



# Simplifying the Expert Elicitation Process

2019 NASA Cost & Schedule Symposium

---

Caleb Williams

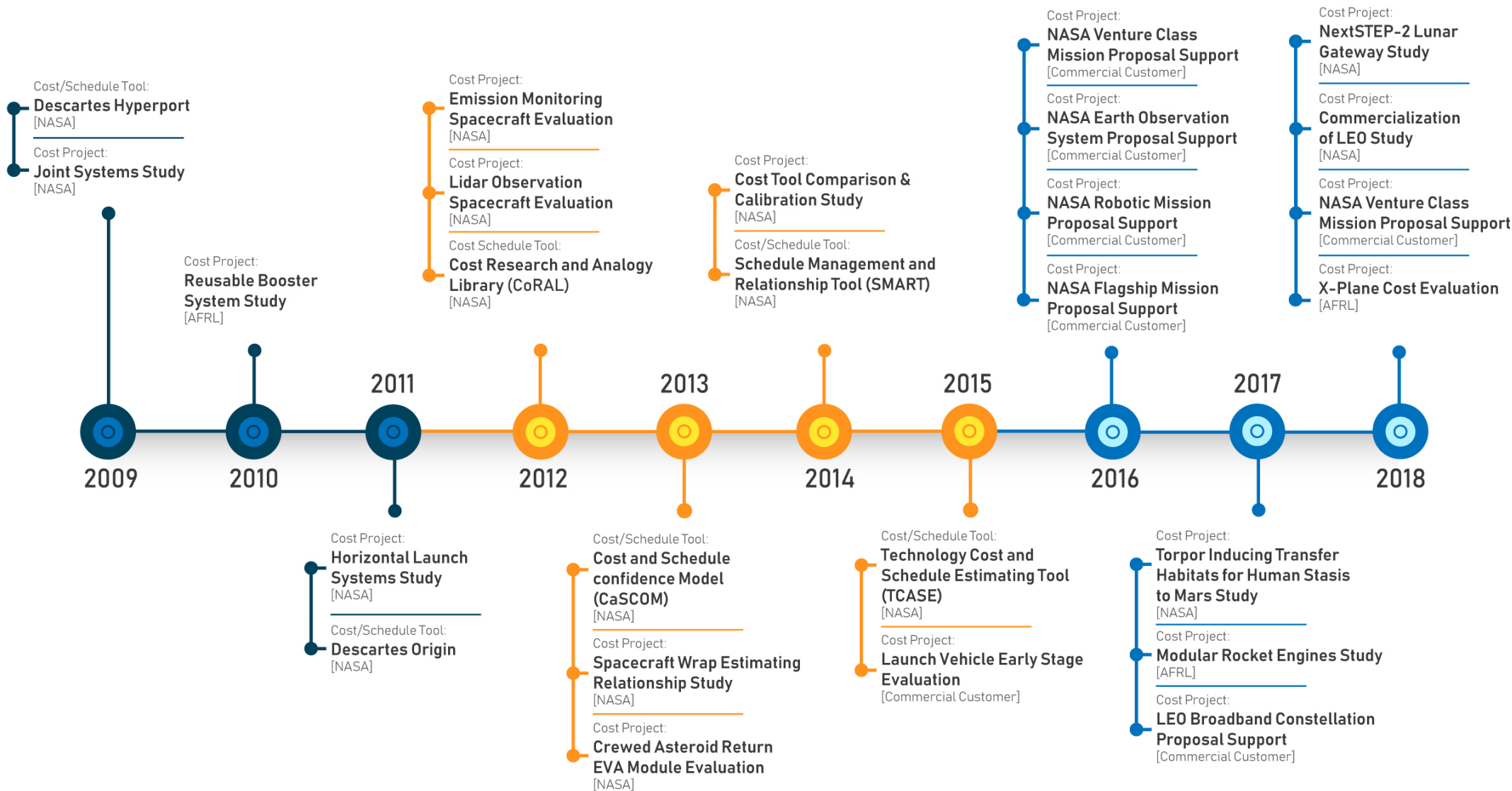
**QUANTITATIVE MODELING  
+ MARKET EXPERTISE**

---

**STRATEGIC INSIGHTS**



# SpaceWorks | History in the NASA Cost & Schedule Community





## Expert Elicitation Overview

**While the physical sciences are thought to be too thorough and exact to rely on the judgement of experts, the field of operations research is more pragmatic...**

