# Alternative Risk Measures for Determining Program Reserves

**Louis Fussell**
**Johnson Space Center**
**Strategic Business and Integration Office**

**louis.r.fussell@nasa.gov**

# Background

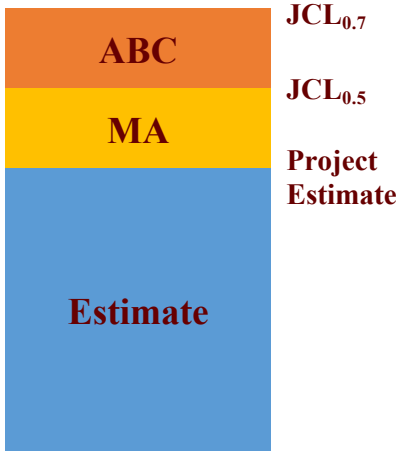
- NASA has requirements for how projects are to be managed
  - NASA 7120.5: NASA Program and Project Management Processes and Requirements

- 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
- Such statistics are generally referred to as risk measures
- This presentation examines the limitations of JCL as a risk measure and proposes alternatives



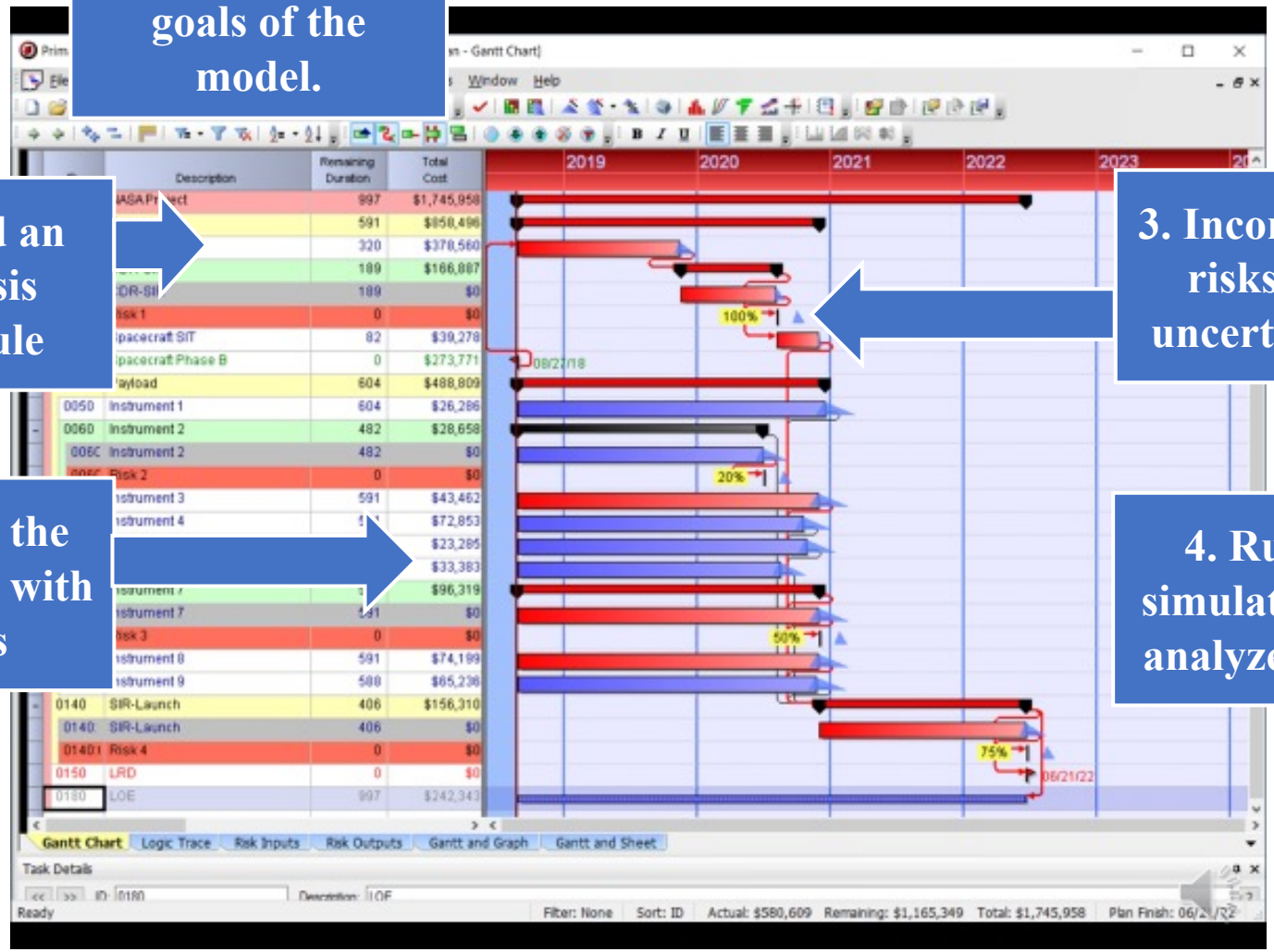

Example of Commitments

# 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 confidence level (CL)
  - Analyzes one variable
  - CL with $\sigma = 0.5$ in red
  - $CL_\sigma$ is unique
