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Alternative Risk Measures for Determining Program Reserves

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Background

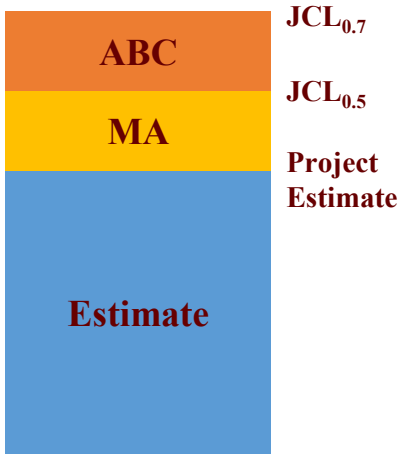
- NASA has requirements for how projects are to be managed
  - NASA 7120.5: NASA Program and Project Management Processes and Requirements
- Since 2005, NASA has required…
  - "project estimates shall include reserves, along with the level of confidence provided by the reserves."
- Current requirement
  - Projects must complete a joint cost and schedule confidence level (JCL) analysis prior to completing specific lifecycle reviews

Background

- NASA requires project be funded at a 50% joint cost and schedule confidence level (JCL)
  - Management Agreement (MA)

- In addition, Mission Directorates must hold budget at a 70% JCL
  - Agency Baseline Commitment (ABC)

- The JCL values are statistics calculated from the results of a Monte Carlo simulation
  - JCL values are quantile risk measures



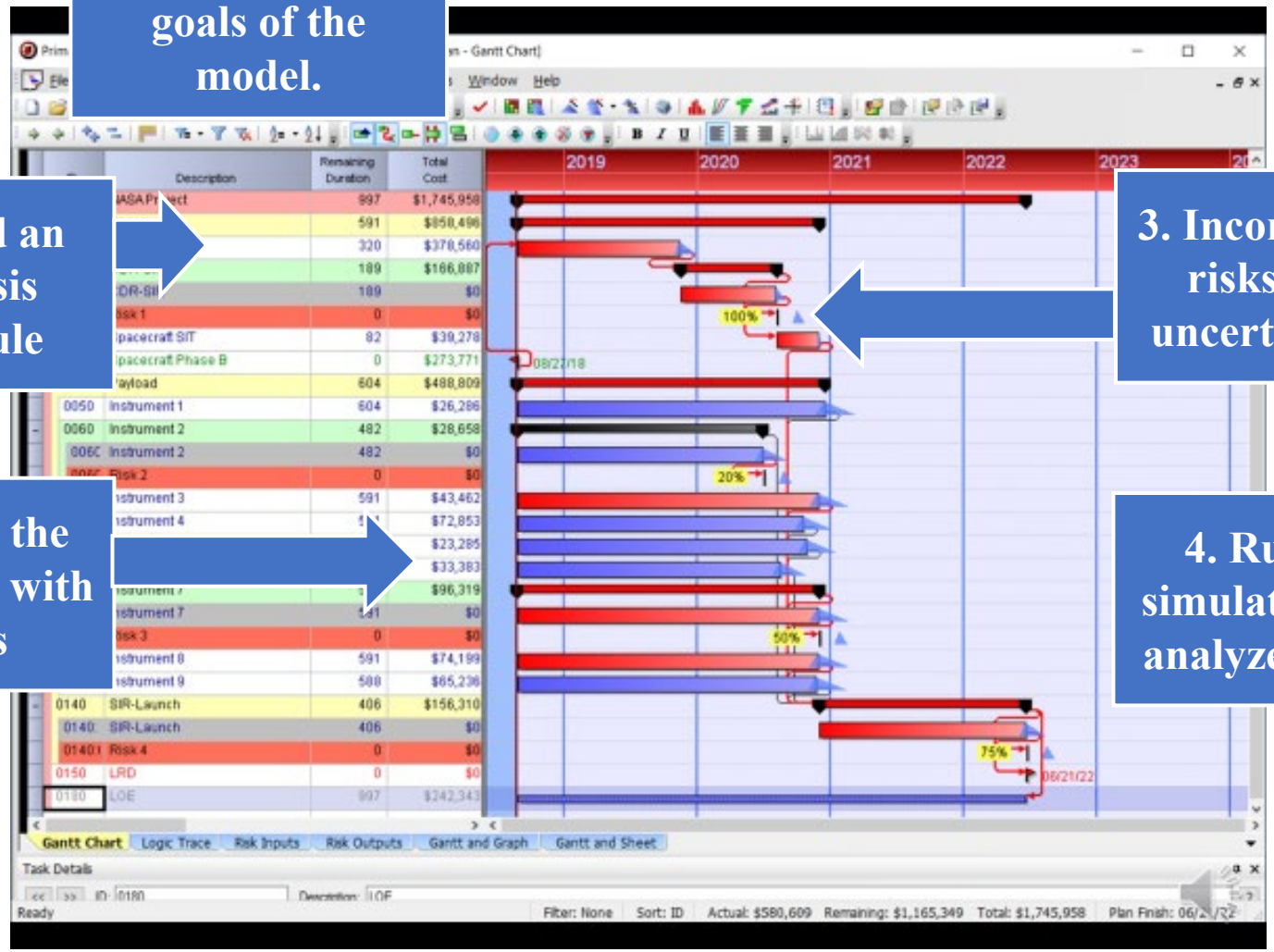
- This presentation examines the limitations of JCL as a risk measure and proposes superquantiles as alternatives