- Dr. Olaf Helmer -



# Overview | What is Expert Elicitation?

- Expert elicitation is a process for **aggregating estimates from a panel of experts**
- It is a useful tool for developing estimates **when there exists insufficient data** or a **significant degree of uncertainty** – i.e., when traditional parametric or analogous approaches aren't possible
- Over the past 75 years, expert elicitation has been used to **yield fascinating insights into a wide-range of global problems:**



Economics



Healthcare



Nuclear Defense



Global Warming



Public Policy

# Overview | Types of Expert Elicitation

---

- A number of both **mathematical** and **behavioral techniques** have been developed to facilitate the creation of precise, aggregated expert estimates
- Behavioral approaches are focused on **bringing the group to a consensus estimate** through a variety of sociological techniques
  - These include the Delphi Process, SHELF Process, Trial Roulette Method, etc.
- Meanwhile, mathematical approaches use **statistical methods** to **aggregate expert estimates**
  - These include Simple Averages, Distribution Fitting, Opinion Pooling, etc.

**Many expert elicitation processes involve a combination of both behavioral and mathematical aggregation techniques**

# Overview | Traditional Expert Elicitation Process (SHELF)

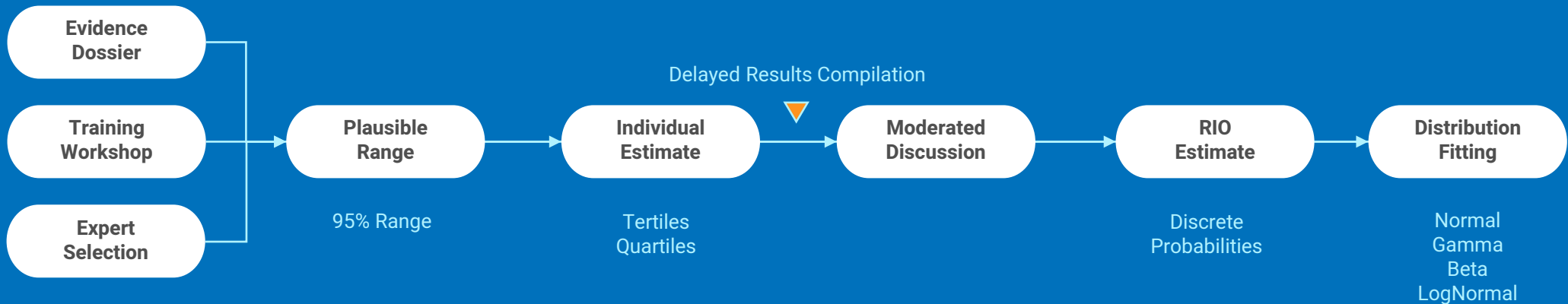
## ROLES

- Decision Maker
- Facilitator
- Normative Experts
- Domain Experts
- Stakeholders
- Analyst

## ARTIFACTS

- Evidence Dossier
- Training Materials
- Preliminary Estimate
- Individual Elicitation Results
- Group Discussion Notes
- Consensus Elicitation Results

## WORKFLOW





## Issues in Conventional Approaches

Numerous  
Roles &  
Artifacts

Complex  
Decision  
Trees

Specialist  
Training  
Required

Delayed  
Results  
Compilation

Cognitive  
Heuristics &  
Bias

**Poorly performed expert elicitation exercises are likely to be misinterpreted and further hurt the adoption of more suitable approaches**





## Simplifying the Process

# Simplifying | A Simplified Approach

- To make systematic **expert elicitation more accessible**, and **drive further adoption of such approaches**, SpaceWorks has developed a simplified approach to expert elicitation
- This new approach preserves many of the essential features of more complex elicitation methods, while simultaneously **reducing process overhead**, **required setup time**, and **decision points**
- The proposed Simplified Approach **incorporates three key elements**:

Element Name	Purpose
Modern Collaboration Tools	Enables real-time aggregation of expert responses and facilitates elicitation workshops with distributed teams
Mini-Delphi Games	Helps to mitigate cognitive heuristics and bias while reducing the required number of artifacts and roles
Opinion Pooling	Provides a flexible, statistical way for aggregating expert estimates without adding numerous decision gates



