2019 Construction CPM Conference

San Diego, CA January 20-23, 2019

Integrated Cost/ Schedule Risk Analysis using Monte Carlo Simulation of a CPM Model

David T. Hulett, Ph.D. FAACE, Hulett & Associates, LLC
Michael R. Nosbisch, CCP PSP FAACE, Spire Consulting Group, LLC

Context

- This presentation will provide up-to-date **integrated project cost and schedule risk analysis using risk drivers**
- The analysis is done in the context of conducting a **Monte Carlo simulation-based schedule risk analysis** of a resource-loaded CPM project schedule
- This presentation illustrates some of the most important features of Risk Drivers used to represent **identified project and systemic risks**
- Modern software that simulates resource-loaded CPM schedules is shown on a **simplified case study**

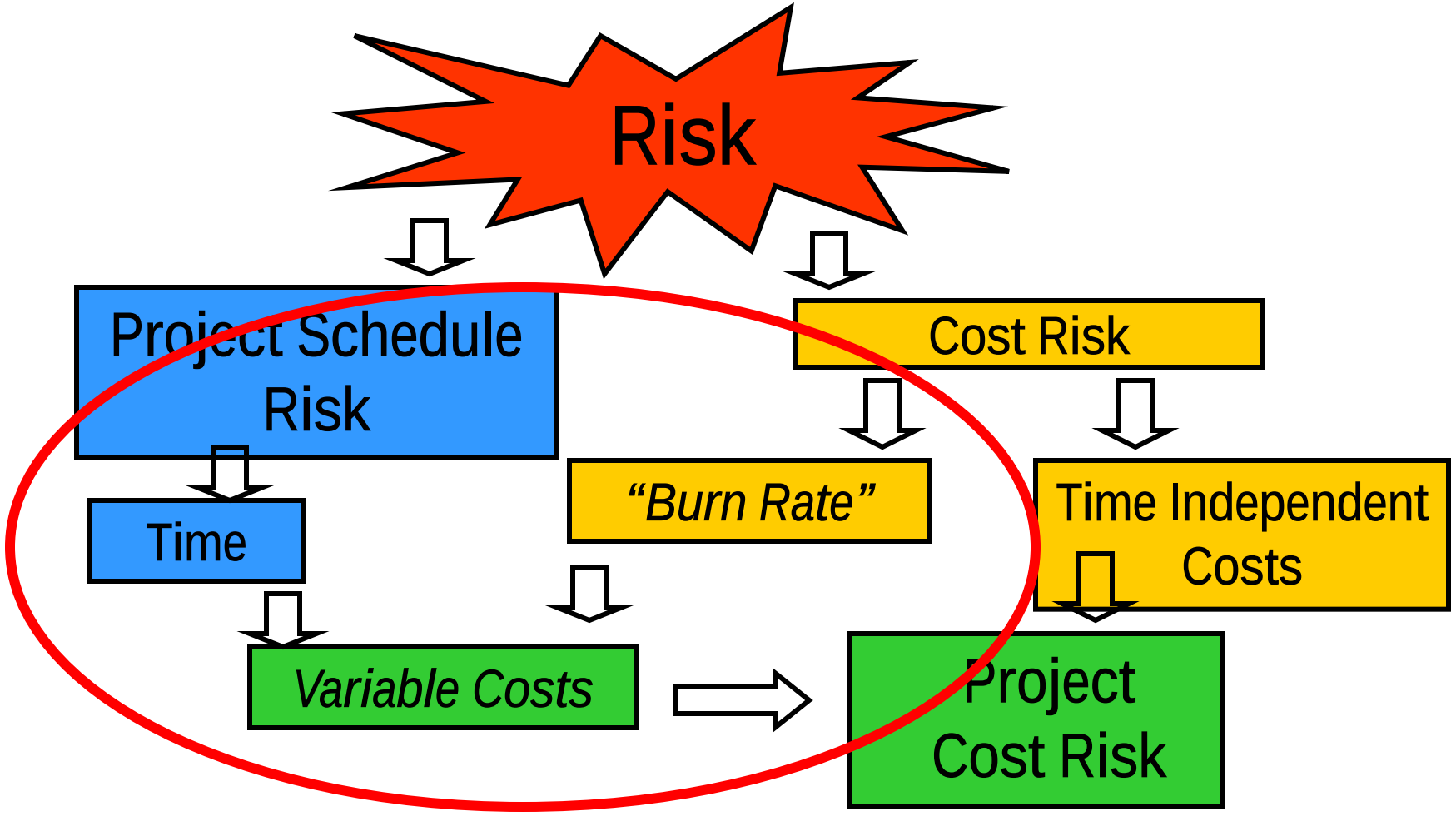
Components of the MCS Analysis

- The value of integrating project schedule and cost risk in a project schedule is that **different resources are applied**, or the same resources are applied in different mixtures, **to activities that do work**.
- Activities' cost depends on schedule if it is **labor, rented equipment** and the like (**time-dependent**).
  - The cost of these resources may also cost more or less independent of time (their burn rate may vary)
- **Material** cost is **time-independent**.
  - It may vary but not because of activity duration (total cost may vary)
- The main importance of this distinction is that **labor and material resources respond differently to schedule uncertainty.**

Hulett & Associates

SPIRE CONSULTING GROUP

Cost and Schedule Risk Integration



Integration of Cost and Schedule Risk

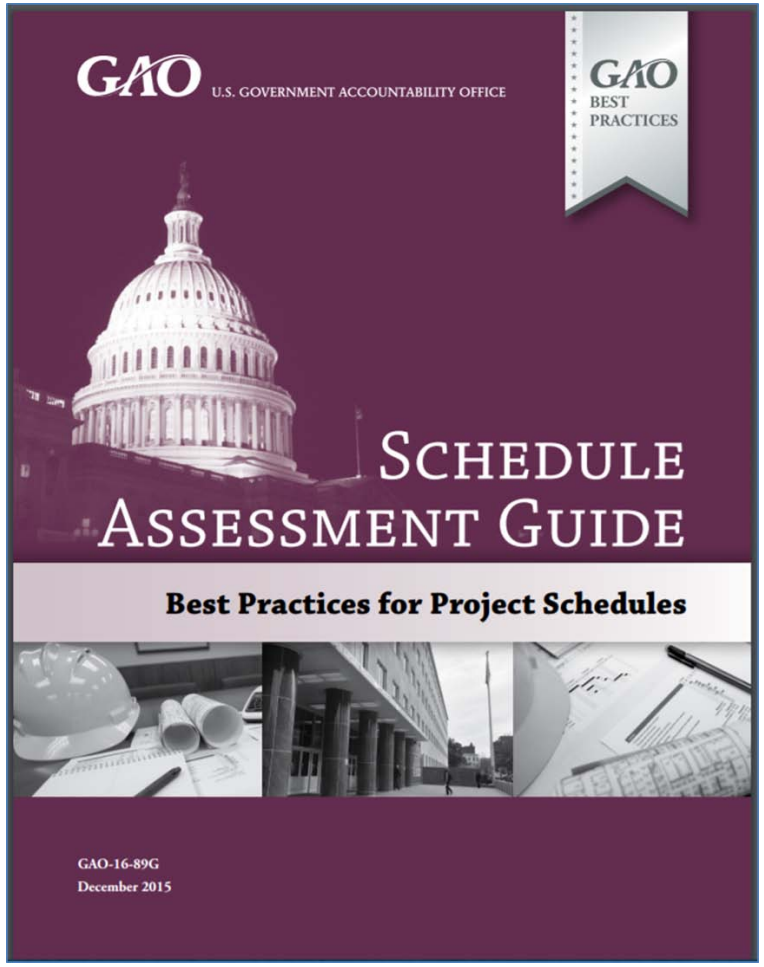
- Today's computer software simulating project schedules can also **simulate cost associated with the schedule results for each iteration**
  - This method requires **loading** of time-dependent (labor) and time-independent (materials) **resources** on the schedule
  - The MCS results show that a significant fraction of **cost contingency is derived indirectly from effect of schedule variation** on cost of project
- Integrating can also provide time and cost scatterplot reveals that the finish date and cost targets needed to achieve a desired **level of confidence in meeting both objectives, the basis of the Joint Confidence Level of NASA**, depends on the degree of time and cost correlation

Hulett & Associates

SPIRE CONSULTING GROUP

Good Quality Project CPM Schedule is the Platform for the Analysis

- Critical Path Method **(CPM) schedule that complies with scheduling best practices.**



Good Quality Data about Risks - Workshops

- Often people find that **sharing honestly and openly in a workshop setting is difficult**
  - If there are risks that cannot be discussed because they are unpopular
  - May conflict with management statements or customer requirements
  - Imply the project is in default of the contract terms, or for other reasons
- Groupthink (suppressing dissent)
- The “Moses factor” (i.e. an influential person such as the project manager who overwhelms others)
- Cultural conformity (i.e. decisions that match the organization’s norms).

