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INTEGRATING WITH PROJECT SCHEDULE RISK IMPROVES ANALYSIS OF COST RISK

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Integrating with Project Schedule Risk Improves Analysis of Cost Risk

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Abstract: The main benefits of integrated cost-schedule risk analysis are in the improvement of the estimates regarding cost risk and identification of the main risks to cost, including risks to schedule that imply risks to cost, for mitigation purposes. Schedule risk is important in itself, but when time-dependent resources are at work longer than scheduled, the cost will also increase. Technical, external, regulatory, and even project management risks (think of biased estimates of activity durations) may affect the project's cost through resources working longer to complete the job. Mitigating risks to schedule may reduce the cost contingency needed because of individual activities being shorter and the marching armies marching for less time. The main focus will be on estimating the cost contingency needed and identifying risks to cost, which may be dependent on or independent of schedule. So one can understand the reasons for holding cost reserves. New simulation software, developed within the last two to three years will be used to illustrate these points. This article was first presented as RISK.1698 at the 2014 Annual Meeting in New Orleans.

The main benefits of integrated cost-schedule risk analysis are in the improvement of the estimates regarding cost risk and identification of the main risks to cost, some of which may be risks to schedule, for mitigation purposes. Schedule risk is important in itself, but when time-dependent resources are at work longer than scheduled, the cost will also increase as schedule increases. Technical, external, regulatory, and even project management risks (think of biased estimates of activity durations) may affect the project's cost through resources working longer to complete the job. Mitigating risks to schedule may reduce the cost contingency needed because of individual activities being shorter and the marching armies marching for less time, since cost contingency should be held in part for the risks that cause schedule to elongate.

In this article, the integrated cost-schedule risk analysis model is described as a project CPM schedule with the cost estimate assigned to activities using summary resources distinguished by time-dependent (labor, rented equipment) and time-independent (raw materials, installed equipment).

A Monte Carlo simulation of this cost-loaded schedule produces both schedule risk analysis and cost risk analysis. The schedule risk analysis is standard, though important in its own right. The cost risk analysis incorporates the influence of schedule risk on cost. The main focus will be on improvements in the cost risk analysis stemming from the integrated approach: estimating the cost contingency needed now includes schedule risk, and identifying risks to cost, which may be dependent on or independent of schedule, so one can understand the reasons for holding cost reserves. New simulation software developed within the last two to three years will be used to illustrate these points.

Integrated Method of Conducting Cost and Schedule Risk Analysis

"Time is money" is a familiar saying to most people. This is true for projects that are conducted, in part, using resources like labor or rented equipment that will cost more if they work longer. However, this fact has not been well implemented in project cost estimating until recently. In fact, many cost estimates assume that the project schedule is fixed, or by its absence in the cost risk analysis the schedule risk does not contribute to cost risk. In contrast, the authors of this article find that the schedule may be the largest contributor to the project cost risk.

A risk analysis of the cost estimate is conducted using the resource-loaded project schedule where the project budget (without any embedded contingency amounts) is assigned to the schedule activities they support. Then, the schedule is simulated using Monte

Carlo techniques wherein:

- The time-dependent costs cost more if their activities take longer because of risks to schedule. These include labor-type resources assigned to the activities and supporting resources, such as the project management team, that work until the schedule is complete. These supporting resources are often placed on hammock tasks rather than work tasks in the schedule.
- Time dependent costs may be uncertain, even if the schedule is fixed, since the daily "burn rate" may vary for reasons of hourly rates or uncertain resource loads. And,
- Time independent costs such as purchased equipment or raw materials may be uncertain but not because of time.

Using this framework, the Monte Carlo simulation of resource-loaded and costed schedules will produce estimates of completion dates and costs that are internally consistent. This means that any iteration will assume the same configuration of risks (whether they occur and the degree of their impact) to calculate the dates and total project cost [5].

The State of Integrated Cost-Schedule Risk Analysis

Usually cost estimates are developed in a spreadsheet format that has no schedule component and analyzed there. Usually the schedule is not cost loaded, yet that is the best way to analyze the impact of schedule risk on cost risk. For instance up to 50 percent of the implied cost contingency comes from schedule risk.

When cost is added to the schedule risk analysis model, it is typically added as an afterthought. Sometimes a representation of the schedule risk is cobbled onto the cost estimate spreadsheet and then applied to indirect costs and other costs that are responsive to time. The representation of schedule risk may be taken from an independent schedule risk analysis or, more likely, from some other notional analysis. It is not integrated to the spreadsheet in the sense that the costs are actually computed using a daily spend rate multiplied by the working days for that activity or phase.

Organizations have often cited the silos that exist between their cost/budgeting and scheduling disciplines as barriers to performing integrated cost-schedule risk analysis. Often, the estimators and schedulers do not work together, side-by-side, and their products become disconnected. Usually the schedulers are not accustomed to cost-loading their schedules. A by-product of integrating the cost and schedule is that estimators and schedulers get coordinated and their two separate products become consistent, perhaps for the first time.

Success Factors for a Good-Quality Project Risk Analysis

There are three main success factors for a good quality integrated cost-schedule risk analysis:

- A good quality CPM schedule, which is mainly defined as a dynamic model of the project plan, wherein changes in durations of activities may ripple through the schedule to potentially affect the finish date, unencumbered by the use of date constraints, lags and leads; but with complete and correct project logic. There are other things a schedule risk needs but not many beyond simply a solid application of scheduling best practices [4].
- Good risk analysis data. Usually the data collected about risks that may happen in the future are based on expert judgment of the project participants. Historical data is useful if it is relevant and recent; but, even without databases there will be risk. Hence, risk quantitative risk data is usually collected using confidential interviews that are designed to encourage the interviewees to give honest responses, even when the risks may be embarrassing or pessimistic for the project [3].
- A risk-aware corporate culture. Establishing a corporate risk-aware culture starts at the top and involves everyone involved in the project and some in the organization not directly involved in any specific project. Corporate culture means that the organization is taking project risk management seriously, vitally concerned to get the correct information no matter how embarrassing or pessimistic it is, and to use the risk information gathered in making important project decisions.

Given the presence of these success factors, the specifics of modeling schedule risk and which Monte Carlo

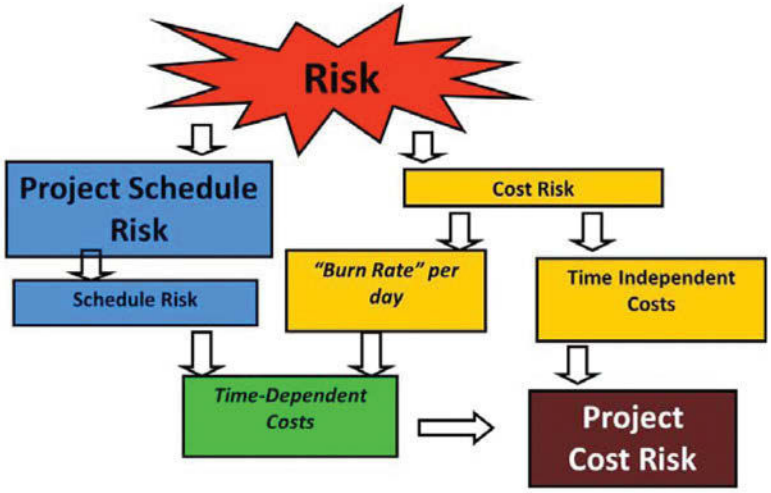
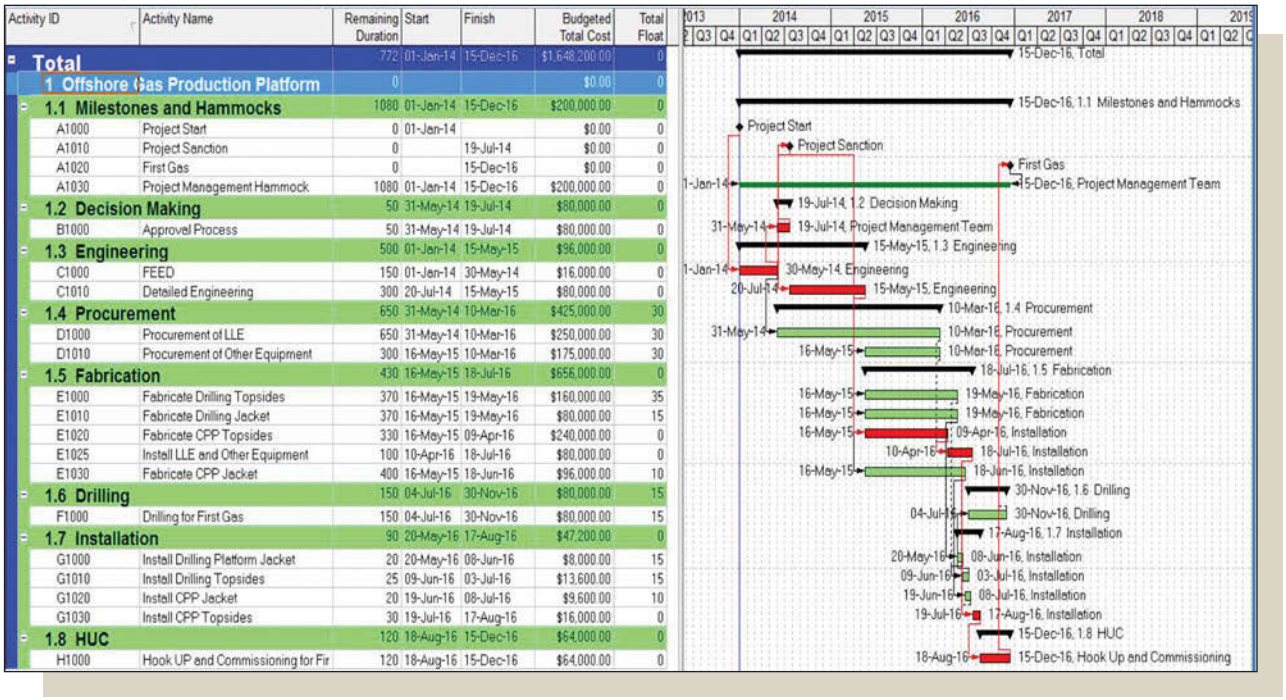