# Simplifying | Key Process Element #1: Modern Collaboration Tools

- Traditional expert elicitation requires a large number of **physical artifacts** (questionnaire responses, individual estimates, etc.)
- By using modern collaboration tools, such as Google Drive or SharePoint Online, the Simplified Approach **streamlines the data collection process** and creates a single source of record
- These tools can be used to **create simple forms** that enable **geographically disaggregated** teams to easily complete expert elicitation exercises
- Perhaps most importantly, they **enable a real-time feedback loop** so there is **no delay between estimating rounds**

Expert Elicitation Workshop #1

\* Required

Initials

Your answer

Task Number \*

Your answer

Estimate Worst Case \*

Your answer

Estimate Best Case

Your answer

Estimate Most Likely

Your answer

Assumptions/Reasoning (Optional)

Your answer

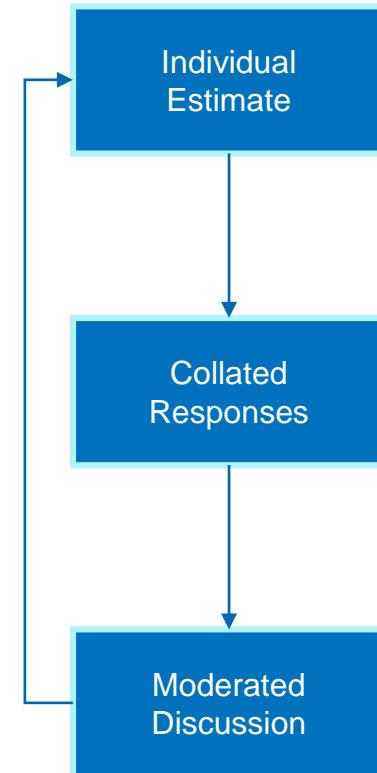
SUBMIT

Never submit passwords through Google Forms.

**Example Modern Collaboration Form (Google Drive)**

# Simplifying | Key Process Element #2: Mini-Delphi Games

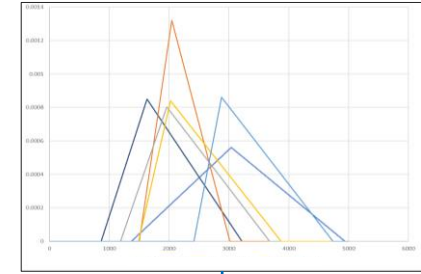
- Mini-Delphi games employ a similar process to the traditional Delphi collection method, but in a **simpler format**
- The approach is **relatively simple**:
  - The process begins with each participant submitting an anonymous individual estimate and any assumptions made
  - Next, the median collated estimate is displayed and a moderator leads a short discussion, introducing any assumptions made by participants
  - After the discussion period, respondents are asked to submit an updated estimate
- This method enables a type of **behavioral consensus** to be reached, **without forcing an artificial point of agreement**
- By limiting the information flow to the “why” but not the “what”, Mini-Delphi games help **reduce cognitive heuristics** and **bias**
  - Similar to traditional Delphi techniques, but with less overhead cost



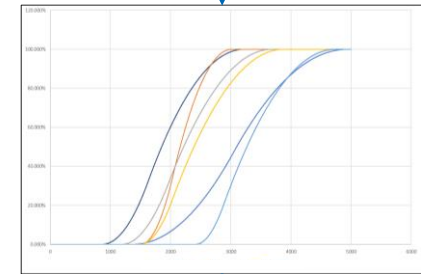
**Mini-Delphi  
Process**

# Simplifying | Key Process Element #3: Opinion Pooling

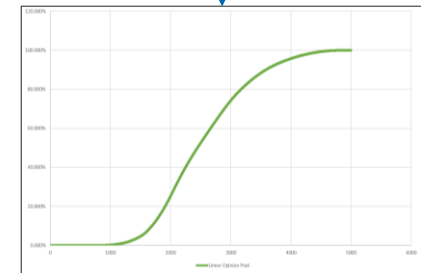
- While behavioral consensus generating techniques are critical to the overall process, it is **unrealistic for expert opinions to converge on a specific point**
- Opinion pools offer a **statistical basis for aggregating expert opinions** beyond behavioral consensus alone
  - They additionally offer the ability to weight individual respondent estimates based on a variety of factors
- The technique involves turning expert probability distributions (in this case, a Triangle Distribution) into **Cumulative Density Functions** (CDFs), which **can then be averaged**
- The Simplified Approach calls only for the use of **Linear Opinion Pools**, though more advanced approaches can also be used