- Bivariate JCL
  - Analyzes both variables
  - JCL with $\sigma = 0.5$ in red
  - $JCL_\sigma$ 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 |
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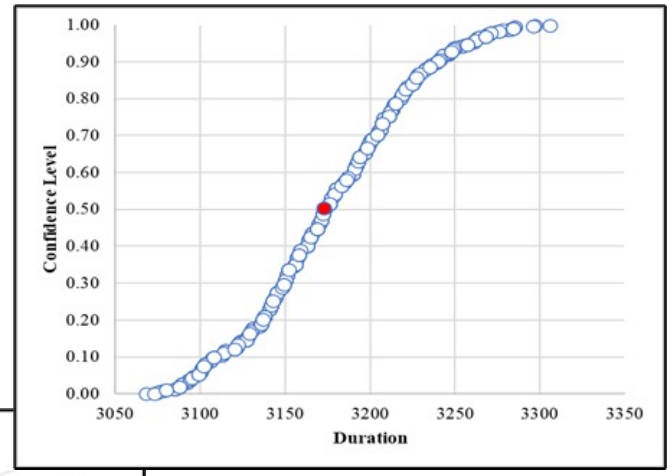
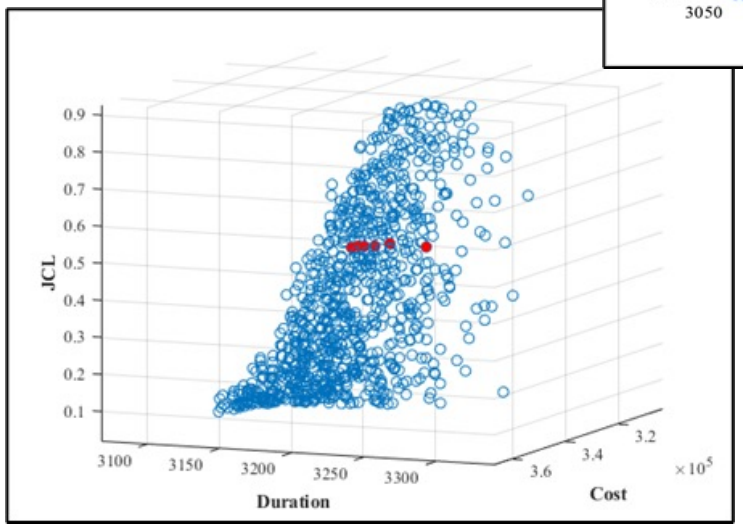


# Relevant Research

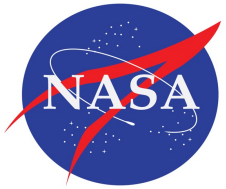
- Risk measures receive a lot of attention in financial sector
  - Investors want to protect against losing too much
  - NASA wants to protect against spending too much

- Financial sector relies on a risk measure called Value at Risk (VaR)
  - VaR is similar to JCL
  - Both are quantile risk measures

- Limitations of quantile risk measures
  - Do not consider tail risk events
  - Presents inadequate information to decision makers
  - Allows analyst bias to influence results