Hulett & Associates

SPIRE CONSULTING GROUP

Good Quality Data about Risks – Confidential Interviews

- **Confidential interviews provide the best opportunity for individuals to express their opinions openly, honestly and without fear of retribution**
  - These interviews usually identify and calibrate some **risks that are not already captured in the risk register**, often identifying unknown knowns for the first time.
  - Once the risks are identified in an interview they can be **commented on by other interviewees in confidence or brought up anonymously** for group buy-in, but nobody knows what anyone else has said in their interviews

Hulett & Associates

SPIRE CONSULTING GROUP

Benchmarking Results with Actual Data

- Review of **existing data on comparable and recent projects** should also be brought to the risk data collection exercise
  - Comparing the data and results for the current project with past experience represented by completed projects may bring what is called the **"outside view" to the discussion**
- Making reference to **historic databases can often bring more realism** to the risk discussion
  - Provide a means to **corroborate identified risks with their likelihood and uncertainty ranges**

Hulett & Associates

SPIRE CONSULTING GROUP

Uncertainty is Background Noise 100% Likely

Project Risks

Name	Description	Risk Type	Probability	Color
Risk- 4	Engineering Risk	Standard	30%	
Risk-1	Project C&S Uncertainty	Standard	100%	
Risk-2	Fabrication Risk	Standard	55%	
Risk-3	Installation Risk	Standard	60%	
Risk-5	Procurement Risk	Standard	20%	
Risk-6	HUC Risk	Standard	70%	
Risk-7	Systemic Team Risk	Standard	30%	
Risk-8	Labor Cost Risk	Standard	75%	

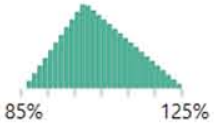
Impacts of Risk-1

☐ Impact activities independently

Pre-Mitigated Position

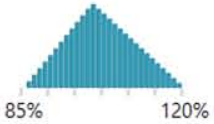
☑ Schedule Impact

Type: Relative Distribution: Triangle Min: 85% Likely: 100% Max: 125%



☑ Cost Impact

Type: Relative Distribution: Triangle Min: 85% Likely: 100% Max: 120%



Hulett & Associates

SPIRE CONSULTING GROUP

Risk Drivers Represent Identified Project-Specific and Systemic Risks

- Risk Drivers are identified “root cause risks” with:
  - Probability of occurring on the project (% of iterations occurring)
  - Impact on activity durations if they do occur, expressed as probability distributions of multiplicative factors

Project Risks

Name	Description	Risk Type	Probability	Color
Risk- 4	Engineering Risk	Standard	30%	
Risk-1	Project C&S Uncertainty	Standard	100%	
Risk-2	Fabrication Risk	Standard	55%	
Risk-3	Installation Risk	Standard	60%	
Risk-5	Procurement Risk	Standard	20%	
Risk-6	HUC Risk	Standard	70%	
Risk-7	Systemic Team Risk	Standard	30%	
Risk-8	Labor Cost Risk	Standard	75%	