Figure 1 – Structure of the Cost - Time - Risk Relationship



Activity ID	Activity Name	Remaining Duration	Start	Finish	Budgeted Total Cost	Total Float
Total		772	01-Jan-14	15-Dec-16	$1,648,200.00	0
1 Offshore Gas Production Platform		0			$0.00	0
1.1 Milestones and Hammocks		1080	01-Jan-14	15-Dec-16	$200,000.00	0
A1000	Project Start	0	01-Jan-14		$0.00	0
A1010	Project Sanction	0		19-Jul-14	$0.00	0
A1020	First Gas	0		15-Dec-16	$0.00	0
A1030	Project Management Hammock	1080	01-Jan-14	15-Dec-16	$200,000.00	0
1.2 Decision Making		50	31-May-14	19-Jul-14	$80,000.00	0
B1000	Approval Process	50	31-May-14	19-Jul-14	$80,000.00	0
1.3 Engineering		500	01-Jan-14	15-May-15	$96,000.00	0
C1000	FEED	150	01-Jan-14	30-May-14	$16,000.00	0
C1010	Detailed Engineering	300	20-Jul-14	15-May-15	$80,000.00	0
1.4 Procurement		650	31-May-14	10-Mar-16	$425,000.00	30
D1000	Procurement of LLE	650	31-May-14	10-Mar-16	$250,000.00	30
D1010	Procurement of Other Equipment	300	16-May-15	10-Mar-16	$175,000.00	30
1.5 Fabrication		430	16-May-15	18-Jul-16	$656,000.00	0
E1000	Fabricate Drilling Topsides	370	16-May-15	19-May-16	$160,000.00	35
E1010	Fabricate Drilling Jacket	370	16-May-15	19-May-16	$80,000.00	15
E1020	Fabricate CPP Topsides	330	16-May-15	09-Apr-16	$240,000.00	0
E1025	Install LLE and Other Equipment	100	10-Apr-16	18-Jul-16	$80,000.00	0
E1030	Fabricate CPP Jacket	400	16-May-15	18-Jun-16	$96,000.00	10
1.6 Drilling		150	04-Jul-16	30-Nov-16	$80,000.00	15
F1000	Drilling for First Gas	150	04-Jul-16	30-Nov-16	$80,000.00	15
1.7 Installation		90	20-May-16	17-Aug-16	$47,200.00	0
G1000	Install Drilling Platform Jacket	20	20-May-16	08-Jun-16	$8,000.00	15
G1010	Install Drilling Topsides	25	09-Jun-16	03-Jul-16	$13,600.00	15
G1020	Install CPP Jacket	20	19-Jun-16	08-Jul-16	$9,600.00	10
G1030	Install CPP Topsides	30	19-Jul-16	17-Aug-16	$16,000.00	0
1.8 HUC		120	18-Aug-16	15-Dec-16	$64,000.00	0
H1000	Hook UP and Commissioning for Fir	120	18-Aug-16	15-Dec-16	$64,000.00	0

Figure 2 – Offshore Gas Production Platform Schedule

software to use become just tools. Absent these factors the tools will not provide risk analysis success.

Integrated Cost-Schedule Risk Analysis Model

The integration of cost and schedule risk analysis focuses on the resources that are influenced by the duration of the activities they support. These are time-dependent resources, such as labor and rented equipment (e.g., tower cranes, drill rigs). There are also time-independent cost factors, such as raw materials and purchased equipment for installation that may have cost variation but not because of the duration of their fabrication or delivery activities. Figure 1 shows the relationship of these factors to cost and risk. Notice that the "schedule risk" and the "burn rate per day" combine to determine the time-dependent costs.

To show how integrated cost-schedule risk analysis occurs, a simple model of an offshore gas production platform and drilling project is used, as shown in Figure 2. The finish date of the schedule is 15 December 2016. Notice that resources are attached and that the total cost is $1.648 billion.

The resources needed to assign the costs to the schedule activities can be summary in nature. There is no reason for integrating cost and schedule to use detailed resources. In fact, some project controls personnel are unwilling to resource-load their schedule because they believe that resource loading means specifying detailed resources and which can become burdensome. Of course, if multi-million dollar amounts are at stake, the burden of resource loading seems to be justified. However, some analysts use just two resources, called "time dependent" and "time independent." The resources, shown in Figure 3, are somewhat more detailed than that extreme simplicity, however, they are summary in nature and cannot be used to manage (e.g., level) resources in the schedule. The only reason to specify resources is to put the cost estimate into the schedule on the correct activities, and if summary resource designation will facilitate that objective then detailed resources are not necessary.

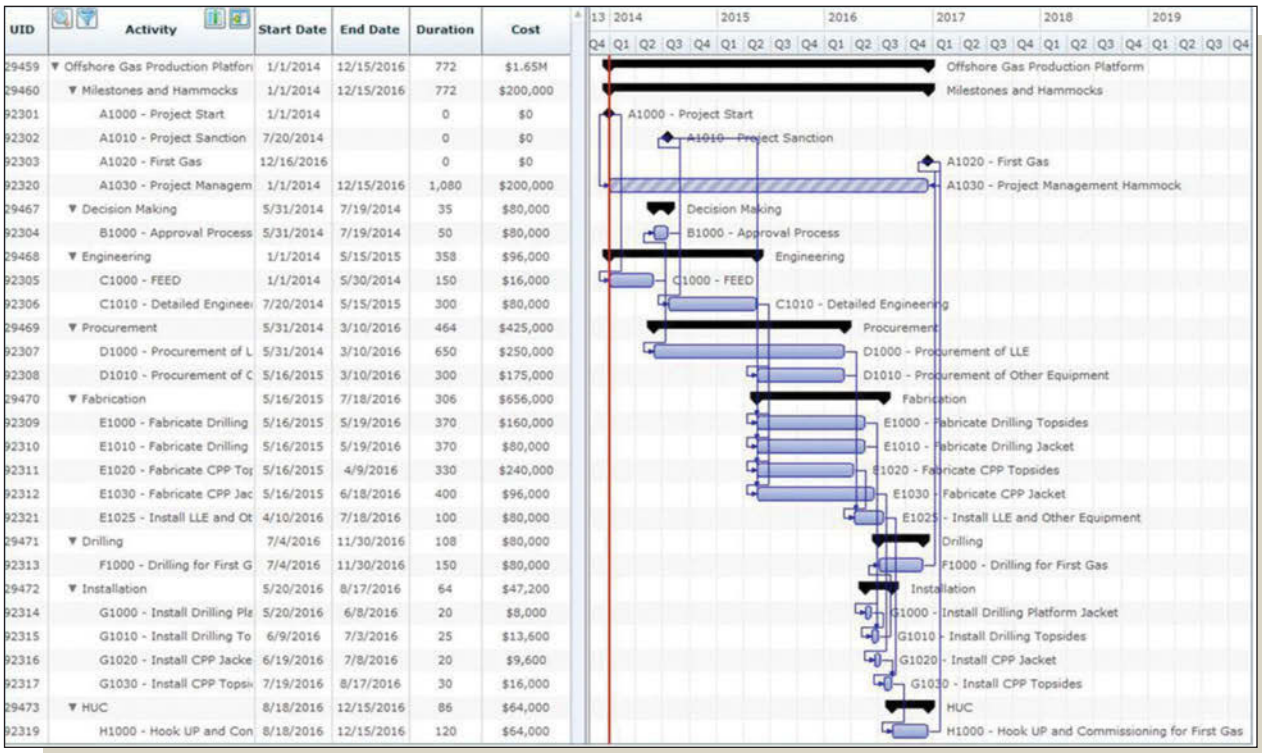
The project schedule with resources imported into the program that will perform the simulations is shown in Figure 4. For this analysis, we are using Polaris developed by Booz Allen Hamilton. There are other simulation packages that can do this analysis. Import check and schedule health checks are performed before proceeding.