Request paper to see list of references

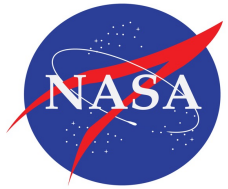
# Coherent Risk Measures




- 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

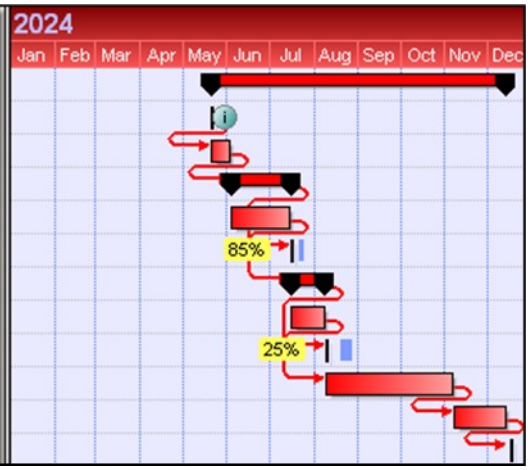
# An Example




- 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 |



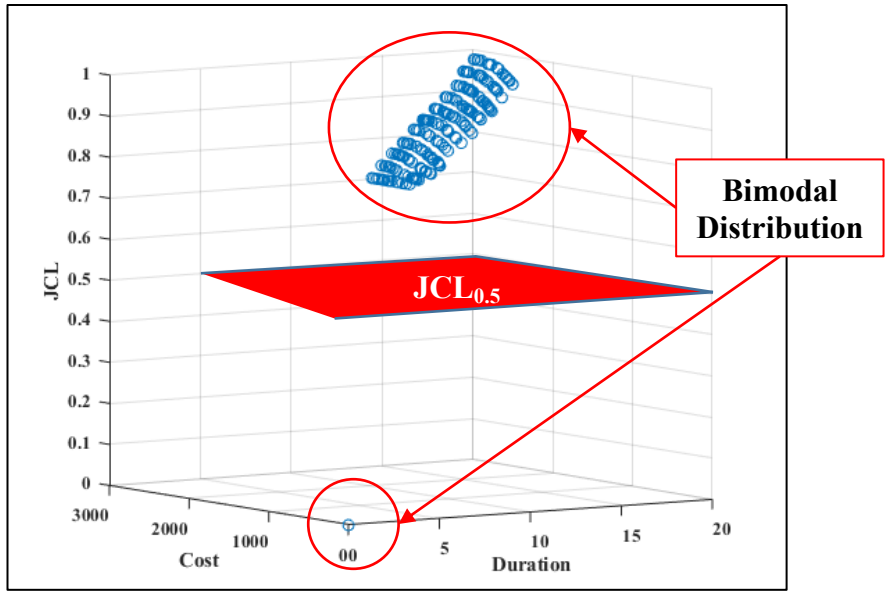

| $JCL_{0.5}$ | Duration | Cost |
|---|---|---|
| **Risk1** | **7 days** | **$824** |
| **Risk 2** | **0 days** | **$0** |
| **Launch Campaign** | **8 days** | **$931** |