The JCL Model Process

1. Identify the goals of the model.

2. Build an analysis schedule

3. Load the activities with costs



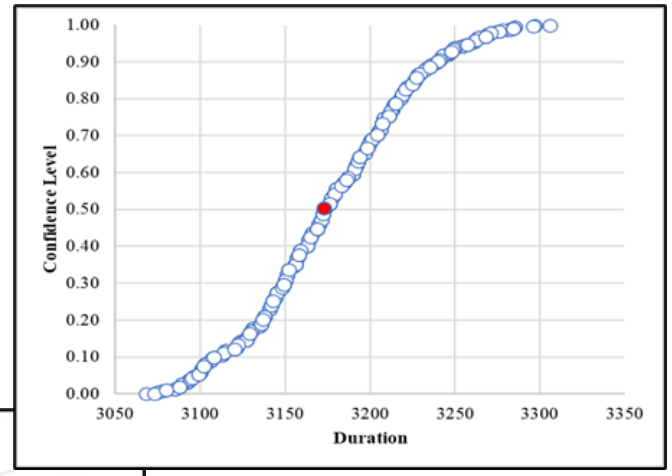
3. Incorporate risks and uncertainties

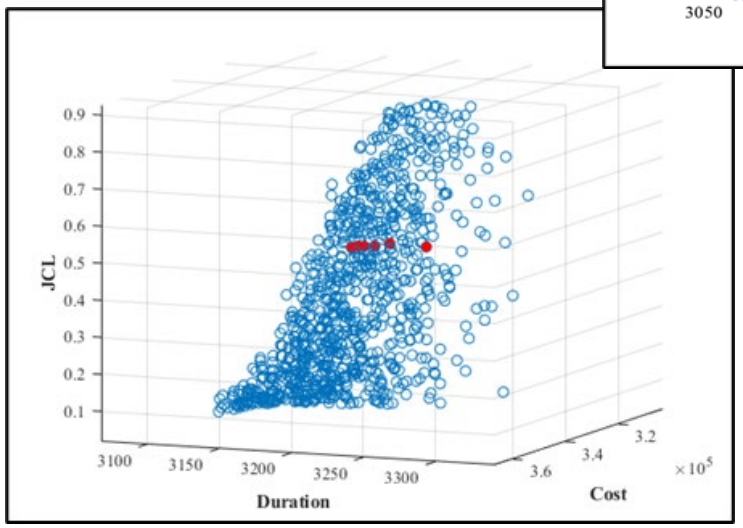
4. Run the simulation and analyze results

JCL Simulation Results

- Monte Carlo simulation performs 10,000 iterations
  - Outputs ordered pairs of project duration and total cost
- Univariate quantile risk measure
  - Analyzes one variable
  - Quantile with $\sigma = 0.5$ in red
  - Quantile is unique
- JCL is a Bivariate Quantile
  - Analyzes duration and cost jointly
  - JCL with $\sigma = 0.5$ in red
  - JCL_σ is not unique