Impacts of Risk-2

Impact activities independently

Pre-Mitigated Position

Schedule Impact

Type: Relative Distribution: Triangle Min: 90% Likely: 105% Max: 150%

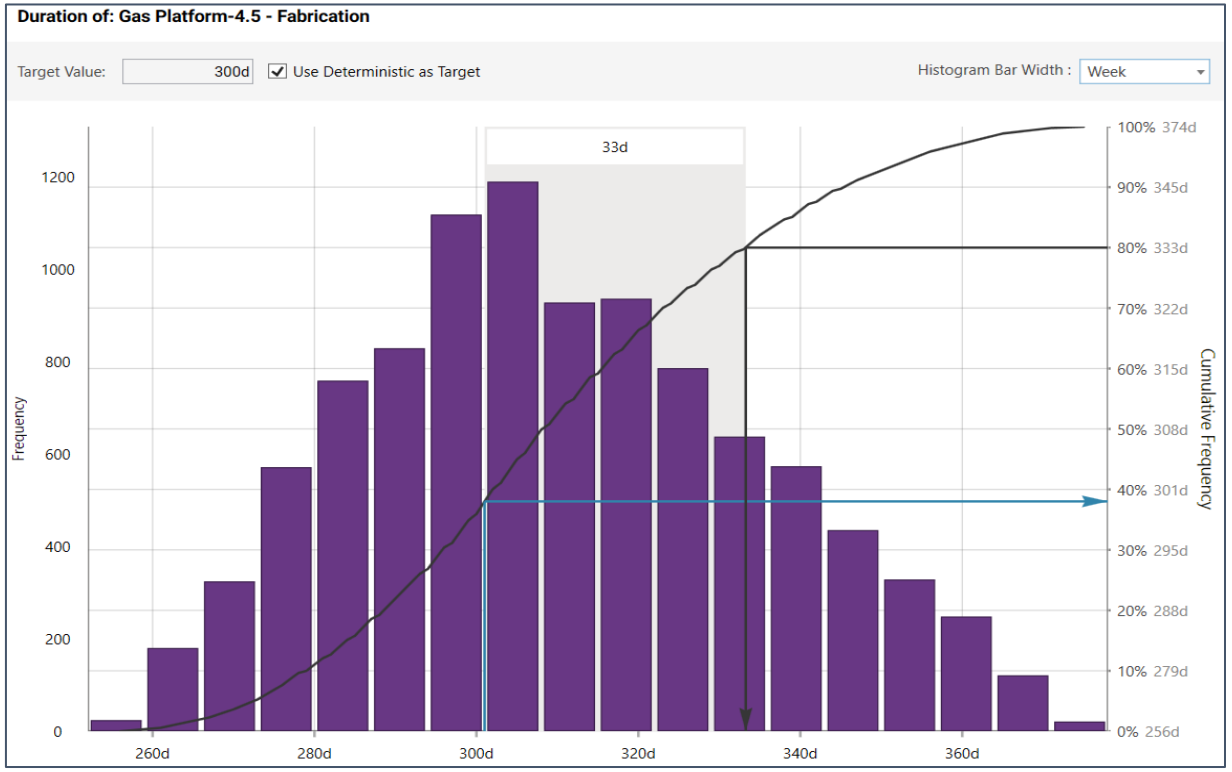
90% 150%

Cost Impact

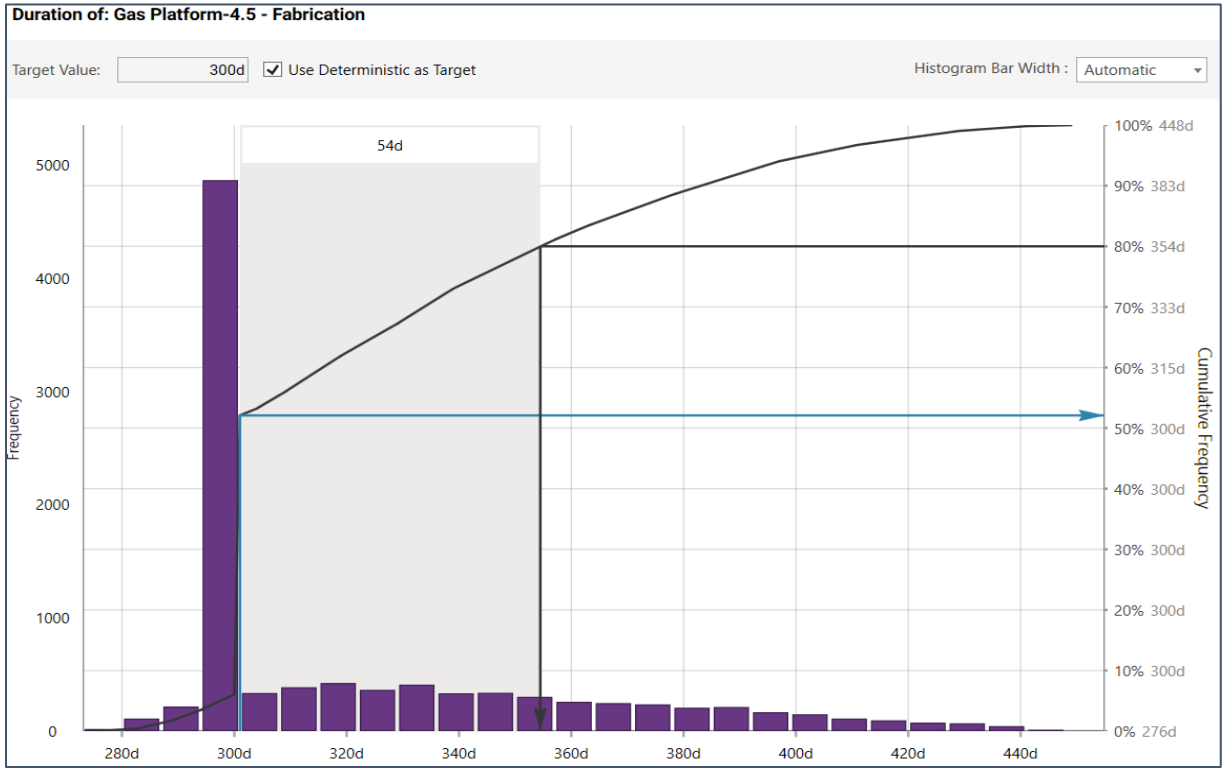
Type: Relative Distribution: Triangle Min: 90% Likely: 100% Max: 120%

90% 120%

Uncertainty and Risk Drivers' Impact on Activity Durations during Monte Carlo



Impact of Uncertainty (100% likely)



Impact of Risk Driver (e.g., 55% likely)

Hulett & Associates

SPIRE CONSULTING GROUP

Assigning Risks to Multiple Activities

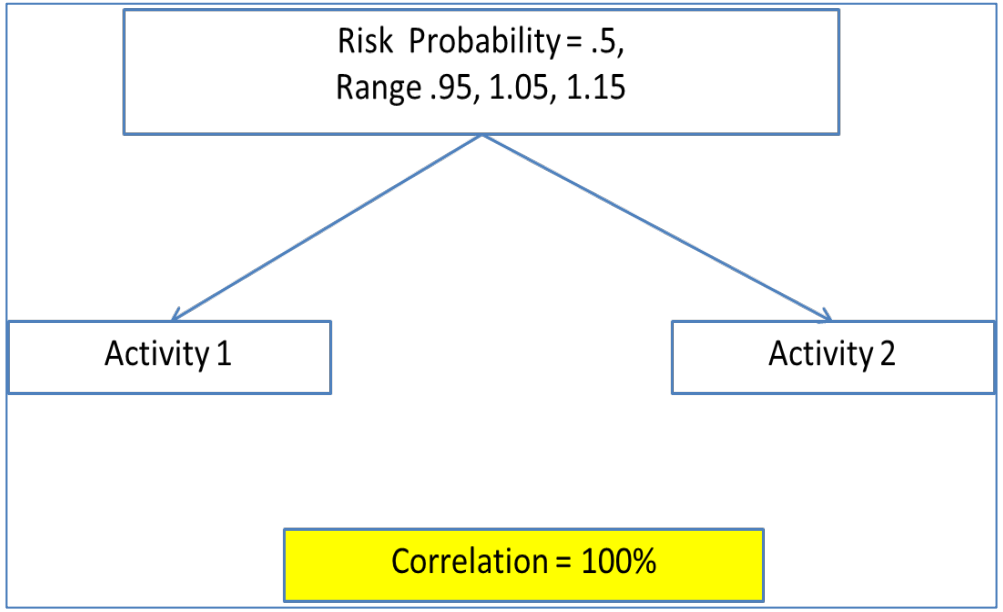
Id	Description	Risk- 4	Risk-1	Risk-2	Risk-3	Risk-5	Risk-6	Risk-7
Gas Platform-4	Offshore Gas Production Platform	■	■	■	■	■	■	■
Gas Platform-4.1	Milestones and Hammocks	☐	☐	☐	☐	☐	☐	☐
Gas Platform-4.2	Decision Making	☐	☑	☐	☐	☐	☐	☑
Gas Platform-4.3	Engineering	☑	☑	☐	☐	☐	☐	☑
Gas Platform-4.4	Procurement	☐	☑	☐	☐	☑	☐	☑
Gas Platform-4.5	Fabrication	☐	☑	☑	☐	☐	☐	☑
E1000	Fabricate Drilling Topsides	☐	☑	☑	☐	☐	☐	☑
E1020	Fabricate CPP Topsides	☐	☑	☑	☐	☐	☐	☑
E1030	Fabricate CPP Jacket	☐	☑	☑	☐	☐	☐	☑
E1010	Fabricate Drilling Jacket	☐	☑	☑	☐	☐	☐	☑
Gas Platform-4.6	Drilling	☐	☑	☐	☐	☐	☐	☑
Gas Platform-4.7	Installation	☐	☑	☐	☑	☐	☐	☑
Gas Platform-4.8	HUC	☐	☑	☐	☐	☐	☑	☑

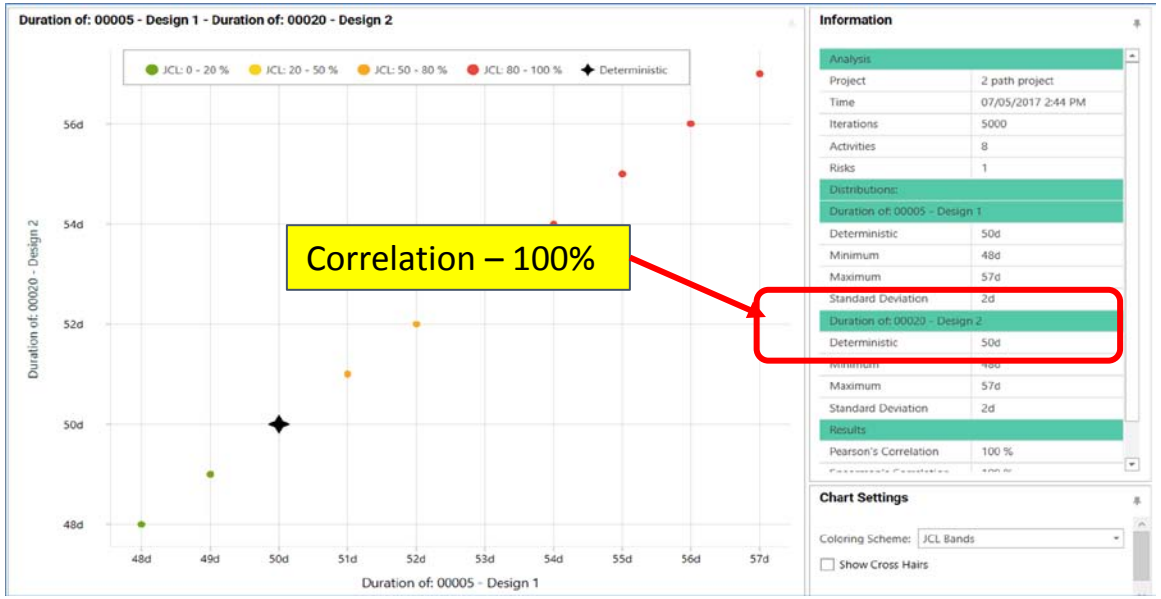
Using Multiplicative Impact Factors with Risk Drivers Helps to allocate risks to long and short activities alike