Adding Uncertainty to the Analysis Model

Uncertainty and discrete risks are different and are handled differently in setting up the Monte Carlo simulation and analysis.

Resource Name	Resource Type	Price / Unit	Calendar
Project Management Team	Labor	$100.00/h	7 Day
Procurement	Material	$100.00/unit	7 Day
Installation	Labor	$100.00/h	7 Day
Hook Up and Commissioning	Labor	$100.00/h	7 Day
Fabrication	Labor	$100.00/h	7 Day
Engineering	Labor	$100.00/h	7 Day
Drilling	Labor	$100.00/h	7 Day

Figure 3 – Summary Resources Used to Insert Costs



UID	Activity	Start Date	End Date	Duration	Cost
29459	▼ Offshore Gas Production Platfor	1/1/2014	12/15/2016	772	$1.65M
29460	▼ Milestones and Hammocks	1/1/2014	12/15/2016	772	$200,000
92301	A1000 - Project Start	1/1/2014		0	$0
92302	A1010 - Project Sanction	7/20/2014		0	$0
92303	A1020 - First Gas	12/16/2016		0	$0
92320	A1030 - Project Managem	1/1/2014	12/15/2016	1,080	$200,000
29467	▼ Decision Making	5/31/2014	7/19/2014	35	$80,000
92304	B1000 - Approval Process	5/31/2014	7/19/2014	50	$80,000
29468	▼ Engineering	1/1/2014	5/15/2015	358	$96,000
92305	C1000 - FEED	1/1/2014	5/30/2014	150	$16,000
92306	C1010 - Detailed Enginee	7/20/2014	5/15/2015	300	$80,000
29469	▼ Procurement	5/31/2014	3/10/2016	464	$425,000
92307	D1000 - Procurement of L	5/31/2014	3/10/2016	650	$250,000
92308	D1010 - Procurement of C	5/16/2015	3/10/2016	300	$175,000
29470	▼ Fabrication	5/16/2015	7/18/2016	306	$656,000
92309	E1000 - Fabricate Drilling	5/16/2015	5/19/2016	370	$160,000
92310	E1010 - Fabricate Drilling	5/16/2015	5/19/2016	370	$80,000
92311	E1020 - Fabricate CPP Top	5/16/2015	4/9/2016	330	$240,000
92312	E1030 - Fabricate CPP Jac	5/16/2015	6/18/2016	400	$96,000
92321	E1025 - Install LLE and Ot	4/10/2016	7/18/2016	100	$80,000
29471	▼ Drilling	7/4/2016	11/30/2016	108	$80,000
92313	F1000 - Drilling for First G	7/4/2016	11/30/2016	150	$80,000
29472	▼ Installation	5/20/2016	8/17/2016	64	$47,200
92314	G1000 - Install Drilling Pla	5/20/2016	6/8/2016	20	$8,000
92315	G1010 - Install Drilling To	6/9/2016	7/3/2016	25	$13,600
92316	G1020 - Install CPP Jacke	6/19/2016	7/8/2016	20	$9,600
92317	G1030 - Install CPP Topsi	7/19/2016	8/17/2016	30	$16,000
29473	▼ HUC	8/18/2016	12/15/2016	86	$64,000
92319	H1000 - Hook UP and Con	8/18/2016	12/15/2016	120	$64,000

Figure 4 – Schedule and Cost Imported into Polaris™

- Uncertainty is 100 percent likely to happen, indeed may be happening now, and is unlikely to be subject to mitigation. Uncertainty represents inherent variability that occurs when humans and organizations perform functions, such as executing projects. The durations of the activities and costs of the project are subject to random errors that could probably be contained over many instances and over time, but for the one project these uncertainties occur.
- Discrete risks or "risk events" are identifiable and quantifiable (if only using expert judgment) events that can occur, leading to an appreciable impact on activity durations of costs, with some probability. The identity of risk events is discovered using tools such as risk breakdown structures and workshops, which often lead to the development of the risk register for the project. However, the authors have found that risk registers are incomplete, perhaps because they are usually developed in workshops where there are biases, such as:

  - Groupthink" where members prefer unanimity and suppress dissent.
  - The "Moses Factor" where an influential person's risk attitude is adopted against personal ones.
  - Cultural conformity, making decisions matching the perceived organizational ethos.
  - "Risky shift" or "cautious shift," where a group may be more risk seeking or risk averse than individual members. And,
  - Hostility to risk in general: "We do not have risk in our project – we are professionals [2]."

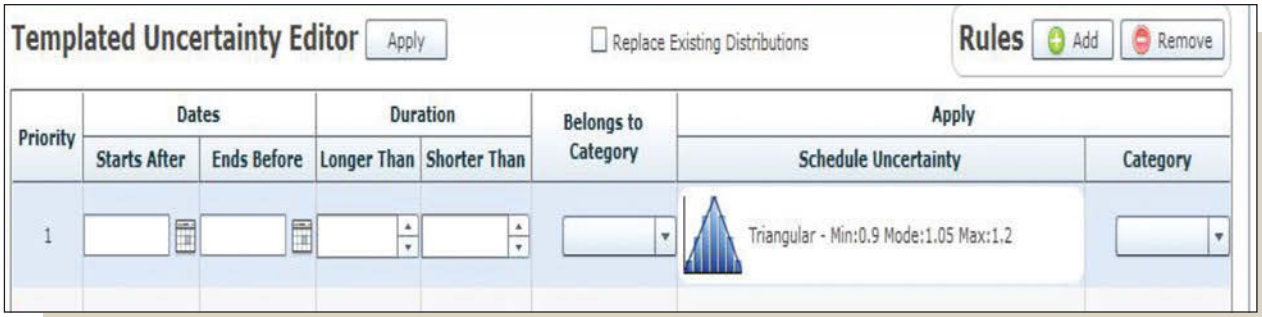


Figure 5 – Applying Uncertainty to the Activity Durations to Represent Inherent Variability

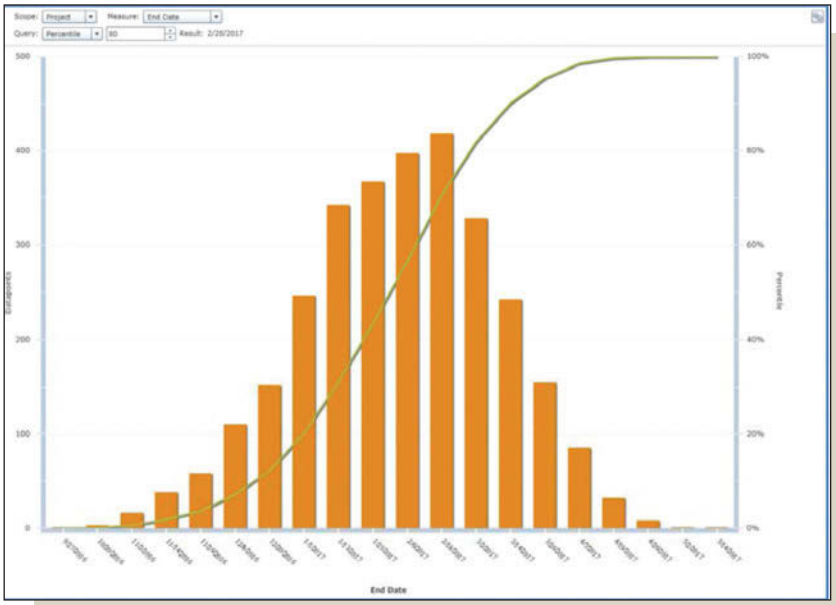


Figure 6 – First Gas with Uncertainty Added

Uncertainty is often inserted into the analysis model using three-point estimates since uncertainty is 100 percent likely and it applies to all estimated durations. Of course some activities exhibit more uncertainty than others, so the uncertainty can be applied differentially to different categories – say, fabrication, detailed engineering, procurement, installation – which might have different "reference ranges" of inherent variability.