Duration	Cost
3236	$349,173
3102	$322,528
3225	$338,130
3099	$320,908
3156	$321,951
3191	$330,580
3136	$329,443
3213	$326,518
3193	$337,711
3144	$325,124
3171	$325,051
•	•
•	•
•	•



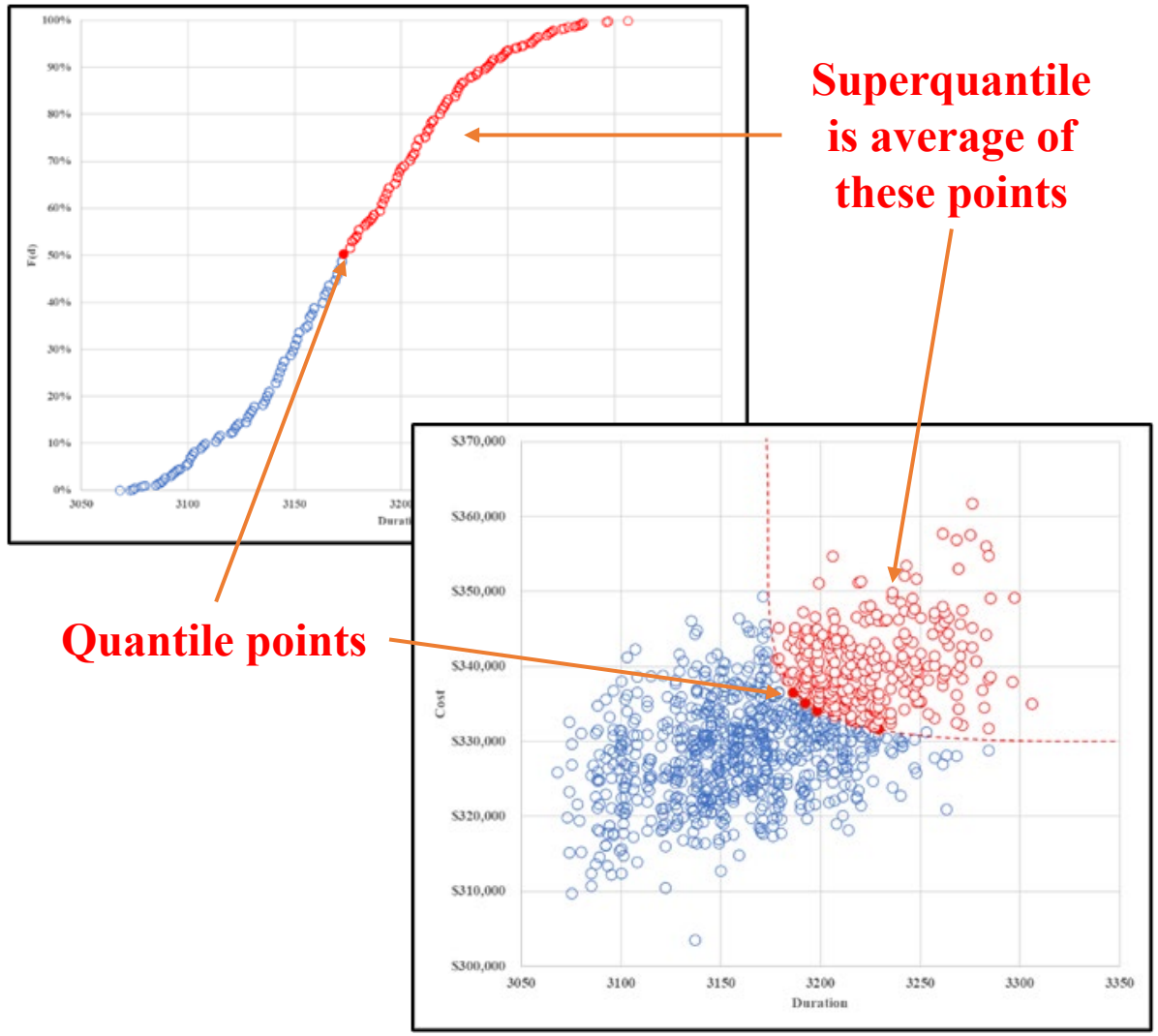


Quantiles and Superquantiles

- **Specified with a given confidence level, α.**

- **Univariate case**
  - **Quantile definition**
    - $Q_\alpha(\boldsymbol{X}) := min[x \in \mathbb{R} \mid (x) \geq \alpha]$
  - **Superquantile definition**
    - $\bar{Q}_\alpha(\boldsymbol{X}) := E[x \in \mathbb{R} \mid F(x) \geq \alpha]$

