billion dollars or about 64% over budget. Also, the estimated cost is about 14% likely to be achieved.

The benefit of implementing the integrated cost and schedule risk analysis approach is that cost risk includes both:

- Direct cost risk from the application of cost impact multipliers of the project-specific and systemic risks
- Indirect risk reflecting the impact of variations of schedule activity durations from risk and uncertainty.

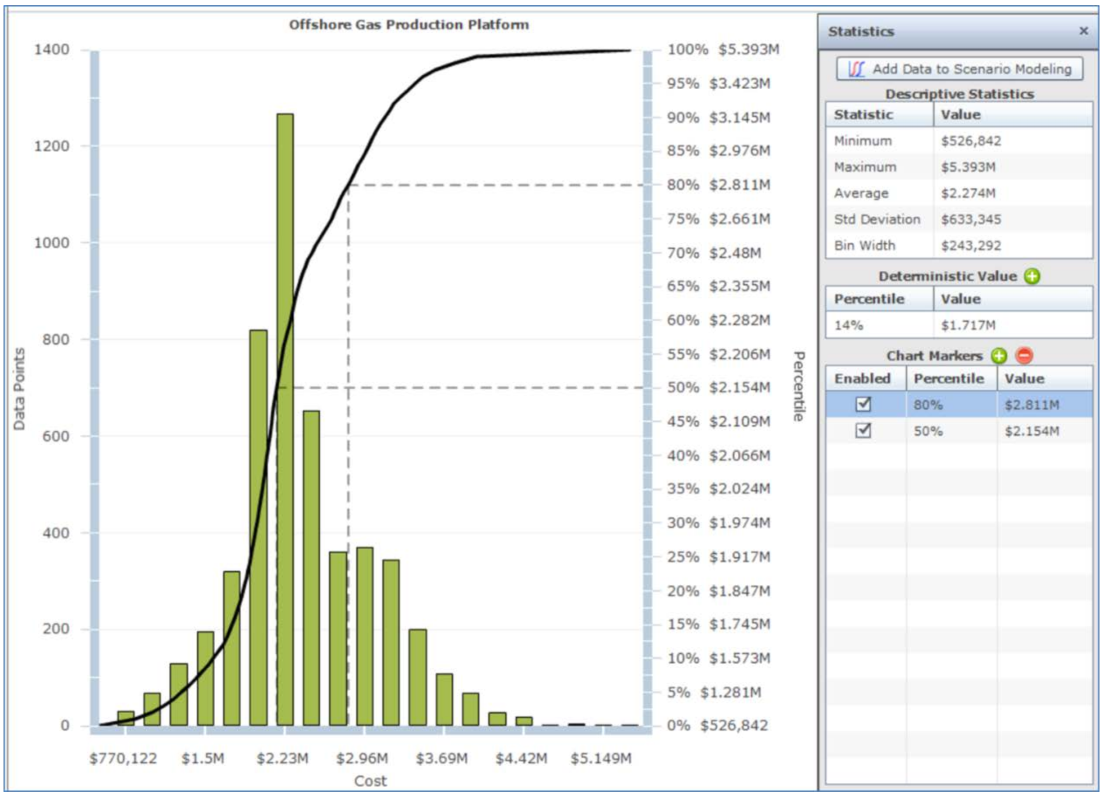
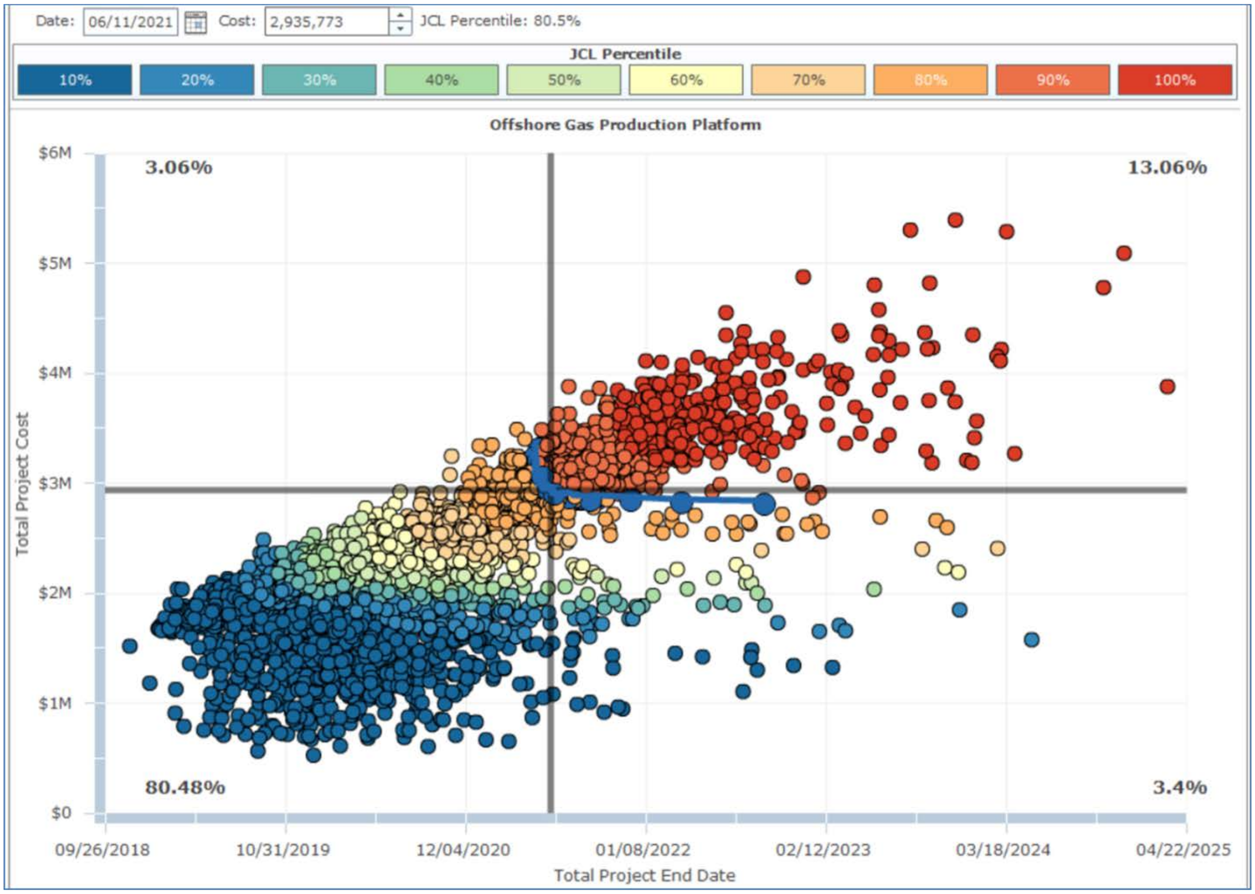