Hulett & Associates

SPIRE CONSULTING GROUP

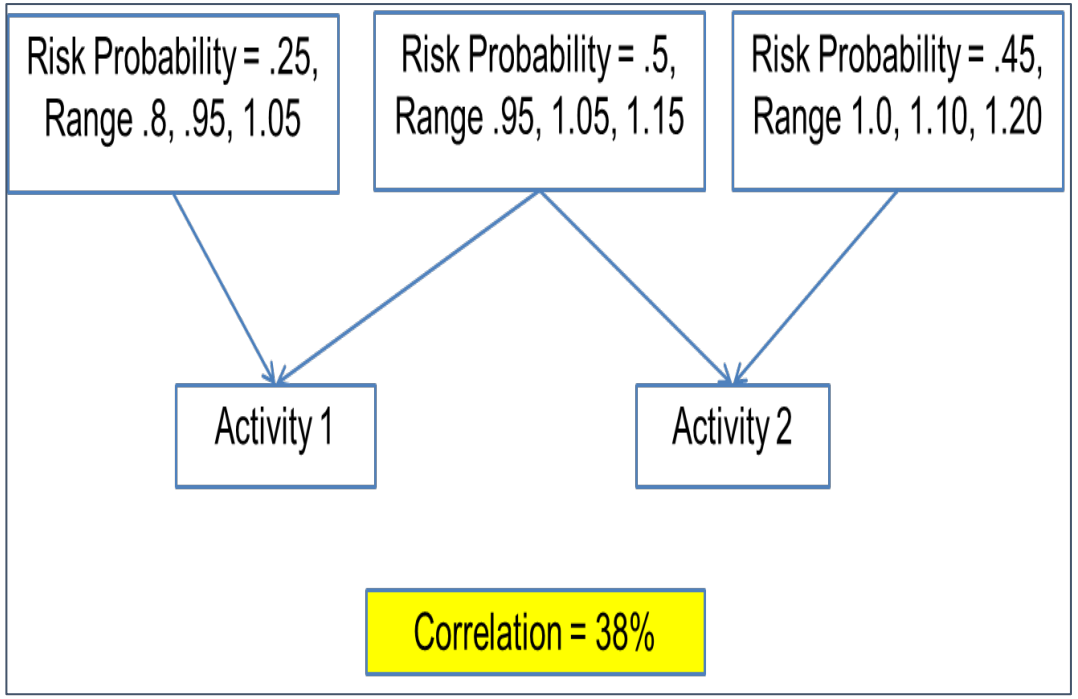
Risk Drivers cause Correlation during Simulation





Correlation between activity durations is an important component of any schedule risk analysis
Correlation is caused by one risk affecting multiple activities

Correlation Depends on Which Risks Affect Durations



With one risk common to two activities but others affecting only one but not the other activity, the correlation declines - to 38% in this example
We are particularly inaccurate in estimating ("guessing") correlation coefficients. It is good to model during simulation

Risks can be Modeled in Parallel or in Series

- Earlier the risks would all build on each other if they occurred on the same activity on the same Monte Carlo iteration
- Originally the multiplicative factor on an activity's duration was the multiplicative product of all risks' occurring in that iteration. This caused some activities' durations to be unreasonably long
- Now, modeling risks in parallel if they can be recovered from simultaneously allows the model to select the largest multiplier occurring in an iteration, assuming the other risks can be addressed simultaneously

Risks can be Modeled in Parallel or in Series

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

Risk 1: 1.2 factor

Risk 2: 1.25 factor

Use (1.2 x 1.25 = 1.5) multiplicative factor for this iteration

If these two risks can be recovered from simultaneously they are entered ***in parallel***

Risk 1: 1.2 factor

Risk 2: 1.25 factor

Use 1.25 (Largest) multiplicative factor for this iteration

Risk Prioritization for Focused Risk Mitigation

- Earlier the sensitivity measures for prioritizing risks showed tornado diagrams based on the correlation of the activity with total project duration
- Then tornado diagrams could show correlation of the identified risk with total project duration, but still based on correlation between the risk and total project duration
- Now we prioritize risks by a successive simulation method that shows risks prioritized by the number of "days saved if the risk were mitigated"
  - This measure is useful for management.
  - Answers the question: "If we spend $5 million how many days do we save"

Hulett & Associates

SPIRE CONSULTING GROUP

Strategy for Risk Prioritization using Simulations

Iterative Approach to Prioritizing Risks (Based on Days Saved if Fully Mitigated at P-80)								
Risk #	1	2	3	4	5	6	7	8
Priority Level	Uncertainty	Fabrication	Installation	Engineering	Procurement	HUC	Systemic Team	Labor Cost
1	X	X	X	X	X	X	1	X
2	2	X	X	X	X	X		X
3		3	X	X	X	X		X
4			X	4	X	X		X
5			X		X	5		X
6			X		6			X
7			7					X
8								8

Identify the risk that provides the greatest number of days if fully mitigated ("disabled"). Remove, repeat the process with remaining risks, repeat until all risks have been chosen in priority order