- **Multivariate case**
  - **Quantile definition**
    - $BQ_\alpha(\boldsymbol{X}) := \partial[X \in \mathbb{R}^k \mid F(X) \geq \alpha]$
  - **Superquantile definition**
    - $\overline{BQ}_\alpha(\boldsymbol{X}) := E[X \in \mathbb{R}^k \mid F(X) \geq \alpha]$
  - **Use BQ due to interest in bivariate case**

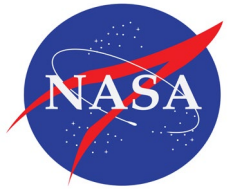


Coherent Risk Measures

- Artzner et al. (1999) defined four criteria for a coherent risk measure
  - Translation Invariance: $\rho(X + c) = \rho(X) - c$
  - Monotonicity: If $X < Y$ for each scenario then $\rho(X) < \rho(Y)$.
  - Positive Homogeneity: $\rho(cX) = c\rho(X)$
  - Sub-additivity: $\rho(X + Y) \leq \rho(X) + \rho(Y)$

- Quantile risk measures are not sub-additive
  - This is caused by one of the limitations of quantile risk measures
  - This leads to another limitation of quantile risk measures

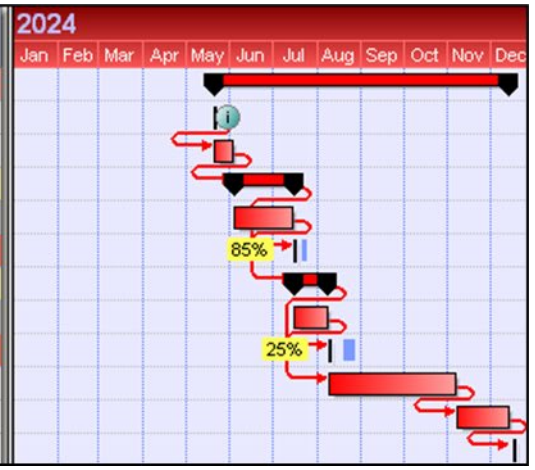
An Example



- Project installing solar arrays after delivery to the launch site
- The solar arrays must be installed and then tested
- Risk 1: a fixture may be broken impacting installation
  - Likelihood is 85%
  - Duration impact is uniform(5 days, 10 days)
  - Cost impact is uniform ($100, $150)
- Risk 2: solar arrays may fail a test impacting testing
  - Likelihood is 25%
  - Duration impact is uniform(10 days, 20 days
  - Cost impact is uniform($500, $1000)
- The other activities in the launch campaign are risk-free.

Example Results

ID	Description	Remaining Duration	Start	Finish	Remaining Cost	Preceding Tasks
0010	**Launch Campaign**	**149**	**05/21/2024**	**12/13/2024**	**$14,900**	
0020	S/C Arrives at KSC	0	05/21/2024	05/20/2024	$0	
0030	Preparations at KSC	10	05/21/2024	06/03/2024	$1,000	0020
0040	**Install Solar Arrays**	**30**	**06/04/2024**	**07/15/2024**	**$3,000**	**0030**
0040:	Install Solar Arrays	30	06/04/2024	07/15/2024	$0	
0040:	Broken fixture	0	07/16/2024	07/15/2024	$0	0040: B
0050	**Test Solar Arrays**	**18**	**07/16/2024**	**08/08/2024**	**$1,800**	**0040**
0050:	Test Solar Arrays	18	07/16/2024	08/08/2024	$0	
0050:	Failed Test	0	08/09/2024	08/08/2024	$0	0050: B
0060	Final S/C Tests	64	08/09/2024	11/06/2024	$6,400	0050
0070	Ground Operations	27	11/07/2024	12/13/2024	$2,700	0060
0080	Launch	0	12/16/2024	12/13/2024	$0	0070