Sometimes duration estimating error/bias is included in these three-point estimates since that may be pervasive and 100 percent likely as well. Correlation may be applied to these uncertainty ranges if necessary, and in this exercise the authors have applied a .3 correlation coefficient.

The schedule uncertainty is derived by performing a Monte Carlo simulation of the cost-loaded schedule. For this article, the authors have used 5,000 iterations and a Latin Hypercube random number selection scheme. The results for the finish date, originally scheduled for 15 December 2016, are shows in Figure 6.

The results using a correlation coefficient of .3 show a 28 March 2017 date for first gas, a time contingency of 3 ½ months at the 80th percentile (P-8-) level of confidence. If the correlation coefficient between uncertainties is 0.0 (independence), the date would be 20 March 2017, whereas a correlation coefficient of 1.0 (perfect positive correlation) the date would be 5 April, 2017.

The cost risk results with uncertainty only are shown in Figure 7.

The cost risk is generated only with the influence of schedule risk on time-dependent resources. The cost, which was baselined at $1.65 billion has become $1.75 billion at the P-80 level of confidence. The relationship of time and cost are shown in the scatter diagram of Figure 8, where the X-axis is finish date and the Y-axis is cost. There are 5,000 separate points graphed in this figure, each one representing finish date and cost for the same risk parameters in a specific iteration.

The correlation of finish date and cost is measured at 92 percent.

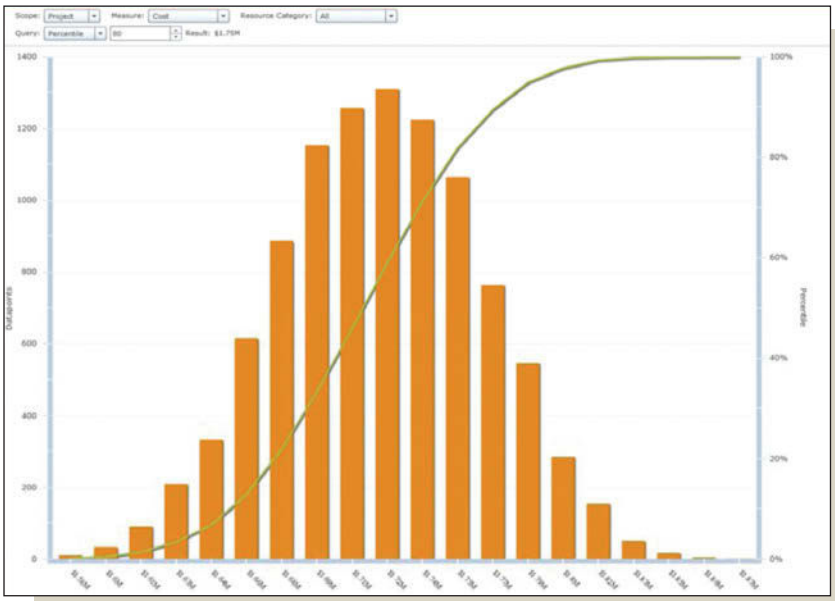


Figure 7 – Cost Risk with Uncertainty Added

Adding Discrete Risks as Risk Drivers

For this article, six risks have been specified with their probability and impact. The probability is stipulated for each risk driver and that driver will "occur" in that fraction of iterations, chosen at random. The impact is specified as a three-point estimate of multiplicative factors. The software will make a probability distribution as desired from these parameters and choose at random the multiplicative factor to use for an iteration for which the risk occurs. The risks are then assigned to different activities:

- A risk driver may be, and often is, assigned to multiple activities. For instance, if the interviewees specify that the risk should influence all construction activities, if it occurs, it will be applied to the most detailed activities in the construction

phase, and this may be many activities indeed. And,

- An activity may, and often does, have several risks applied to it. This occurs because some of the risk drivers' influences overlap. In this case, the risk "EPC contractor's quality is questionable, would be assigned to all activities performed by that EPC contractor. Of course the risk "Installation productivity may not be as good as assumed" will also affect some of the same risks. Figure 9 shows a risk assigned to four activities.

Figure 9 also shows a typical setup of risk drivers, with their probability, impact range if they occur, and activities to which they are assigned.

Correlation is modeled by assigning risk drivers to more than one activity. If the risk driver occurs on an iteration, it occurs for all the activities to which it is assigned. If it picks a multiplicative value, say 1.07 for that iteration, that value is applied to the schedule duration for all the activities to which it is assigned. Hence, if one risk is assigned to two activities and no other risks are assigned, those two activities become 100 percent correlated as shown in Figure 10.

If, however, there are other risks that affect Activity 1, but not Activity 2, and *vice versa*, the correlation between those two activities is altered, as shown in Figure 11.

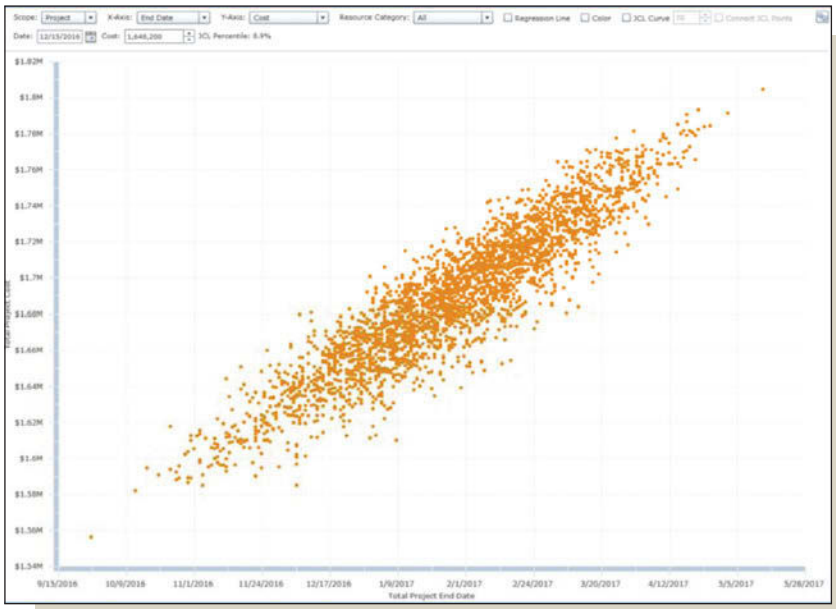


Figure 8 – Cost - Finish Date Scatter Diagram with Uncertainty Only

Correlation is created when some common uncertainty (e.g., a "risk") affects two activities' durations and causes them to vary together. This correlation can be generated in the model, by using risk drivers, during simulation. The effect of correlation is correctly transmitted through the schedule to the completion date. Hence, this does not apply to the correlation coefficients applied to the uncertainties mentioned above. Consider the following:

- You do not have to guess at the value of the correlation coefficient between different activities' durations. This is good because most people are notoriously bad at guessing these values.
- You will never get an inconsistent correlation matrix since you are modeling how correlation arises [1]. And,
- You really do not care what the correlation coefficients between activity durations are.

The results for the first gas date when these risk drivers are assigned are shown in Figure 12.