Raw Respondent Distributions



Respondent CDFs



Combined Linear Opinion Pool

# Simplifying | Simplified Expert Elicitation Process

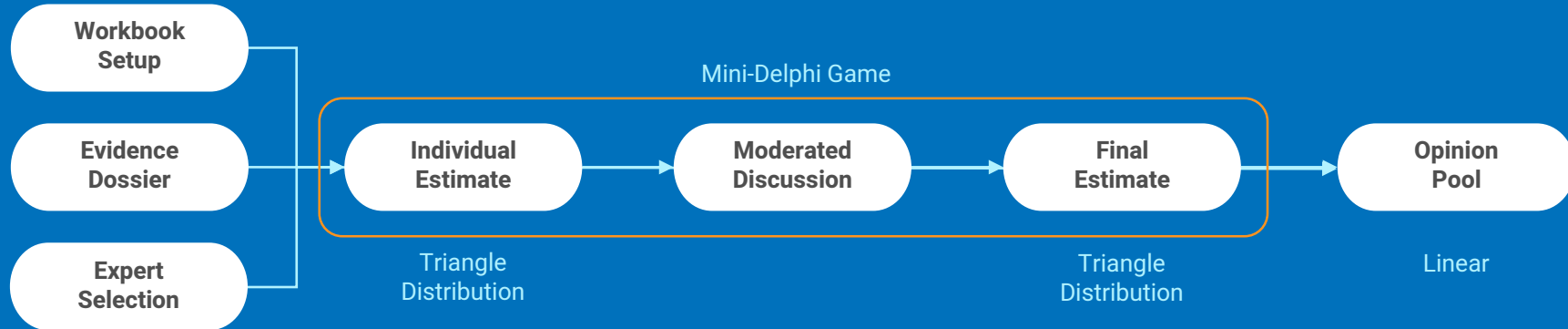
## ROLES

- Facilitator
- Analyst
- Subject Matter Experts

## ARTIFACTS

- Evidence Dossier
- Online Workbook

## WORKFLOW







The goal of the simplified approach is to eliminate overhead and decision gates in an effort to drive responsible adoption of expert elicitation





## Case Study: Reusable Spaceplane

- As part of an ongoing study, SpaceWorks was tasked with creating an **estimate of turnaround times for a reusable spaceplane vehicle**
- Six individual experts were identified and asked to participate in the Simplified Approach for expert elicitation to **estimate man-hours required for each task** involved in the vehicle turnaround
  - Nearly 200 maintenance activities were condensed into 20 individual tasks that encompassed the entirety of the vehicle's turnaround operations

---

## Task 2.4 – Perform Servicing/Closeout

---

2.4.1 Drain and flush fluid systems

2.4.2 Replenish, fill, or verify fluids and gas commodities (including chemical purity)

2.4.3 Lubricate and adjust subsystems as required

2.4.4 Perform cleaning close-out

2.4.5 Remove any access hardware or other non-flight hardware

2.4.6 Perform close-out photography

...