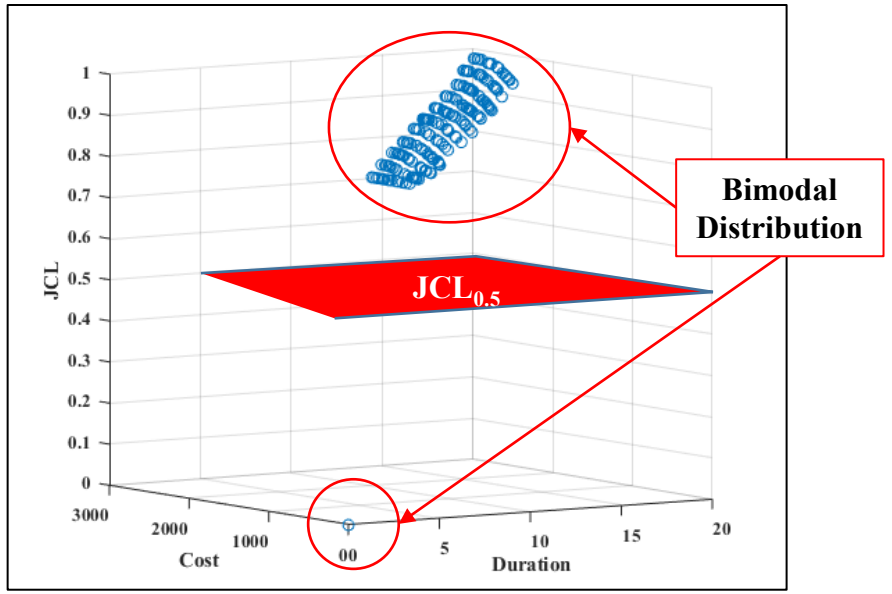
$JCL_{0.5}$	Duration	Cost
Risk1	**7 days**	**$824**
Risk 2	**0 days**	**$0**
Launch Campaign	**10 days**	**$1,127**

- **$JCL_{0.5}$(Launch Campaign) = $JCL_{0.5}$(Risk 1 + Risk 2)**
- **$JCL_{0.5}$(Risk 1 + Risk 2) > $JCL_{0.5}$(Risk 1) + $JCL_{0.5}$(Risk 2)**
- **So, JCL is not sub-additive**

JCL Limitation #1

- Modeling risks with likelihood and impact produces bimodal distributions

- Quantile risk measures ignore risk events in the tail of the distribution
  - $JCL_{0.5}$(Risk 2) in graphic
  - Likelihood = 0.25 < α = 0.5
  - All the risk impacts occur in the tail
  - No simulation results are in the $JCL_{0.5}$ area
  - So, $JCL_{0.5}$(Risk 2) = (0 days, $0)



Distribution of Risk 2

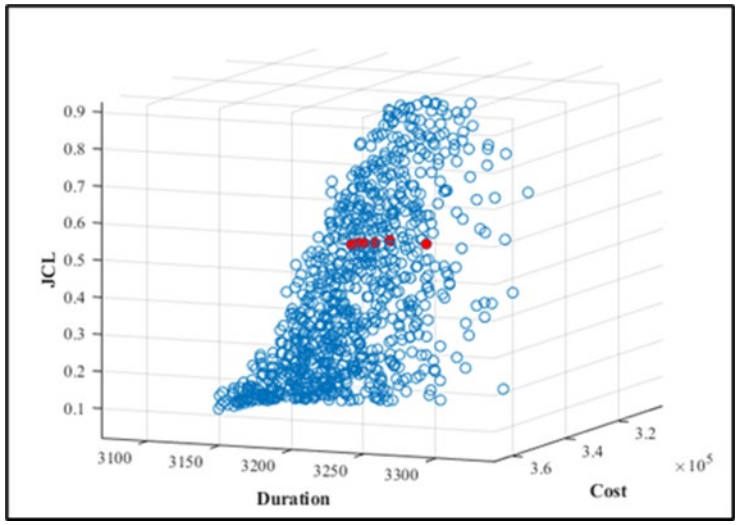
JCL Limitation #2

- Because JCL is not sub-additive
  - Analyst may underestimate the impact of a risk
  - Inadequate information relayed to decision maker
  - Faulty decisions are made