Hulett & Associates

SPIRE CONSULTING GROUP

Successive Elimination of Risks in Priority Order

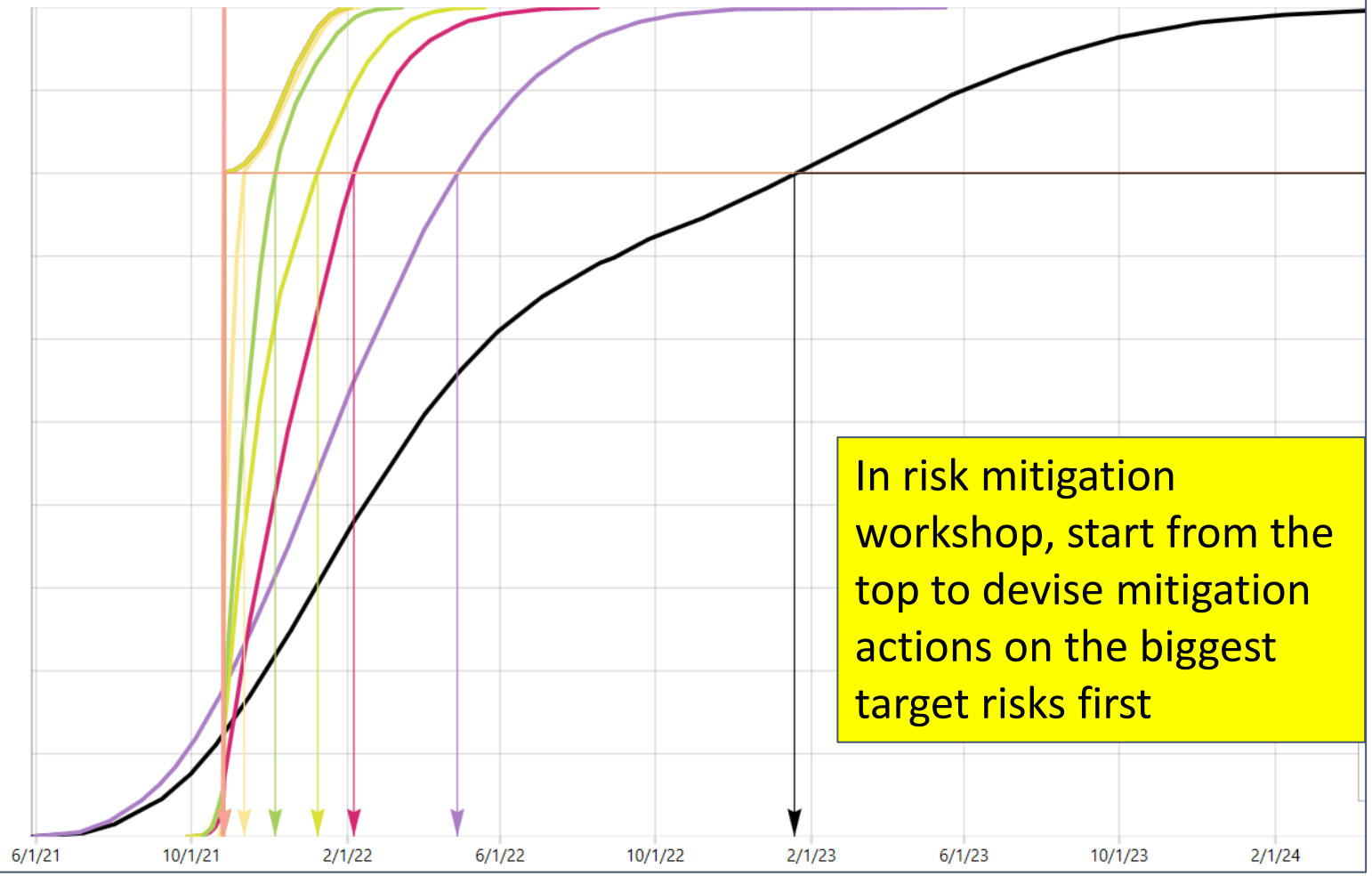
Impacts

View Schedule Impact on: Project

At: P80

	Schedule Impact	Cost Impact
☑	265d	505,863
☑	82d	139,294
☑	28d	107,310
☑	33d	6,277
☑	25d	4,951
☑	16d	5,650
☑	0d	165,009
☑	0d	0
☑	0d	0

Impact of Risks on Finish Date of Project (Sensitivity Method: Multiple Passes)



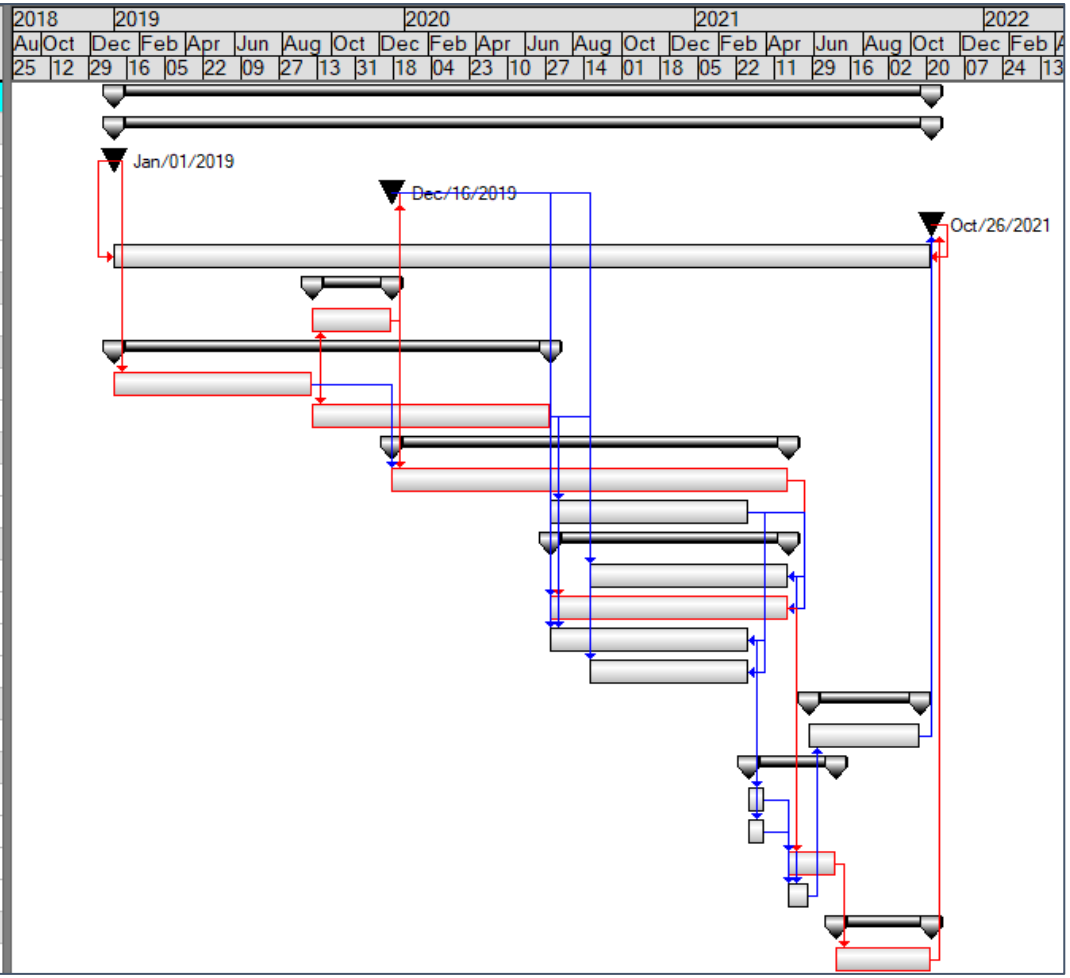
In risk mitigation workshop, start from the top to devise mitigation actions on the biggest target risks first

Hulett & Associates

SPIRE CONSULTING GROUP

Case Study to Illustrate Risk Drivers on Project

Activity ID	Description	Duration	Early Start	Early Finish	Planned Total Cost	Total Float
Gas Platforn	Offshore Gas Production Platform	1030	Jan/01/2019	Oct/26/2021	1,781,840	
Gas Platforn	Milestones and Hammocks	1030	Jan/01/2019	Oct/26/2021	80,340	
A1000	Project Start	0	Jan/01/2019	Jan/01/2019	0	0
A1010	Final Investment Decision (FID)	0	Dec/16/2019	Dec/16/2019	0	0
A1020	First Gas	0	Oct/26/2021	Oct/26/2021	0	0
A1030	Project Management (Hammock)	1030	Jan/01/2019	Oct/26/2021	80,340	0
Gas Platforn	Decision Making	100	Sep/08/2019	Dec/16/2019	20,000	
B1000	Approval Process	100	Sep/08/2019	Dec/16/2019	20,000	0
Gas Platforn	Engineering	550	Jan/01/2019	Jul/03/2020	101,000	
C1000	FEED	250	Jan/01/2019	Sep/07/2019	35,000	0
C1010	Detailed Engineering	300	Sep/08/2019	Jul/03/2020	66,000	0
Gas Platforn	Procurement	500	Dec/17/2019	Apr/29/2021	450,000	
D1000	Procurement of LLE	500	Dec/17/2019	Apr/29/2021	250,000	0
D1010	Procurement of Other Equipment	250	Jul/04/2020	Mar/10/2021	200,000	30
Gas Platforn	Fabrication	300	Jul/04/2020	Apr/29/2021	971,000	
E1000	Fabricate Drilling Topsides	250	Aug/23/2020	Apr/29/2021	275,000	15
E1020	Fabricate CPP Topsides	300	Jul/04/2020	Apr/29/2021	390,000	0
E1030	Fabricate CPP Jacket	250	Jul/04/2020	Mar/10/2021	146,000	30
E1010	Fabricate Drilling Jacket	200	Aug/23/2020	Mar/10/2021	160,000	45
Gas Platforn	Drilling	140	May/25/2021	Oct/11/2021	96,000	
F1000	Drilling for First Gas Only	140	May/25/2021	Oct/11/2021	96,000	15
Gas Platforn	Installation	110	Mar/11/2021	Jun/28/2021	39,500	
G1000	Install Drilling Platform Jacket	20	Mar/11/2021	Mar/30/2021	6,000	45
G1020	Install CPP Jacket	20	Mar/11/2021	Mar/30/2021	6,000	30
G1030	Install CPP Topsides	60	Apr/30/2021	Jun/28/2021	15,000	0
G1010	Install Drilling Topsides	25	Apr/30/2021	May/24/2021	12,500	15
Gas Platforn	HUC	120	Jun/29/2021	Oct/26/2021	24,000	
H1000	Hook UP and Commissioning for F	120	Jun/29/2021	Oct/26/2021	24,000	0