- $JCL_{0.5}$(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

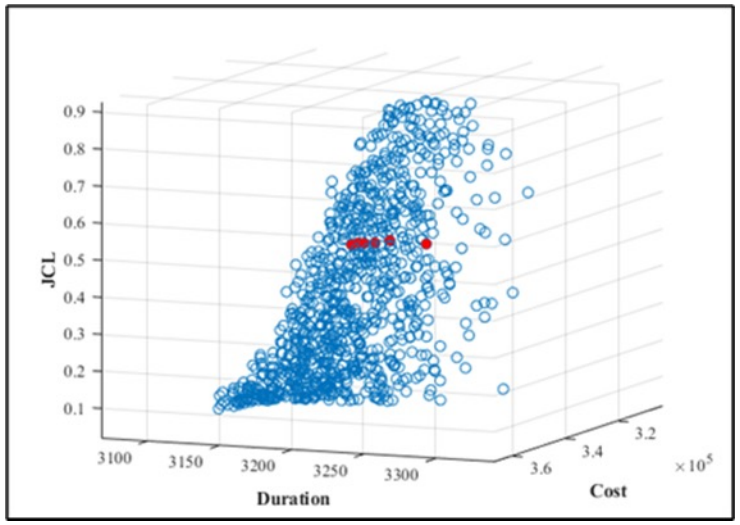
# JCL Limitation #2

- 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

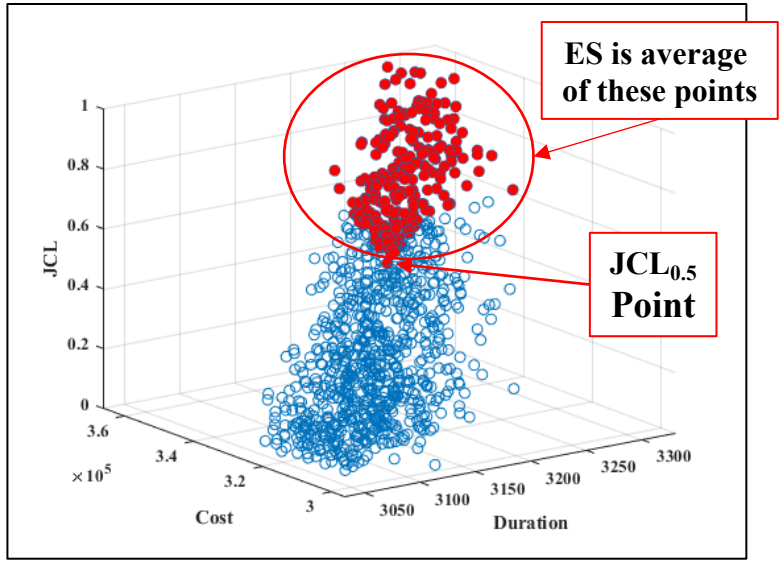


# Risk Measure Alternatives

- To overcome JCL limitations…
  - Risk measure should be sub-additive
  - Risk measure should be unique

- Expected Shortfall (ES) is a popular alternative to quantiles
  - ES is an average of all points greater than a baseline point
  - ES is sub-additive
  - If the baseline point is unique, so is ES

- The mean (μ) is also a viable alternative
  - It is unique and sub-additive
  - $\mu_{(x, y)} = (\mu_x , \mu_y)$



# Alternatives Considered

- Want alternatives to $JCL_{0.5}$ and $JCL_{0.7}$
- Alternative 1: $ES_{0.5}$ and $ES_{0.7}$
  - For it to be unique, standardize method for selecting JCL point
- Alternative 2: $\mu$ and $ES_{\mu}$
- Continuing example…

| | $JCL_{0.5}$ Duration | $JCL_{0.5}$ Cost | $ES_{0.5}$ Duration | $ES_{0.5}$ Cost | $\mu$ Duration | $ES_{\mu}$ Cost |
|---|---|---|---|---|---|---|
| Risk1 | 7 days | $824 | 9 days | $1023 | 6 days | $746 |
| Risk 2 | 0 days | $0 | 15 days | $2269 | 4 days | $567 |
| Launch Campaign | 8 days | $931 | 16 days | $2132 | 10 days | $1313 |

# Assess Alternatives

- Obtained 10 JCL Models from NASA projects
- Ran Monte Carlo simulation with 1000 iterations
- Calculated risk measures
- $JCL_{0.5}$ compared to $ES_{0.5}$ and $\mu$
  - Percentage change calculated
- $JCL_{0.7}$ compared to $ES_{0.7}$ and $ES_{\mu}$
  - Percentage change calculated