- From our example
  - $JCL_{0.5}$(Risk 2) = (0 days, $0)
  - *Appears* Risk 1 is responsible for impact to Launch Campaign
  - Project Manager applies extra resources to Installation
    - Mitigates Risk 1
  - No mitigation applied to Testing

JCL Limitation #3

- JCL value is not unique
  - Requires analyst to choose which JCL point to report



- All the JCL points are possible

- Some JCL points are *unfavorable*
  - Cost is too high and project will not be approved
  - Duration pushes launch outside the launch window

- A point is chosen to fit the analysts (or decision-makers) narrative
  - This is confirmation bias

Risk Measure Alternative

- To overcome JCL limitations…
  - Risk measure should be sub-additive
  - Risk measure should be unique for each α-level

- Superquantiles overcome the weaknesses of quantiles
  - Popularly referred to as Expected Shortfall in financial domain
    - "Expected Shortfall" has negative connotation in project management
  - Also referred to as Conditional Tail Expectation and Tail Value-at-Risk
  - "Superquantile" devised as an application-neutral term

- I will use the term "Super JCL" to refer to the JCL superquantile

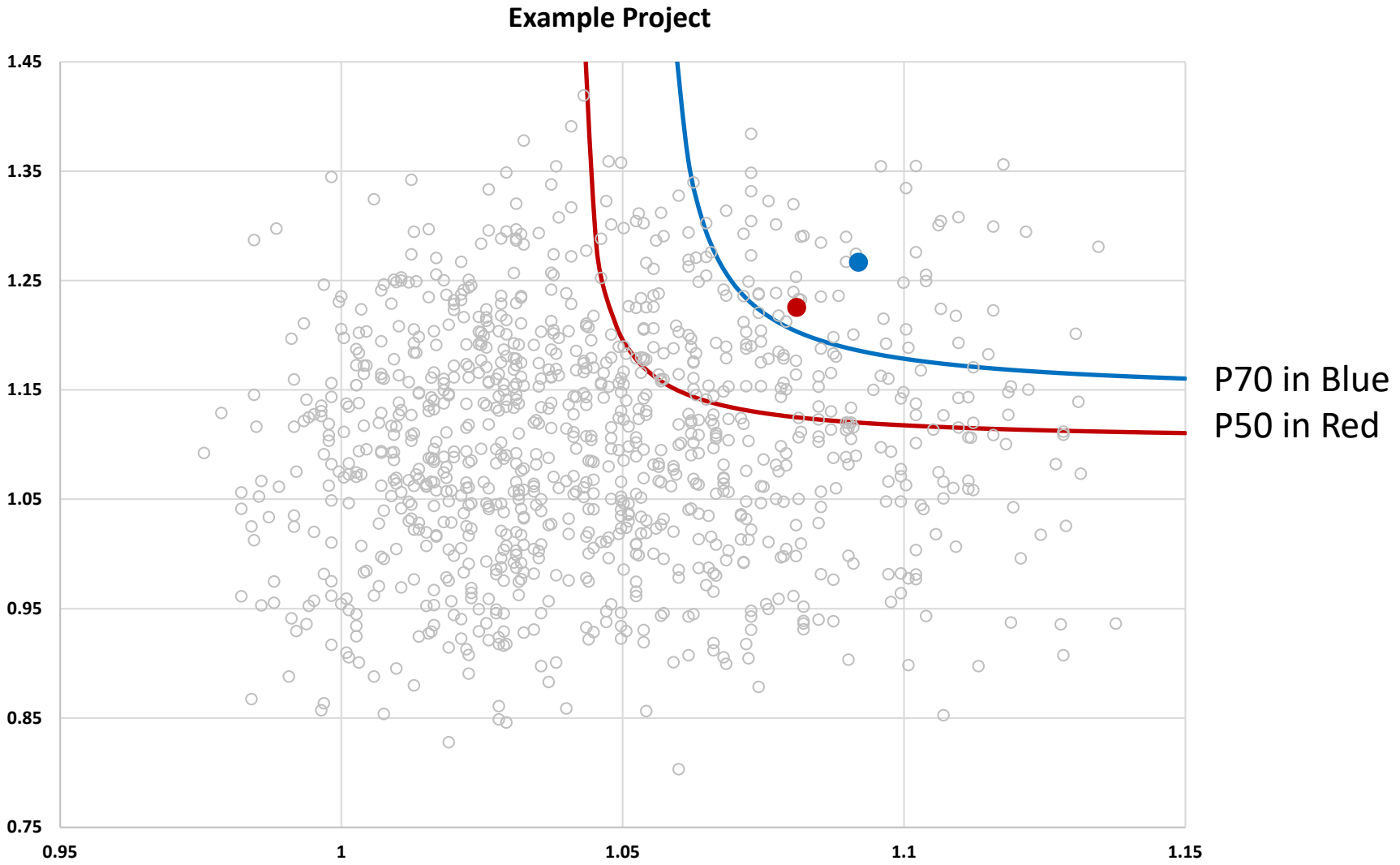
Benefit of Superquantiles

- Superquantiles include tail information
  - It is the expected value of outcomes in the tail
  - Brings attention to risks with impacts beyond α-level threshold
  - Communicates total risk impact to decision makers

- Superquantiles are sub-additive (most of the time)
  - Simplifies prioritization of risks based on impact
  - Facilitates allocation of reserves
  - Captures the diversification benefit

- Eliminates bias in choosing a JCL value
  - Superquantiles are unique for each α-level

JCL Curves and Super JCL Points



P70 in Blue
P50 in Red

Assess Superquantiles

- Obtained 10 JCL Models from NASA projects
- Ran Monte Carlo simulation with 1000 iterations
- Calculated risk measures
- $JCL_{0.5}$ compared to Super $JCL_{0.5}$
- $JCL_{0.7}$ compared to Super $JCL_{0.7}$

Alternative Assessment Data