Adding and assigning risk drivers,

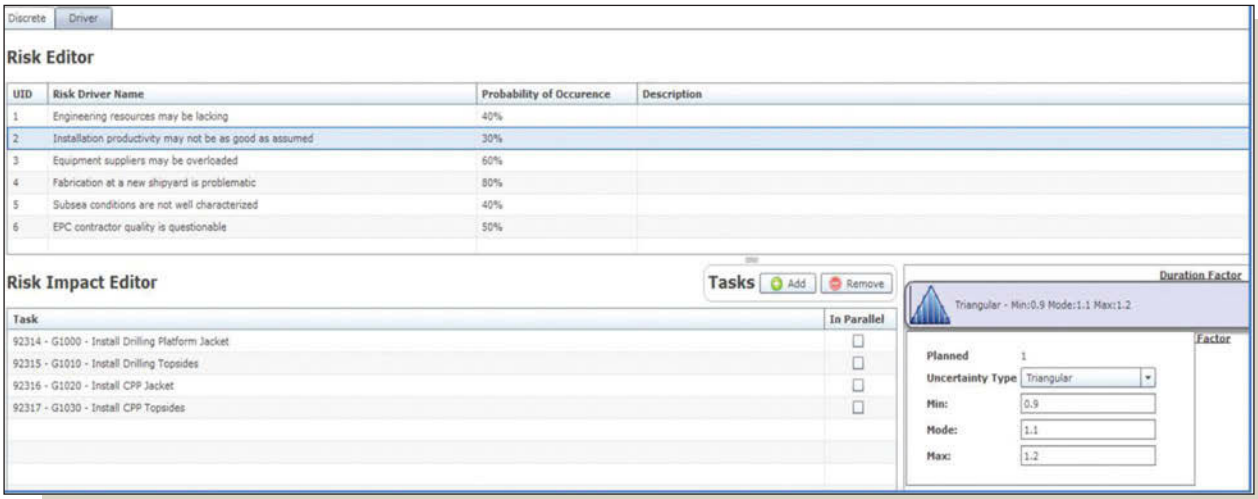


Figure 9 – Assigning Risk Drivers with Their Parameters to Activities

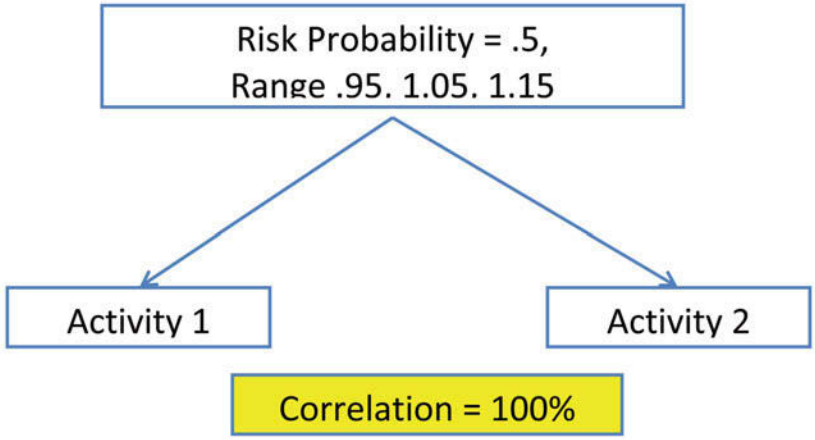


Figure 10 – Risk Drivers Create Correlation During Simulation

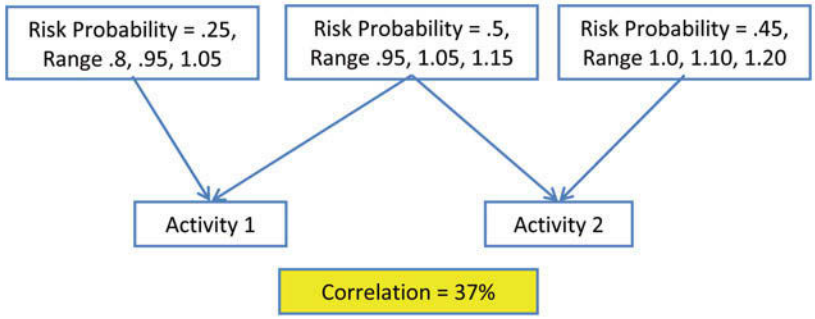


Figure 11 – With Confounding Risk Drivers Correlation is Reduced

with the modest parameters given in this case for illustration only, has added four months to the first gas date, making the P-80 of 21 July 2017.

The cost risk has been increased to $1.87 billion based solely on adding schedule risk to schedule uncertainty. The correlation between the finish date of first gas and cost is still .92; since, at this point in our risk analysis modeling, the only way cost can change is with schedule risk drivers and schedule uncertainty.

Adding "Cost Risk" to the Risk Model

There are many "risks to cost" that do not involve the project schedule, and these are also modeled in the schedule-based integrated cost-schedule risk analysis method. These risks, typically thought of as "cost risks" may affect the cost of the project in two ways:

- As they apply to the daily expenditure rate or burn rate of the time-dependent resources; and,
- As they apply to the total risk of time-independent resources.

Adding burn-rate uncertainty to time-dependent resources means that their cost will vary by both time and burn rate variations. In the extreme, if the schedule were not risky there would still be an uncertain cost for time-dependent resources. More typically the cost of time-dependent resources will vary according to both burn rate and schedule variations. Figure 13, shows applying a burn-rate uncertainty to the cost of time-dependent resources. Only the common risk EPC Contractor quality is questionable, assigned to almost all of the activities, is shown in Figure 13.

The cost risk now amounts to $1.95 billion at the P-80, up from $1.87 billion with just schedule uncertainty and schedule risk drivers. Figure 14 shows that the linkage or correlation between the finish day first gas and the cost of the project has been loosened somewhat and is now only 84 percent instead of 92 percent, before the burn rate uncertainty was introduced.

Cost risk factors can also cause the time-independent resources' costs to vary. Figure 15, shows the addition of uncertainty to time independent resources from the cost risk: Equipment suppliers may be overloaded, added to the activities, 'procurement of LLE' and detailed engineering." (In this example, the authors have used nominal three-point estimates of .85, 1.1 and 1.3 for low, most likely, and high values describing a triangular distribution. Often the ranges of impact can be much larger).

In this case, the risk added to the time-independent resources was small in comparison to the risks from schedule causes and burn rate uncertainty. The impact on the total cost was not very much, bringing the P-80 of cost to $1.97 billion, from $1.95 billion, with just schedule uncertainty and risk drivers and burn rate uncertainty. As would be expected, adding just 20 million to the cost did not affect the correlation between time and cost.

Prioritizing Discrete Risks to Schedule and to Cost

Typically, risk analyses of time and cost have used the traditional tornado charts to exhibit the importance of risk inputs to the final milestone date or total project cost. This method is flawed in several respects, as guides to which risk are important in driving schedule risk, and hence – since schedule drives cost – cost risk:

- First, the traditional tornado chart shows which activities' durations are correlated with the finish date. The correlation coefficients do not really show managers the extent of the impact of a risk to the final delivery date, since correlation coefficients are not days. Also, correlation is a concept centered on means of the two correlates, and you really want to know about the 80th (or some other certainty target) date.

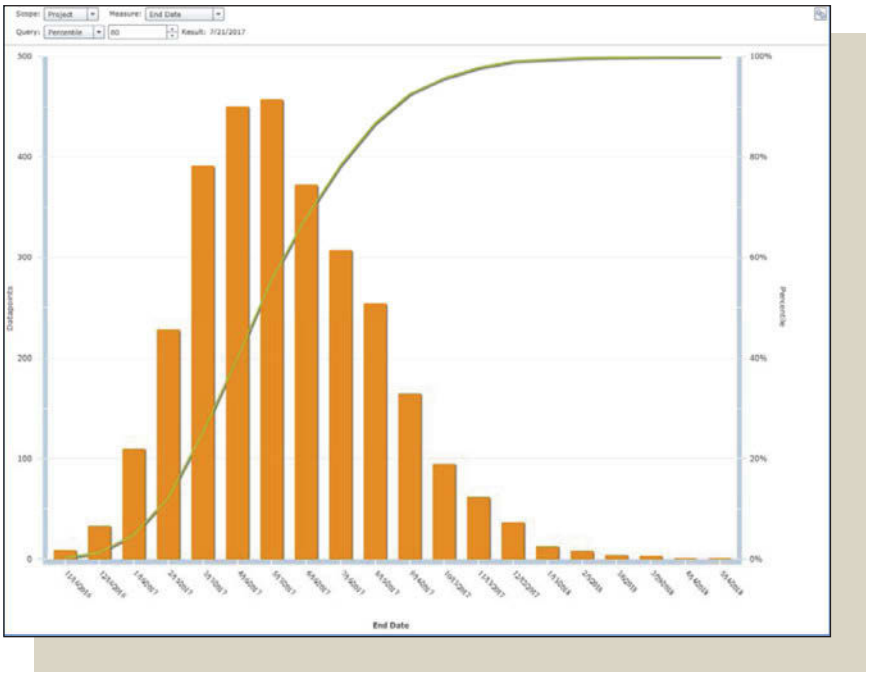


Figure 12 – First Gas Date with Uncertainties and Risk Drivers

- Second, the typical tornados show which activities are correlated, not which risks are correlated with the finish date. This is largely because until recently (the last six to seven years) one could not focus on the root cause of risks and hence their impact on multiple activities. Now that you can do that, it is logical to focus on the risks, since people can mitigate risks, but they cannot mitigate activities or paths.
- The standard tornado, or even the risk tornado shown in Figure 16, shows only the risks that are correlated to the final date or total cost. Actually, when one risk is mitigated, one derives an entirely new tornado chart to determine which risk is second-most important. This second tornado may show different risks than the first tornado with all risks considered because of the structure of the schedule. The prioritization needs to go one step at a time, identifying the most important risk, then the second-most important risk and so on as described below.
- The standard, or the risk tornado, is not a good indicator of the second and subsequent risks and may not even be a good indicator of the top risk, since correlation may not be a reliable indicator of priority.