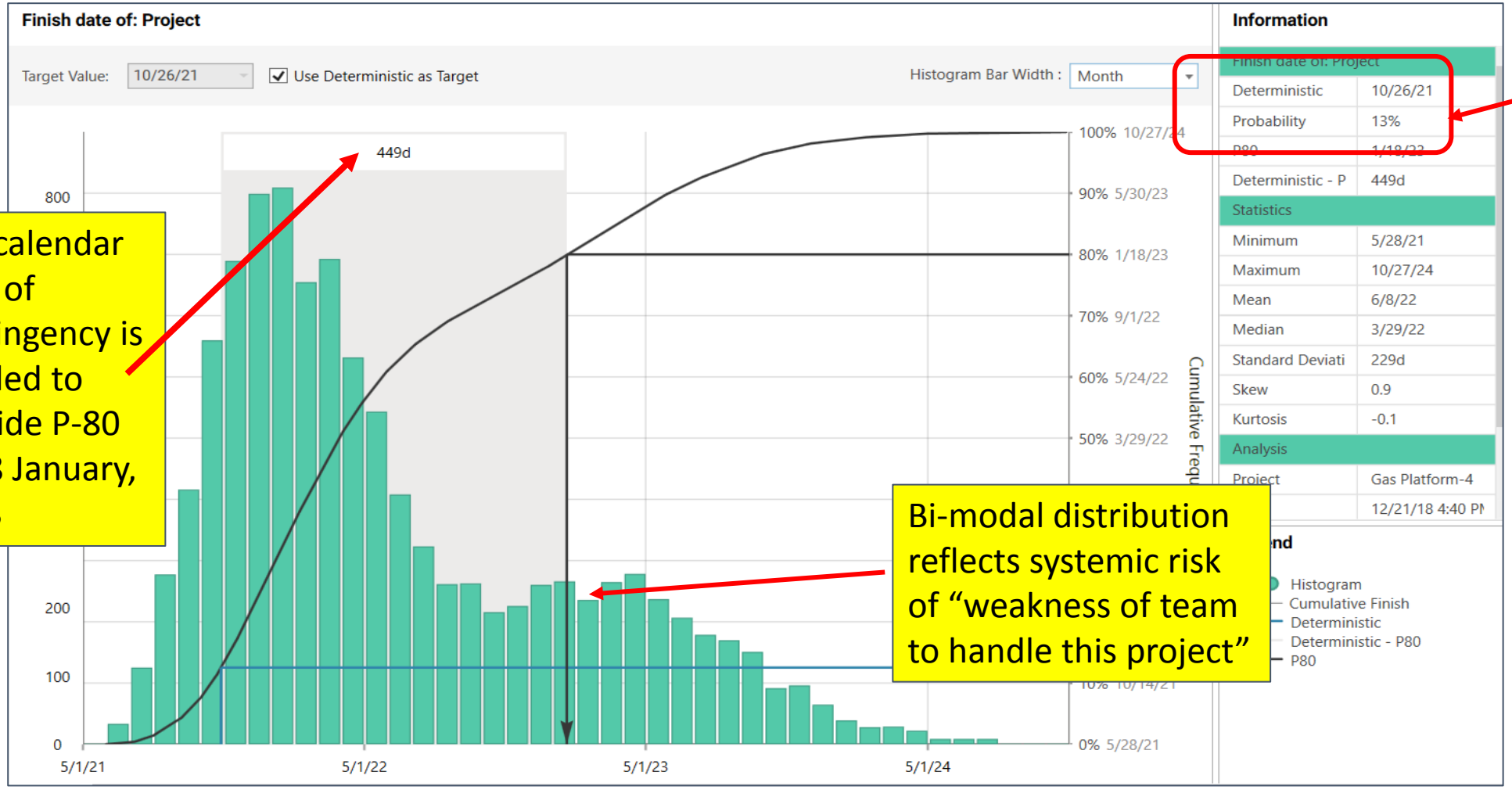
Results for Schedule and Cost Targets

- The organization sets its own targets for cost and schedule success
- Often clients use the 80th percentile, "P-80," to provide a cushion for risks not yet identified
- P-80 means that there is an 80% chance, given the schedule and risks, that the project will <u>finish on that date or earlier, at that cost or less</u>
  - The P-80 for schedule represents uncertainty and risk drivers plus the logic of the schedule
  - The P-80 for cost represents the indirect effect of schedule risk on cost as well as the uncertainty and risk drivers affecting cost items, such as price of steel, suppliers being busy

Hulett & Associates

SPIRE CONSULTING GROUP

Example of P-80 Schedule Results



449 calendar days of contingency is needed to provide P-80 at 18 January, 2023

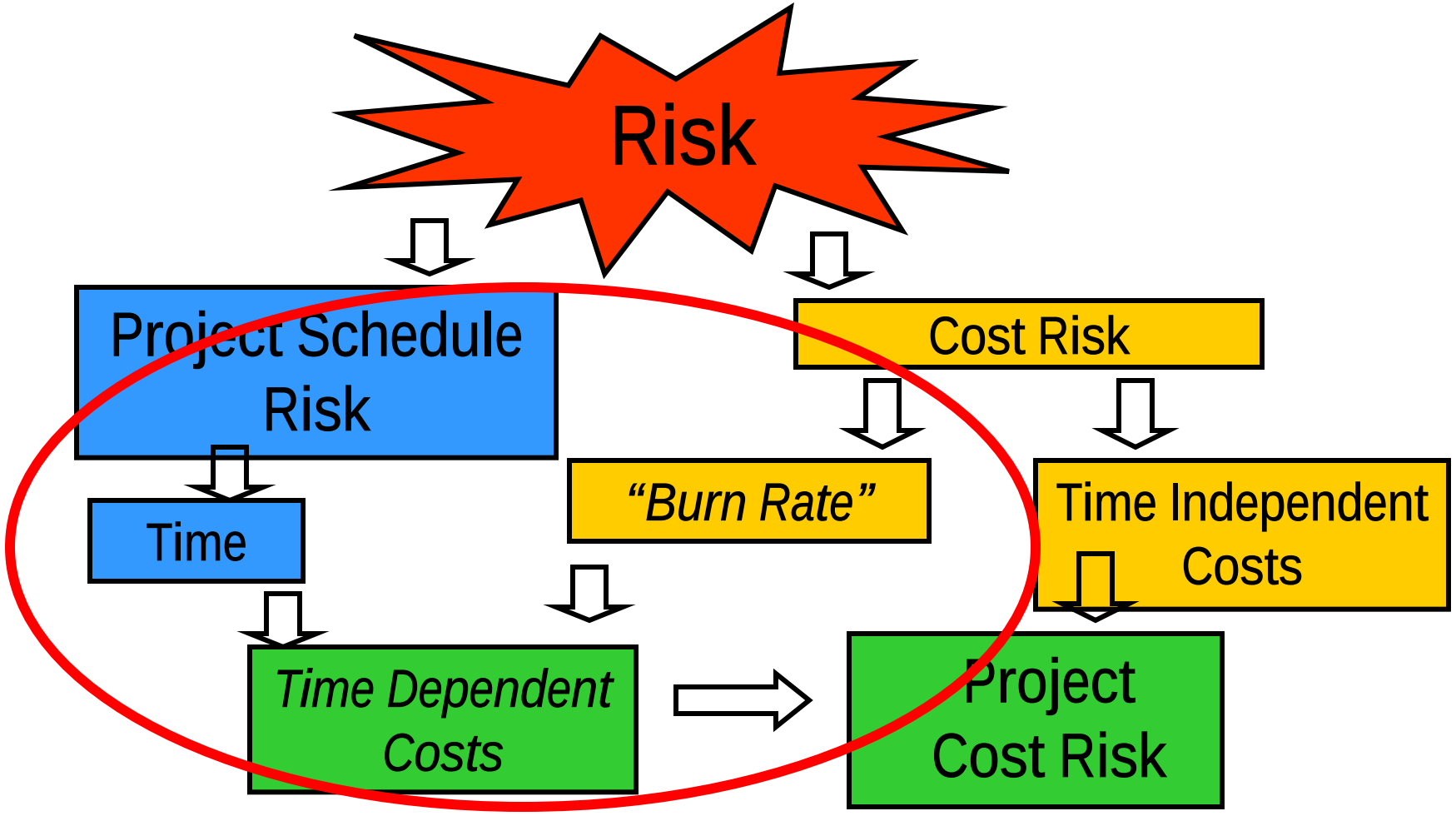
Probability of deterministic date is 13%