	50% JCL		50% Super JCL		Duration Difference	Cost Difference
	Duration	Cost	Duration	Cost		
Project 1	1.50	1.52	1.54	1.60	3.9%	7.9%
Project 2	1.02	1.29	1.04	1.31	1.6%	2.5%
Project 3	1.14	1.02	1.19	1.06	4.6%	3.9%
Project 4	1.54	1.38	1.56	1.45	2.4%	7.0%
Project 5	1.03	0.97	1.05	1.01	1.6%	3.4%
Project 6	1.26	1.17	1.27	1.18	0.5%	1.0%
Project 7	1.42	0.99	1.50	1.06	7.7%	7.2%
Project 8	1.02	0.91	1.05	0.95	3.7%	3.8%
Project 9	1.06	0.99	1.08	0.99	2.5%	0.3%
Project 10	1.07	1.13	1.08	1.23	1.0%	9.3%

Alternative Assessment Data

	70% JCL		70% Super JCL		Duration Difference	Cost Difference
	Duration	Cost	Duration	Cost		
Project 1	1.57	1.54	1.57	1.66	0.1%	11.7%
Project 2	1.04	1.30	1.05	1.33	1.1%	2.1%
Project 3	1.17	1.04	1.21	1.08	4.3%	3.6%
Project 4	1.56	1.43	1.58	1.48	2.0%	5.5%
Project 5	1.04	1.00	1.06	1.02	2.0%	2.4%
Project 6	1.27	1.18	1.27	1.19	0.2%	0.9%
Project 7	1.46	1.04	1.54	1.10	8.6%	6.2%
Project 8	1.03	0.94	1.07	0.97	3.9%	3.1%
Project 9	1.07	0.99	1.09	0.99	2.3%	0.0%
Project 10	1.09	1.18	1.10	1.27	0.1%	8.3%

Conclusions

- Superquantile risk measure values were close to JCL values
  - Percent change was small

- Explanation
  - Projects were assessed early in their lifecycles
  - JCL Models dominated by uncertainties and not bimodal risks
  - Models from mature projects may show different results

- Project managers are “sensitive” to risk assessment results
  - If superquantiles were much lower than JCL, project may be overly constrained
  - If superquantiles were much greater than JCL, project may not be approved
  - Adoption of superquantiles may be eased by small difference from JCL values

Final Word

- Superquantiles are not intended to drastically change MA and ABC
  - JCL process improves performance more than JCL results

- Superquantiles remove existing limitations
  - Consider tail risk events
  - Communicate accurate information to decision makers
  - Eliminate confirmation bias

- Recommend adopting superquantile risk measures
  - Easy to calculate

- Future research?
  - Evaluate risk prioritization based on quantiles and superquantiles