# Alternative Assessment Data

| | $JCL_{0.5,d}$ | $JCL_{0.5,c}$ | $ES_{0.5,d}$ | | $ES_{0.5,c}$ | | $\mu_d$ | | $\mu_c$ | |
|---|---|---|---|---|---|---|---|---|---|---|
| Project 1 | 5646 | $2,490M | 5840 | 3% | $2,743M | 10% | 5610 | -1% | $2,377M | -5% |
| Project 2 | 3371 | $222M | 3391 | 1% | $229M | 3% | 3355 | 0% | $218M | -2% |
| Project 3 | 4240 | $11,091M | 4344 | 2% | $11,129M | 0% | 4231 | 0% | $11,079M | 0% |
| Project 4 | 1645 | $762M | 1713 | 4% | $798M | 5% | 1640 | 0% | $755M | -1% |
| Project 5 | 3160 | $494M | 3364 | 6% | $536M | 8% | 3133 | -1% | $488M | -1% |
| Project 6 | 2739 | $1,100M | 2758 | 1% | $1,110M | 1% | 2730 | 0% | $1,090M | -1% |
| Project 7 | 2981 | $687M | 3055 | 2% | $711M | 4% | 2955 | -1% | $680M | -1% |
| Project 8 | 3368 | $487M | 3446 | 2% | $509M | 5% | 3355 | 0% | $478M | -2% |
| Project 9 | 1643 | $277M | 1724 | 5% | $291M | 5% | 1625 | -1% | $273M | -1% |
| Project 10 | 3192 | $335M | 3230 | 1% | $342M | 2% | 3175 | -1% | $332M | -1% |

| | $JCL_{0.7,d}$ | $JCL_{0.7,c}$ | $ES_{0.7,d}$ | | $ES_{0.7,c}$ | | $ES_{\mu,d}$ | | $ES_{\mu,c}$ | |
|---|---|---|---|---|---|---|---|---|---|---|
| Project 1 | 5750 | $2,645M | 5930 | 3% | $2,881M | 9% | 5807 | 1% | $2,670M | 1% |
| Project 2 | 3386 | $227M | 3410 | 1% | $232M | 2% | 3377 | 0% | $227M | 0% |
| Project 3 | 4302 | $11,115M | 4384 | 2% | $11,148M | 0% | 4333 | 1% | $11,122M | 0% |
| Project 4 | 1670 | $781M | 1744 | 4% | $810M | 4% | 1708 | 2% | $794M | 2% |
| Project 5 | 3273 | $515M | 3484 | 6% | $553M | 7% | 3332 | 2% | $530M | 3% |
| Project 6 | 2753 | $1,109M | 2765 | 0% | $1,117M | 1% | 2752 | 0% | $1,104M | 0% |
| Project 7 | 3015 | $703M | 3088 | 2% | $724M | 3% | 3033 | 1% | $706M | 0% |
| Project 8 | 3415 | $500M | 3484 | 2% | $522M | 4% | 3432 | 1% | $504M | 1% |
| Project 9 | 1696 | $284M | 1767 | 4% | $297M | 4% | 1704 | 0% | $287M | 1% |
| Project 10 | 3215 | $339M | 3247 | 1% | $345M | 2% | 3220 | 0% | $339M | 0% |

# Conclusions

- Alternative risk measure values were close to $JCL_{0.5}$ and $JCL_{0.7}$
  - Percent change was small
  - T-test showed that differences were insignificant
    - Small t-values and large p values

| | $ES_{0.5,d}$ | $ES_{0.5,c}$ | $ES_{0.7,d}$ | $ES_{0.7,c}$ | $\mu_d$ | $\mu_c$ | $ES_{\mu,d}$ | $ES_{\mu,c}$ |
|---|---|---|---|---|---|---|---|---|
| Average Change | 3% | 4% | 3% | 4% | -1% | -2% | 1% | 1% |
| t-value | 0.23 | 0.04 | 0.22 | 0.04 | 0.05 | 0.02 | 0.06 | 0.01 |
| p | 41.08% | 48.34% | 41.69% | 48.51% | 48.13% | 49.35% | 47.72% | 49.76% |

- 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

# Final Word

- Alternative risk measures not intended to change MA and ABC

- Alternative risk measures remove existing limitations
  - Consider tail risk events
  - Communicate accurate information to decision makers
  - Unique property eliminates confirmation bias

- **Recommend adopting μ and $ES_{\mu}$ risk measures**
  - Do not require standard method for selecting a baseline point
  - Easy to calculate

- Future research?
  - Evaluate risk prioritization based on different risk measures