Bi-modal distribution reflects systemic risk of "weakness of team to handle this project"

Hulett & Associates

SPIRE CONSULTING GROUP

Cost and Schedule Risk Integration



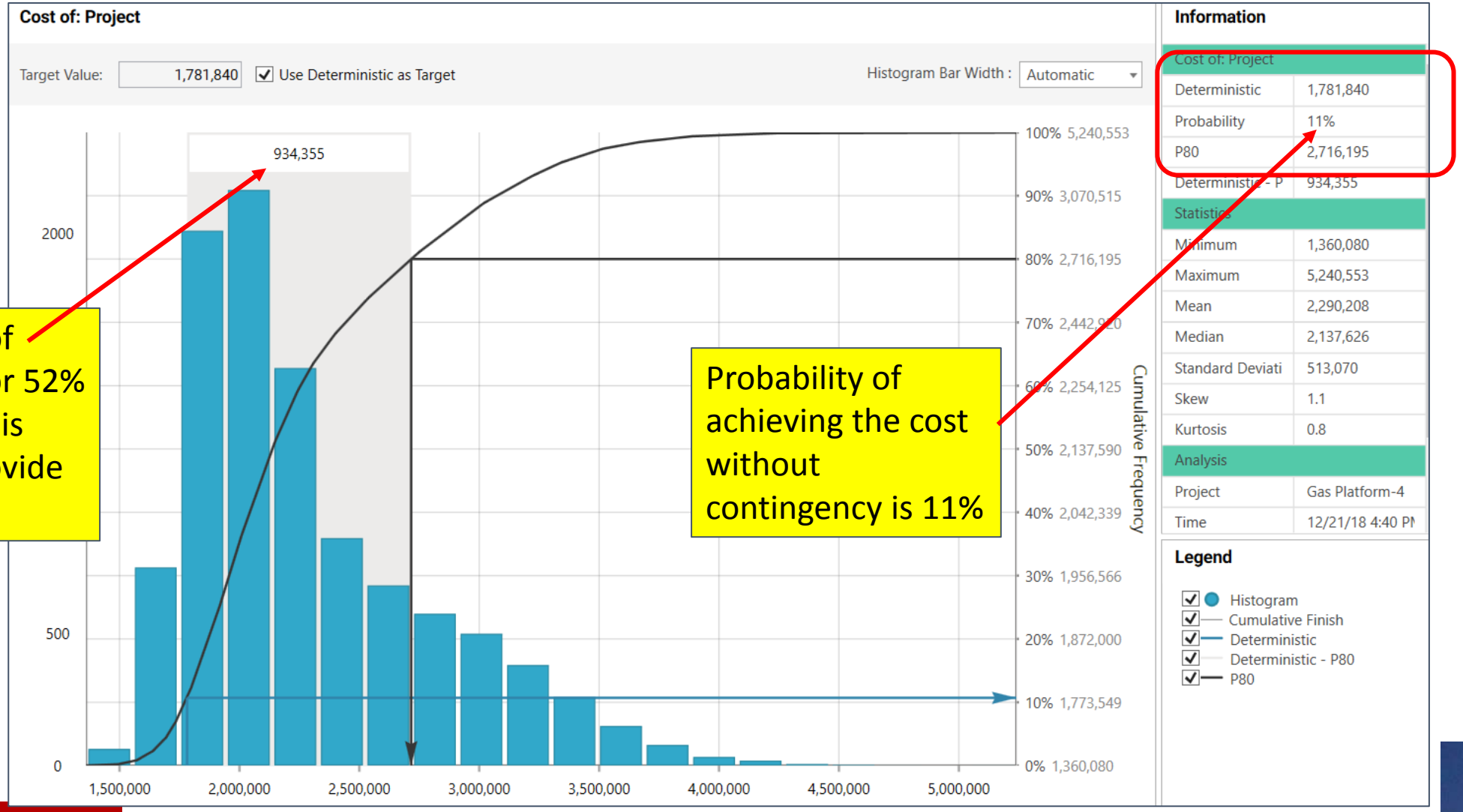
Representing the Risk to Both Cost and Schedule – The Joint Confidence Level (JCL)

- Schedule is loaded with costs as Time-Dependent and Time-Independent resources
- Time dependent resources are labor and rented equipment that cost more if the activities (including indirect cost hammocks) take longer
  - With some cost-type risks e.g., labor market drives labor rates, labor cost can vary even if the schedule is perfect
- Time-independent resources are materials and equipment for installation.
  - They may cost more or less than estimated but not because of time
- This analysis does not say who pays. It is not an analysis of contracts or an assessment of whether fixed price contracts successfully transfer the risk to contractors from owners

Hulett & Associates

SPIRE CONSULTING GROUP

Example of P-80 Cost Risk Results



Contingency of $934 million or 52% pre-mitigated is needed to provide a P-80 cost.