Figure 5 - Cost Risk Results Including Indirect risk through Schedule Risk

Joint Confidence Level results

Since schedule and cost are modeled simultaneously there is a presumption that the organization would like to establish targets and achieve them for both time and cost. The Joint Confidence Level (JCL) scatterplot allows us to identify a duration or finish date and a total cost that could both be achieved at some level of confidence (e.g., look at the JCL-80).[6]

[6] NASA Cost Estimating Handbook Version 4.0, Appendix J: Joint Cost and Schedule Confidence Level (JCL) Analysis, https://www.nasa.gov/sites/default/files/files/CEH_Appj.pdf

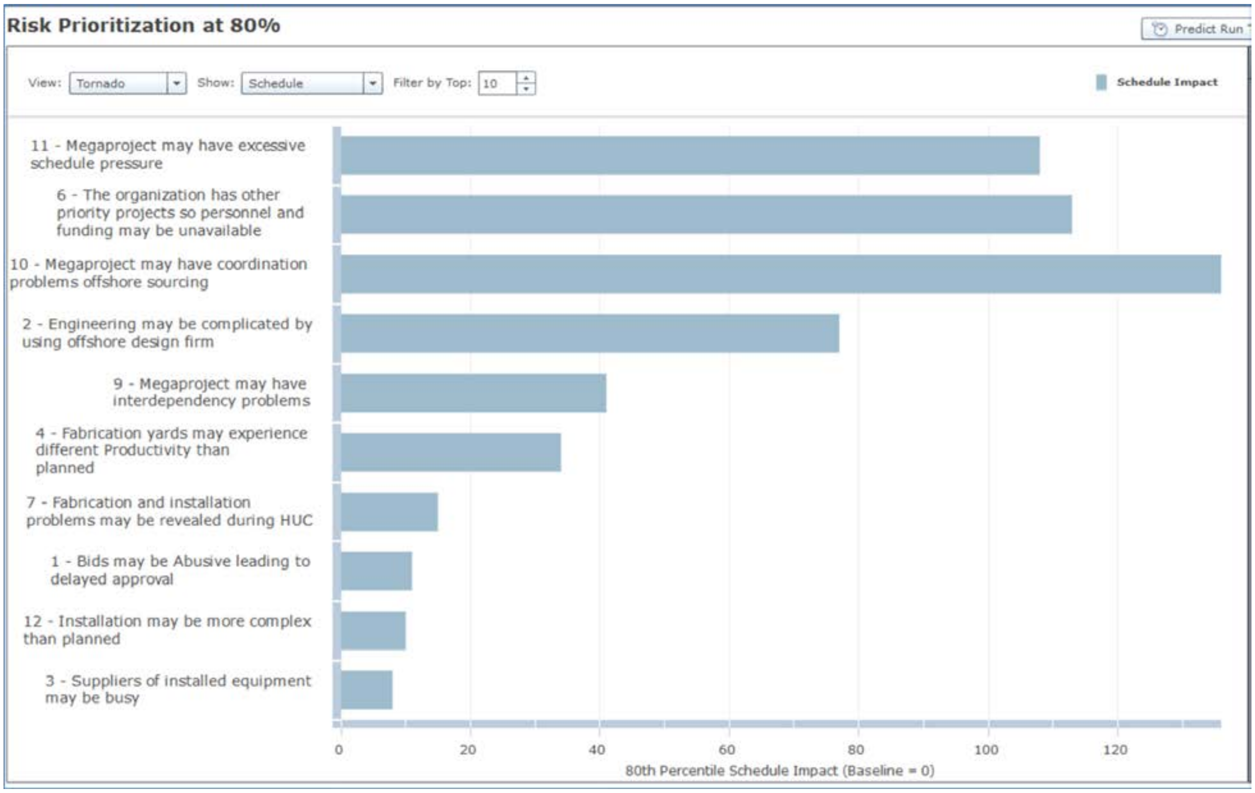


In general, the targets for joint achievement of finish date and cost are later and greater than those date and cost values derived from the histogram and cumulative distribution looking at finish date and total cost separately. How much later and greater depends on how disperse (low correlation coefficient) is the time-cost scatterplot. Hence, the JCL dates and costs set are more likely to be achieved than those derived from the histograms for date and for cost individually. In this simple example the differences are 50 days and $125 million:

Compare P-80 and JCL-80 results		
	Date	Cost ($m)
Individual Histograms P-80	22-Apr-21	2,811
JCL cost-schedule Scatterplot JCL-80	11-Jun-21	2,936
	Calendar Days	Million
Difference	50	125

Risk Prioritization

After the simulation with all risks applied we prioritize the risks to schedule and to cost using a process that David Hulett first introduced in 2009. Polaris has automated this prioritization process, making it much easier and faster to prioritize risks to the entire project or to specific milestones, and to cost as well. Of course the prioritizations of cost and schedule show many similar risks since schedule drives cost for time-dependent (labor, rented equipment) resources. The risks are prioritized at the P-80 (or other customer-desired target level) and expressed in days (time) or dollars (cost) as shown in the tornado diagram below:



In other words, unlike the standard sensitivity approaches in "tornado diagrams," the prioritization results in the terms (days or dollars saved at the 80th percentile) that the manager can understand and use to make decisions.