The authors will now show a different approach to prioritizing risks to time and cost.

First, the software can provide a new tornado diagram, one that shows different discrete risks (using risk drivers or a risk register), as they are correlated with the finish date or the total cost of the project. As mentioned above, this is better than a tornado using activities as they are correlated, since you need to prioritize risks, not activities. Figure 16 shows an example of this risk-based tornado diagram as it affects first gas in this example schedule.

This risk tornado shows that the risk with the highest correlation to first gas is EPC contractor quality is questionable. This risk is ranked first probably because, in addition to its probability (50 percent) and its impact it is assigned to all EPC activities.

Still, even though a risk is high on the risk tornado, it may not be more important than every one of the risks somewhat further down the list. The authors have found that when risks correlations with the end date are close (not in this case, obviously) it may

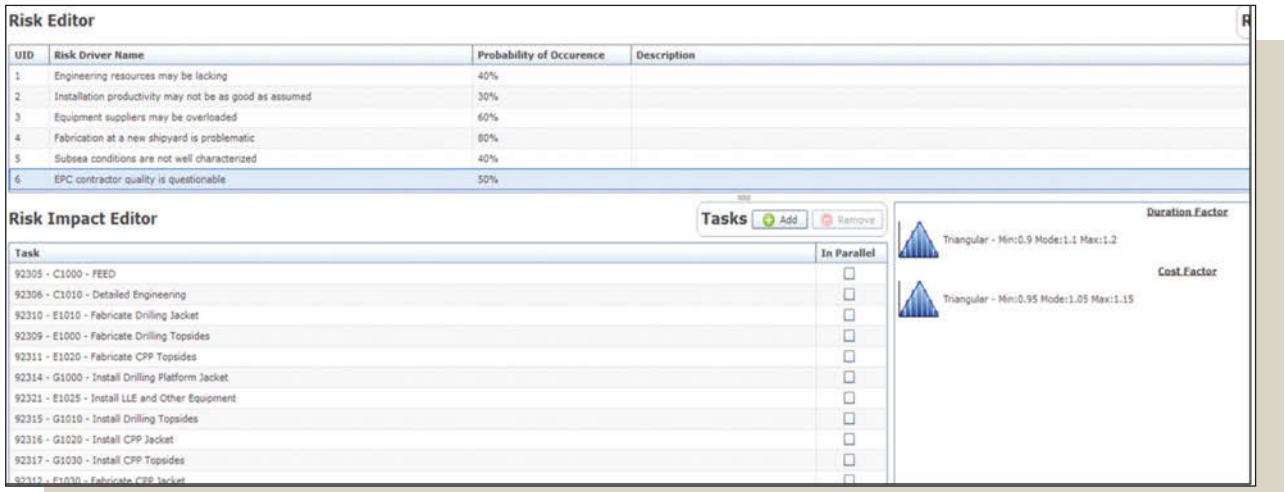


Figure 13 – Adding Burn Rate Uncertainty to Time-Dependent Resources

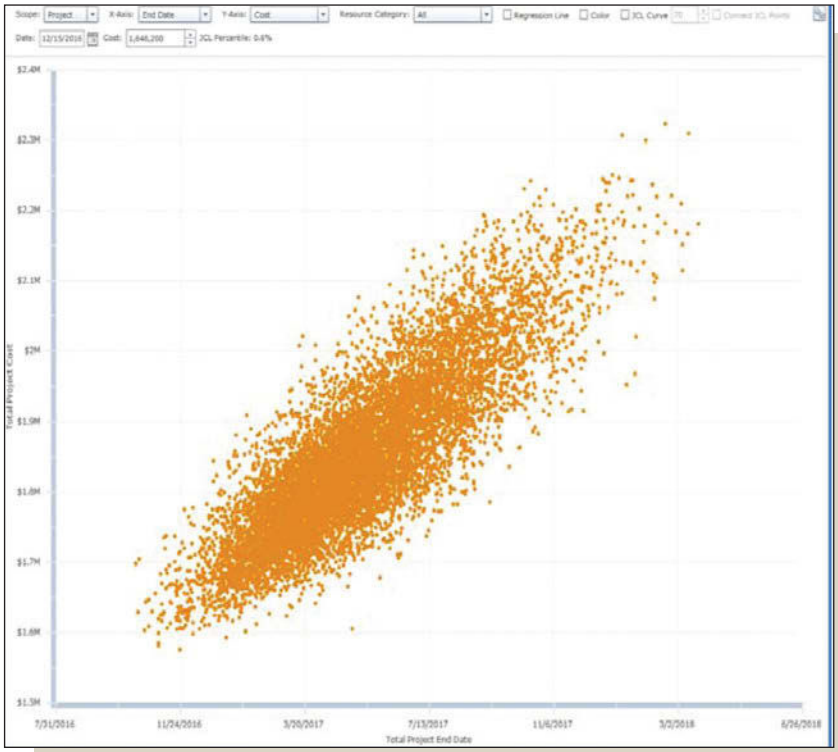


Figure 14 – Cost – First Gas Date Scatter Chart with Uncertain Burn Rate Added

be that the top risk is not more important than the next risk, or the one after that.

Consider a different, sequential method, of prioritizing discrete risks to schedule. Consider the following.

- With all risks present, run the simulation and record the P-80 (or other target) date.
- Take out one risk, probably by reference to the risk tornado, by disabling it (equivalent to setting its probability to zero percent). That will take out all of its influence on all activities to which it is assigned. Re-run the simulation and record the P-80 date.
- However, the top risk on the risk tornado may not be the most important risk; so, re-enable it and choose another risk from the risk tornado. Repeat the process for that risk, disabling it – simulating without just that one risk – record the P-80 date.
- Repeat this process with each of the possible top-risk candidates in turn, taking one out and simulating.
- Identify the risk that, when it is disabled, the P-80 date is earliest. That is the highest priority risk in the sense that unless you mitigate that risk it is not very productive to mitigate any other risk.
- After the top risk is identified in this iterative way, let that risk remain disabled, run the simulation, and derive a new risk tornado diagram. This may show different risks with highest correlation because of the structure of the schedule. That is, if the top risk is disabled it might expose a parallel path that has an important risk that was not high in the initial risk tornado.
- Examine each likely risk in the same iterative fashion as above, with the top risk disabled. Identify the risk that has the greatest impact on the finish date when disabled, and that is the second-most important risk.

These are listed in their priority order, their entire influence on the schedule is taken into account, their impact is measured in days that management can understand, and it takes account of the schedule structure. Table 1 shows such a prioritized list of risks to the first gas of the case study.

Notice in Table 1 that the calendar days saved is not monotonic from largest to smallest, since the structure of the schedule can cause hidden risk-slack paths to have risks with a serious number of days saved when it is uncovered by removing a higher-priority risk. Also notice that inherent uncertainty and duration estimation error is at the bottom with 102 days, since that is inherent and not as a result of any particular discrete risk, hence not really a

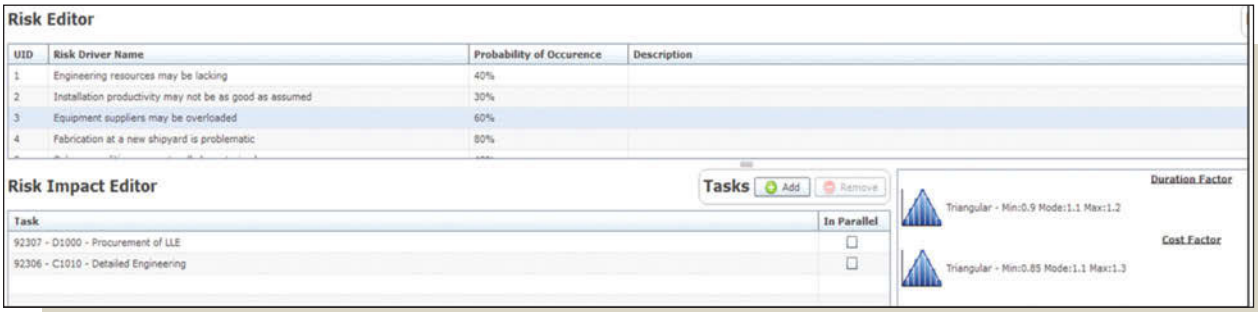


Figure 15 – Adding Cost Risk Factors to Time-Independent Resources' Cost

good candidate for effective mitigation.