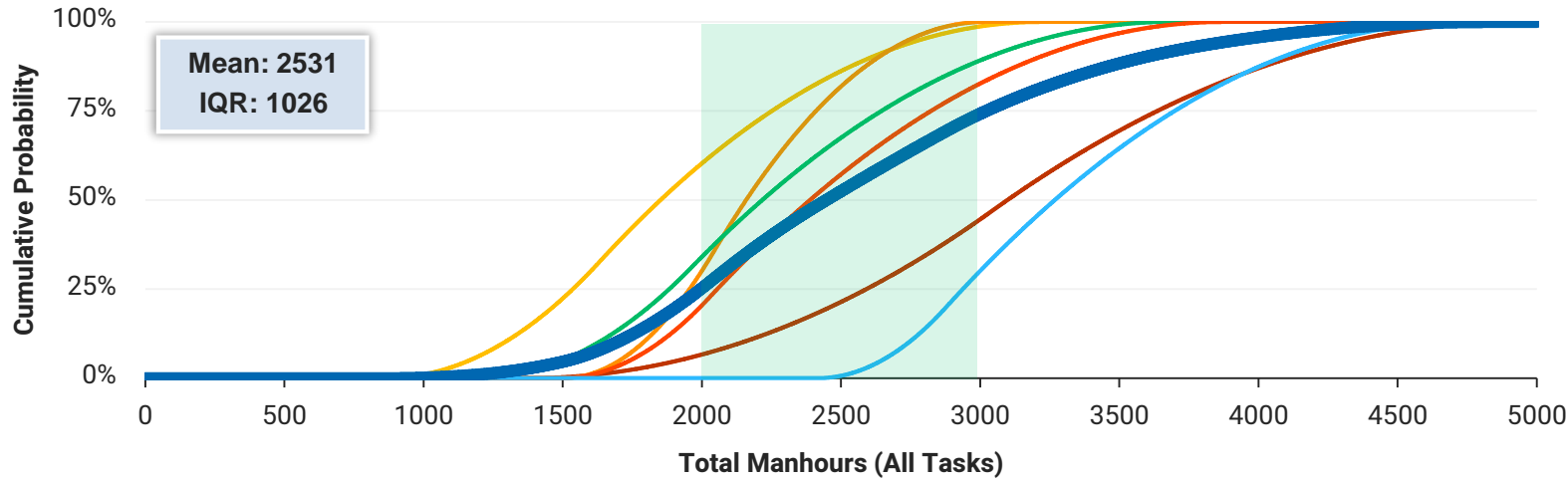
---

# Case Study | Reusable Spaceplane Turnaround Operations



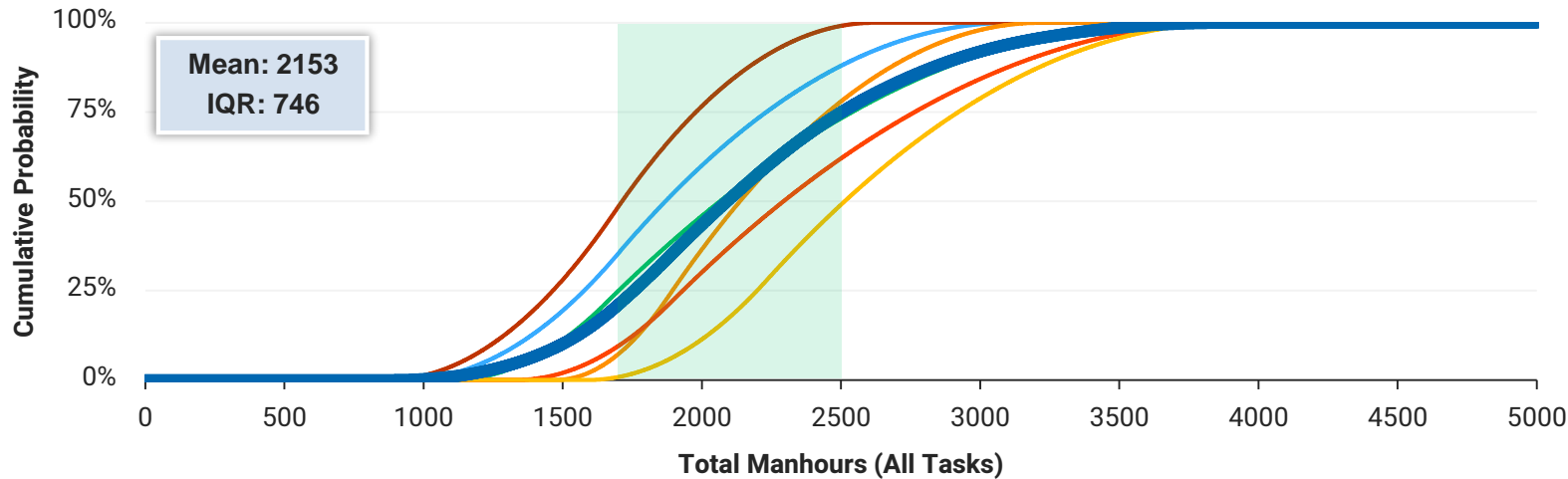


# Case Study | Results Summary



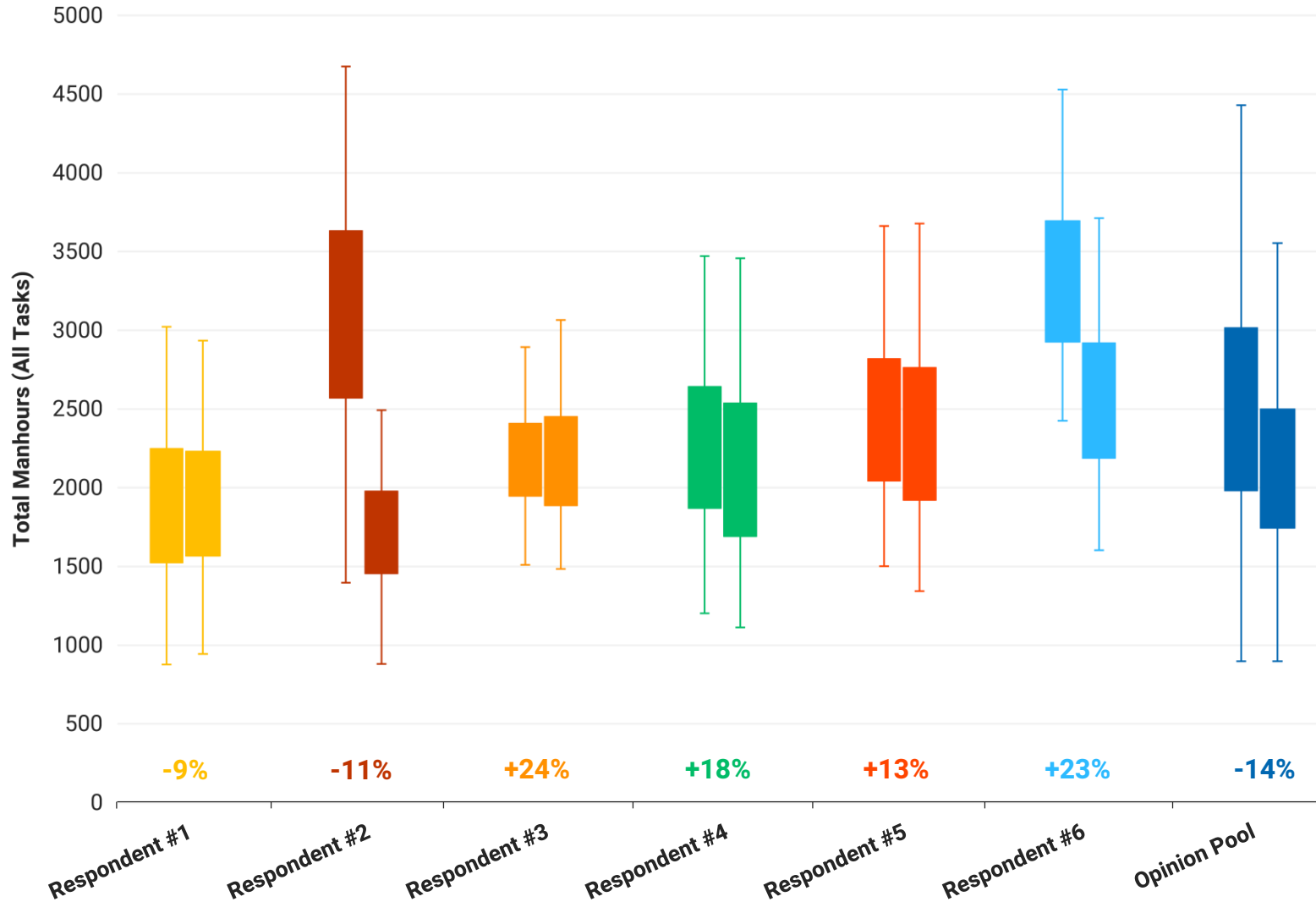
The Simplified Approach had a **significant impact on group consensus** and the actual **manhours estimate**

The **mean manhours estimate was reduced by nearly 15%** in Game B, a sizable shift from the initial estimate



More importantly, the **interquartile range shrunk by 27%**, demonstrating a much greater degree of respondent consensus