Probability of achieving the cost without contingency is 11%

Hulett & Associates

SPIRE CONSULTING GROUP

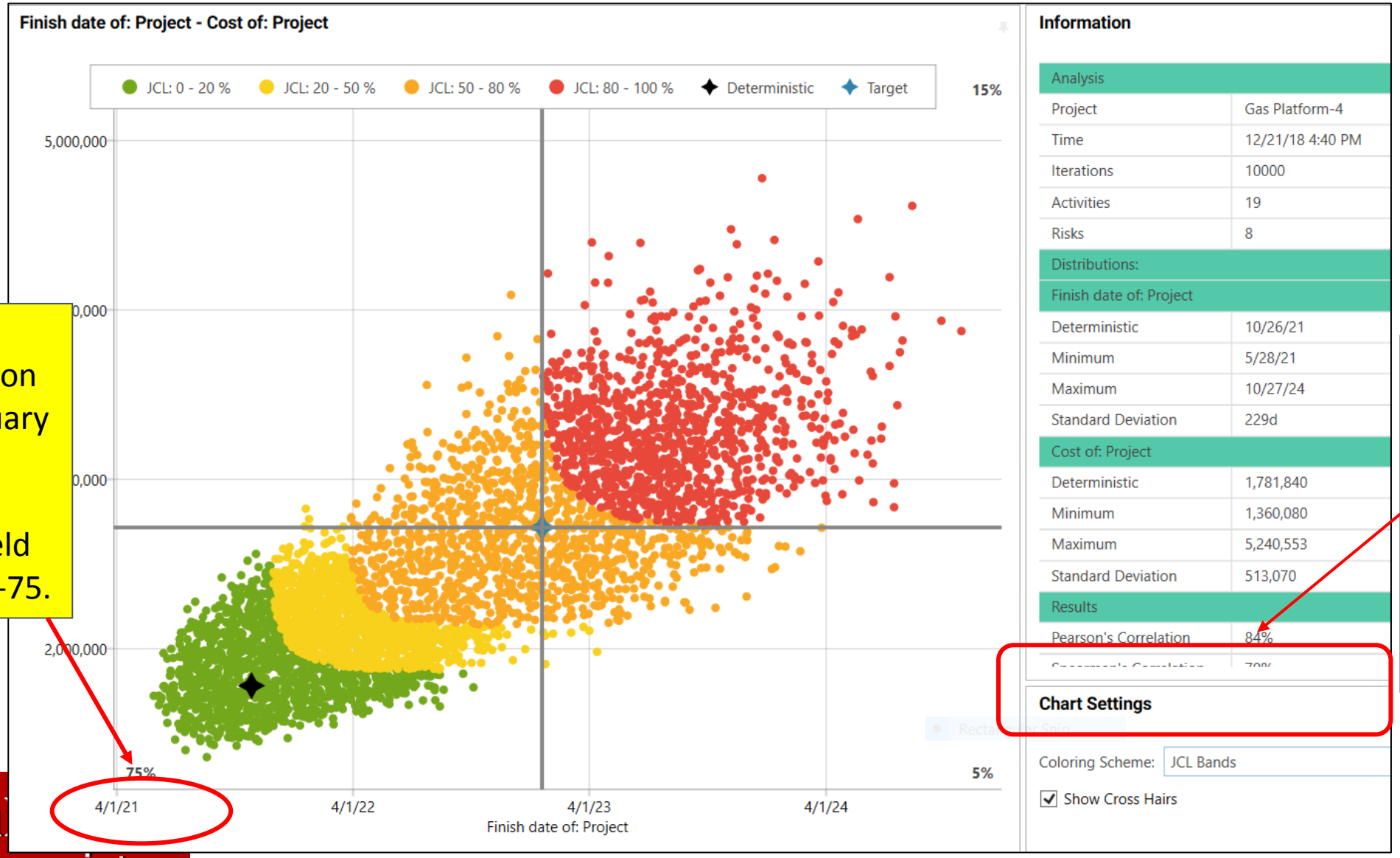
A New Concept – the Joint Confidence Level

- Joint (cost and schedule) Confidence Level ("JCL") is just NASA's name for integrated cost-schedule risk analysis
- The JCL highlights the fact that cost and schedule are not perfectly linked (their correlation is < 100%) so using the P-80 values for schedule and cost will not ensure meeting those two targets together
- Additional time and money will be needed above the P-80 values of 18 January 2023 and $2,716.2 million if <u>BOTH COST AND SCHEDULE ARE TO BE MET TOGETHER</u>
- The JCL is based on matching the P-80 (NASA uses P-70) joint probability of cost and schedule with the cost-finish date scatter diagram to find the most likely combination of cost and finish date to achieve 80% (JCL-80) confidence

Hulett & Associates

SPIRE CONSULTING GROUP

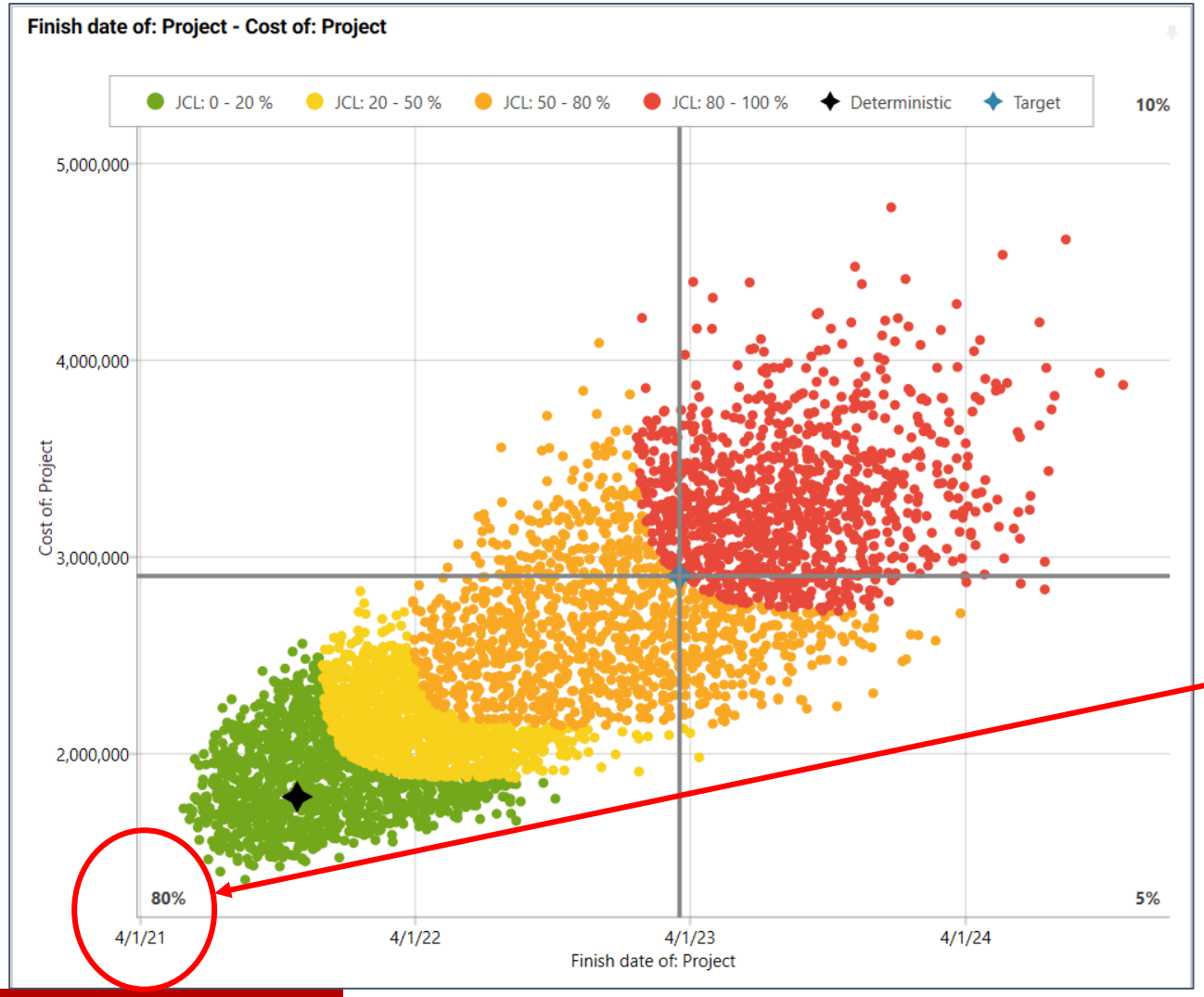
P-80 Cost and Schedule do Not Make JCL-80



The combination of 18 January 2023 and $2,716.2 million yield only a JCL-75.

In this case total project cost and finish date are correlated 84%

How Much Time and Budget are needed for JCL-80?



One possible JCL-80 combination that looks like it lies in the "sweet spot" of the scatter diagram would require:

- A finish date of 3/18/2023 or an additional 2 months from the P-80 schedule result
- A budget of $2,903.9 million or $187.7 million more than the P-80 cost result

This result is more achievable than the P-80 values

Hulett & Associates

SPIRE CONSULTING GROUP

What is the benefit of JCL-80 over P-80?

- There is some evidence, presented at the 2018 NASA Cost and Schedule Symposium, that NASA is having better success achieving the cost and schedule targets provided to Congress after implementing the Joint Confidence Level
- This is not because they are suddenly better project mangers at NASA, but they are better “project prognosticators” and more able to make more realistic targets using JCL than P-values

2019 Construction CPM Conference

San Diego, CA January 20-23, 2019

Integrated Cost/ Schedule Risk Analysis using Monte Carlo Simulation of a CPM Model

David T. Hulett, Ph.D. FAACE, Hulett & Associates, LLC
Michael R. Nosbisch, CCC PSP FAACE, Spire Consulting Group, LLC