Finally, notice that risks two and five had to be taken out together to make even a two-day impact. This clustering is also present when risks are introduced to the analysis model in parallel rather than in series, as they are in this case study. That is, when risks can be recovered simultaneously they are entered in parallel, so when one is disabled in the prioritization exercise there is always the parallel risk(s) and none of the parallel risks matters much. That is not the case here, since all risks have been entered in series, but it is good to keep these risks in mind.

This prioritization exercise is currently a manual process today and a fast simulator. Polaris has automated this risk prioritization process, saving much time and frustration.

Risks to cost can also be prioritized. Since the important risks usually include some risks to schedule, you need to follow the same procedure as in prioritizing the schedule risks, described above. Start with a risk tornado on cost, as shown in Figure 17.

This risk cost tornado chart incorporates all ways that the risk affects the costs. Included are the schedule risks and the burn rate risks affecting time-dependent resources' costs, as well as the cost risks affecting time-independent resources' costs. Since schedule risk can be a key driver of cost risk, it is not surprising that the same EPC risk occurs at the top of the cost risk tornado. In fact, in this case, Tables 1 and 2 show the same risks in the same priority positions for both time and cost, indicating that the approach of integrating the two in the same analysis is crucial to understanding cost risk. The cost risk prioritization method is the same as described above for the schedule risk method. The risks prioritized for cost are shown in Table 2.

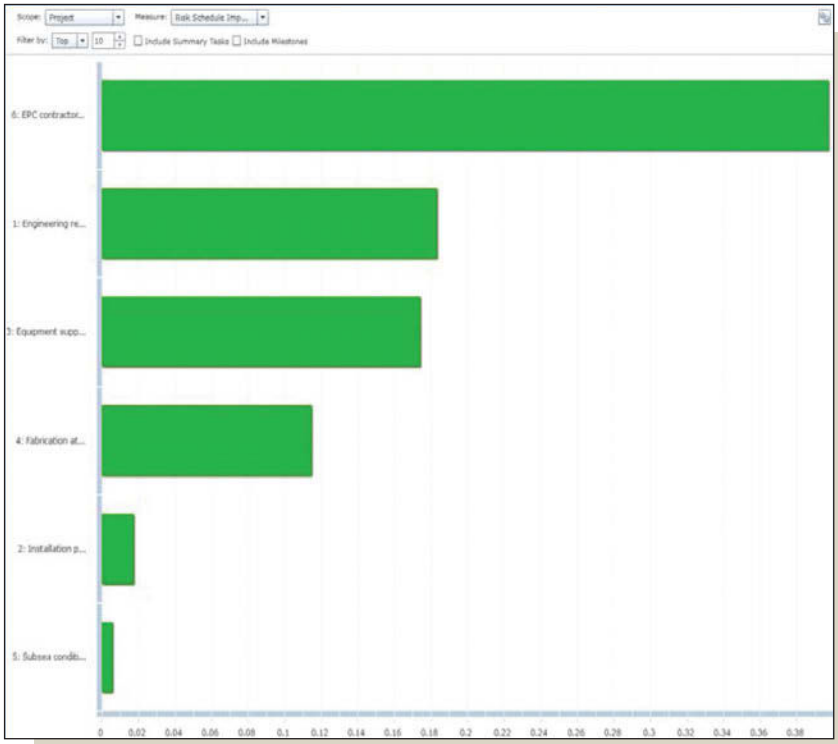


Figure 16 – Risk Tornado Chart on Finish Date

Prioritized Risks to Schedule			
	Baseline Date	16-Dec-16	
		P-80 Date	
	All Risks Included	21-Jul-17	Calendar Days
Risk ID	Risk Name		Saved
6	EPC contractor quality is questionable	31-May-17	51
4	Fabrication at a new shipyard is problematic	9-May-17	22
3	Equipment suppliers may be overloaded	15-Apr-17	24
1	Engineering resources may be lacking	30-Mar-17	16
2	Installation productivity may not be as good as assumed	28-Mar-17	2
5	Subsea Conditions are not well characterized		
	Inherent uncertainty and duration estimation error	16-Dec-16	102

Table 1 – Prioritized List of Risks Driving First Gas

NASA's Joint Confidence Level (JCL) Approach

The National Aeronautics and Space Administration (NASA) has adopted a policy that its larger project should budget to a cost and schedule to a date such that it is 70 percent likely to hit both time and cost targets. This policy is applied at two major milestones, KDP-C and KDP-D. Integrated cost and schedule risk analysis is the standard way the analysis is conducted to find those time and cost parameters that can jointly be achieved, given the current plan and the uncertainties and risks as known today, modeled as shown in this article. In fact, Polaris, the software shown here, was developed initially for NASA and with NASA financial support, although Polaris is now a commercial product. Another software package, JACS developed by Tecolote Research, was also developed and optimized to support the NASA JCL requirements. Oracle Primavera Risk Analysis (OPRA) can perform these operations as well, and there may be other capable software products.

Figure 18 shows a color-coded cost—finish date scatter diagram with a frontier curve superimposed on it, indicating a number of different combinations of finish dates and costs that all show a 70 percent likelihood of being jointly met. That is, there are 70 percent of the dots (iterations) in the south-west quadrant. What is shown in Figure 18 is a standard picture.

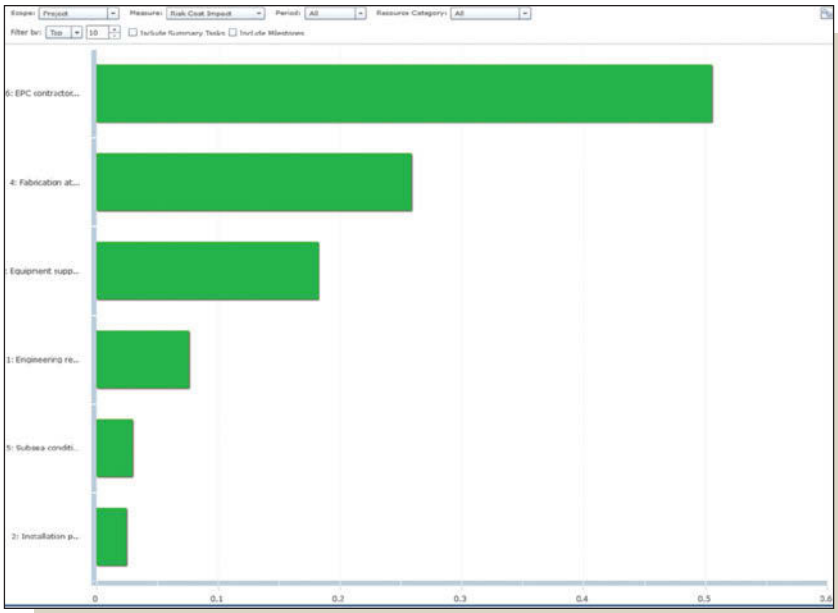


Figure 17 – Risk Tornado Chart on Cost

Some people, seeing a curve that looks like an isoquant, think that they can choose any point on it. Such a choice is tempting, since it seems that an earlier date is associated with an increasing cost, which seems to be correct as accelerating the schedule probably means adding resources at their increased cost.

In fact, this isoquant does not represent different time-cost combinations that can be chosen. It is better to view the "football" scatter as a three-dimensional ridge of probability. One should conclude that the current project plan, both cost and finish date, will probably occur where the peak of the probability ridge occurs, where the concentration of iteration result is densest, which is usually thought of as the "elbow" of the JCL curve.