To help the risk mitigation workshop these prioritized risks are shown in a table as below. Notice that the effect of uncertainty is shown at the bottom of the table indicating that uncertainty is different from risks. In this case, of the 749 calendar days of schedule contingency indicated by the histograms and cumulative distributions above, only 553 days may be subject to mitigation:

Risks In Order of Priority by Days Saved if Fully Mitigated		
UID	Name	Days Saved
11	Megaproject may have excessive schedule pressure	108
6	The organization has other priority projects so personnel and funding may be unavailable	113
10	Megaproject may have coordination problems offshore sourcing	136
2	Engineering may be complicated by using offshore design firm	77
9	Megaproject may have interdependency problems	41
4	Fabrication yards may experience different Productivity than planned	34
7	Fabrication and installation problems may be revealed during HUC	15
1	Bids may be Abusive leading to delayed approval	11
12	Installation may be more complex than planned	10
3	Suppliers of installed equipment may be busy	8
5	The subsea geological conditions may be different than expected	0
	Total Days Saved Fully Mitigating Risks	553
	Total Days from Uncertainty Alone	196
	Total Days from Scheduled Date to P-80 Date	749

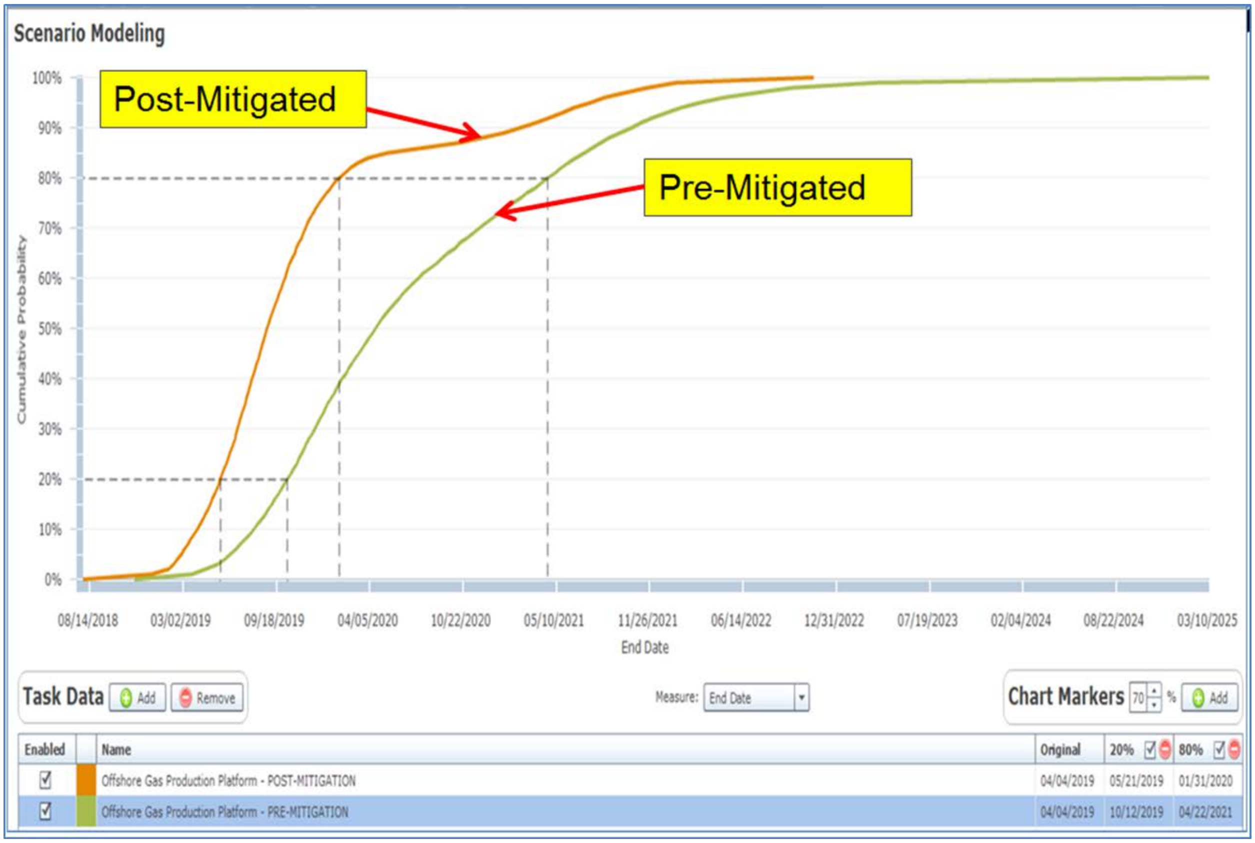
Risk Mitigation

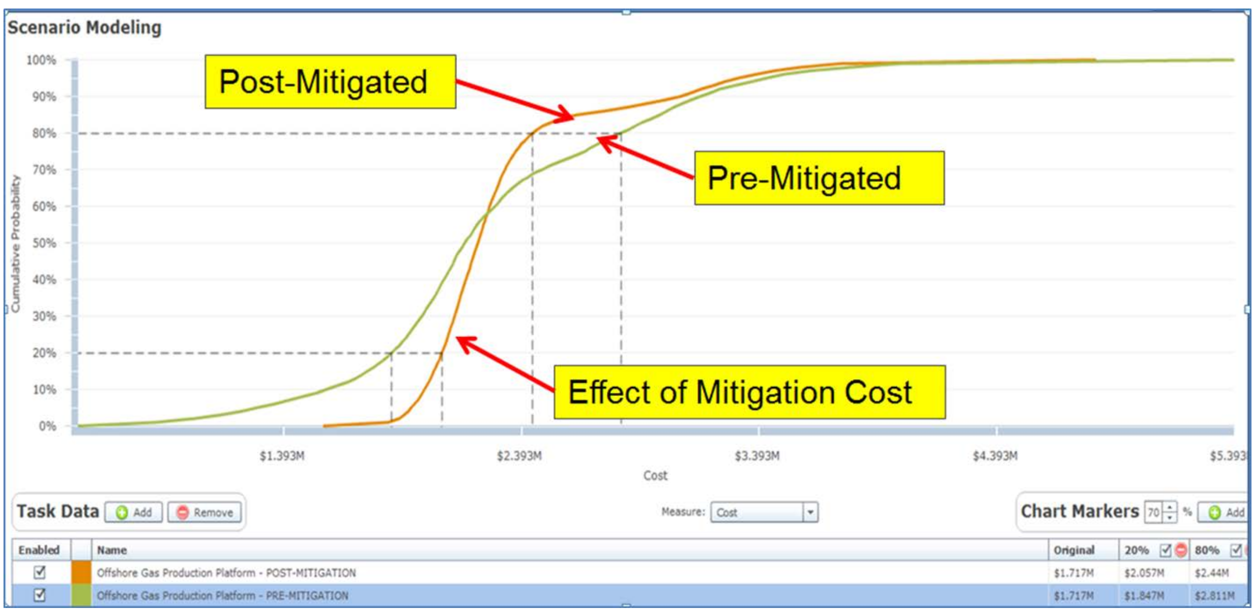
Using the prioritized risks, the project teams are asked to meet among themselves to develop risk mitigation actions. After that we hold a Mitigation Workshop between the customer, contractor and other stakeholders to make final decisions. The mitigation actions adopted are; (1) different from what went before, (2) agreed to and committed, (3) budgeted, staffed and (4) monitored. Adopted mitigations lead to new probability and impact parameters which are then modeled for a post-mitigation result, providing some "good news" for the final report.

To illustrate the impact of risk mitigation we have some *pro forma* mitigations:

- 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

The results below show the impact of mitigation on the pre-mitigated results for schedule and cost:





Reports

Typically we have provided PowerPoint reports for the pre-mitigated and post-mitigated results. The final PowerPoint result is the basis for a text report with the same information included that includes the background, pre-mitigated results, post-mitigated results, risk data interviewees, special modeling issues, caveats about the results, a data appendix with all the uncertainties and risks, the latter being both pre-mitigated, mitigation actions adopted and post mitigated parameters, an appendix describing the schedule assessment against GAO's 10-point Scheduling Best Practices (final document is anticipated in the near future) and an appendix detailing how the approach complies with the GAO's Cost Estimating and Assessment Guide's chapters 13 and 14 dealing with sensitivity and uncertainty.