Prioritized Risks to Cost			
	Baseline Cost	1.65	
		P-80 Cost	
	All Risks Included	1.97	$ Billions saved
Risk ID	Risk Name		
6	EPC contractor quality is questionable	1.88	0.09
4	Fabrication at a new shipyard is problematic	1.80	0.08
3	Equipment suppliers may be overloaded	1.77	0.03
1	Engineering resources may be lacking	1.76	0.01
2	Installation productivity may not be as good as assumed	1.75	0.01
5	Subsea Conditions are not well characterized		
	Inherent uncertainty and duration estimation error	1.65	0.10

Table 2 – Prioritized List of Risks Driving Total Cost

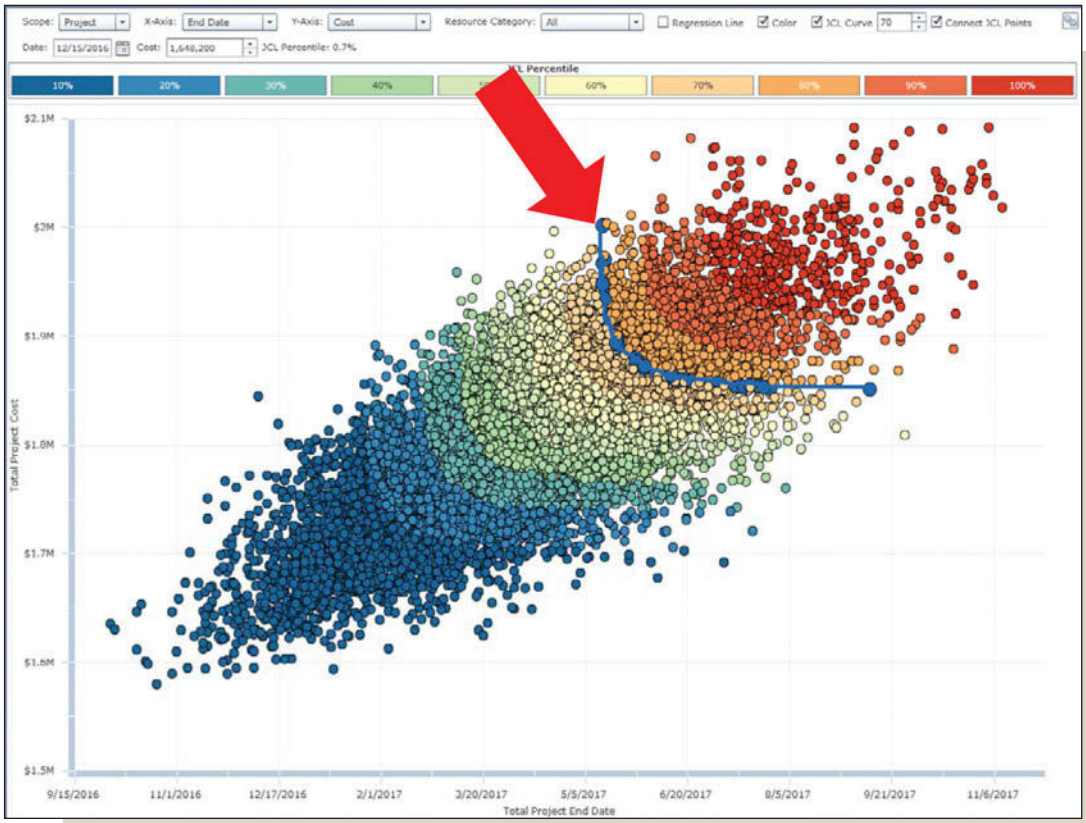


Figure 18 – NASA's Joint Confidence Level Concept Implemented

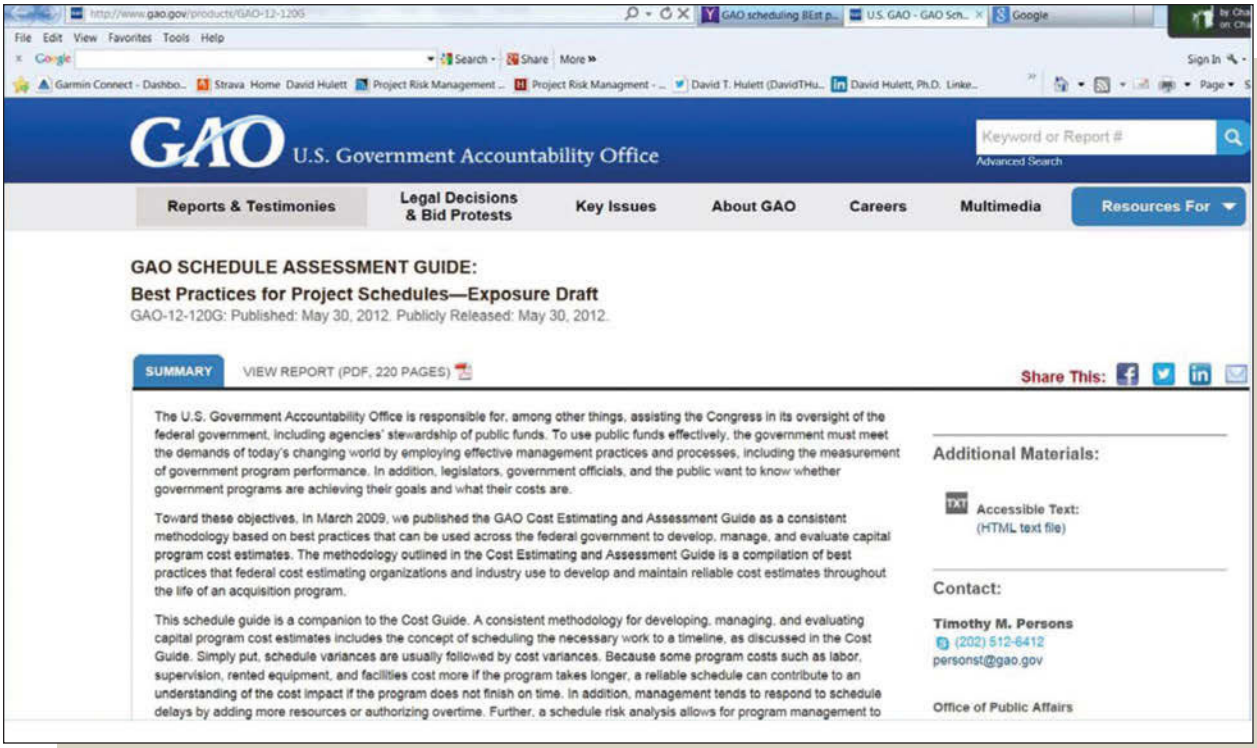


Figure 19 – Screen Capture Listed with Reference 4

If an earlier date is required, the best strategy is to mitigate the important schedule risks, realizing the cost that the mitigation actions require, and developing the new schedule-risk mitigated plan. A new Monte Carlo simulation with the residual risks and new costs would probably result in an earlier date and higher cost. However, there is no assurance that the new, earlier date plan would be on the JCL isoquant, as shown in Figure 18.

Conclusion

The cost and timeline (schedule) of the project are related. If the schedule is elongated, then the resources used to accomplish the tasks that take longer than expected will also cost more, as will the overhead or indirect "marching army" resources. Even if there is a fixed price contract, the causes of the longer performance period may be claimed and some cost increase is expected. Also, the bidders on the project will put the implications of schedule risk, even the penalties for late finish, into their bids if they expect delays.

Integrating the schedule and cost risk analyses together into one cost-loaded project analysis schedule allows the analyst to model the implications of a longer schedule onto its implications for cost. During a Monte Carlo simulation the time-dependent resources, such as labor and rented equipment, will cost more if the schedule risks dictate that the activities take longer than originally planned. It turns out in practical implementation that many of the most important risks to cost are those risks to schedule that have a knock-on effect on the cost of performing tasks and supporting the overall project.

A simple model of an offshore gas production platform and drilling campaign was used to illustrate the various types of risk that can be analyzed together in the same simulation:

- Schedule-driven cost of time-dependent resources;
- Cost risk drivers of uncertain daily expense burn rate for the time-dependent resources; and,
- Cost risk drivers of uncertain cost of time-independent resources.

This article describes the distinction in concept and implementation of inherent variability in human and organizational endeavors, characterized by their impact on durations, given that they are 100 percent certain to occur, versus discrete risks that are characterized by their probability, impact if they occur and activities they affect. The discrete risks are implemented in this paper using risk drivers for which the impact is expressed in a range (usually three-point estimate) of multiplicative factors that will multiply the schedule duration if they occur, on an iteration. The multiplicative factors allow the risk drivers to be assigned to multiple activities, which is usually the case since many strategic risks are described as affecting project phases.

The described approach is particularly suited to NASA's Joint Confidence Level (JCL) policy. ◆

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