# Case Study | Variation Across Games

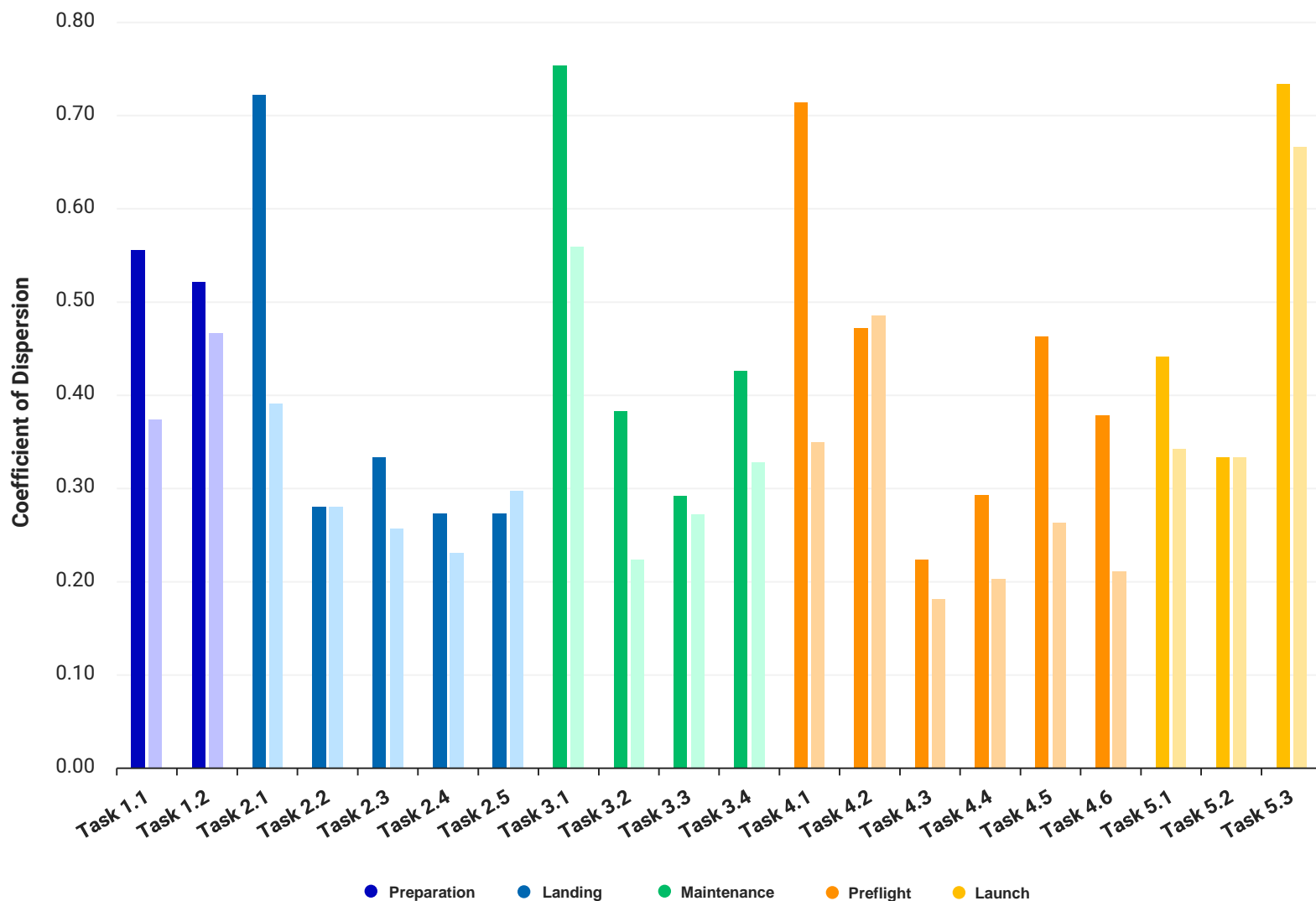


The coefficient of dispersion provides insight into **how certain experts are about their estimate**

Respondents in this case actually had **greater variation in Game B as compared to Game A**

Despite greater variation within individual estimates, the **consensus estimate has a lower coefficient of dispersion in Game B**

# Case Study | Consensus in Tasks

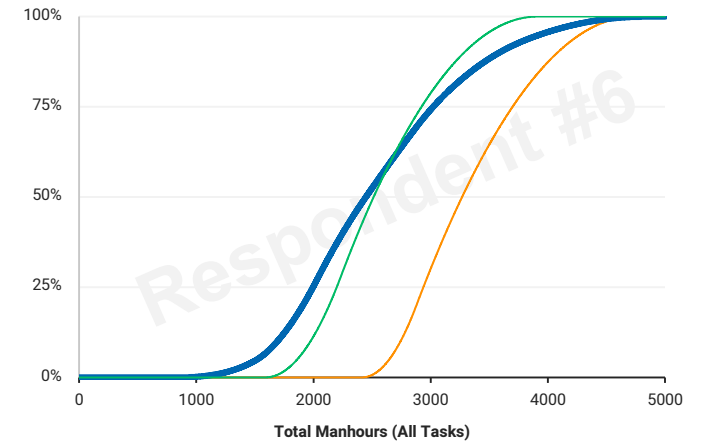
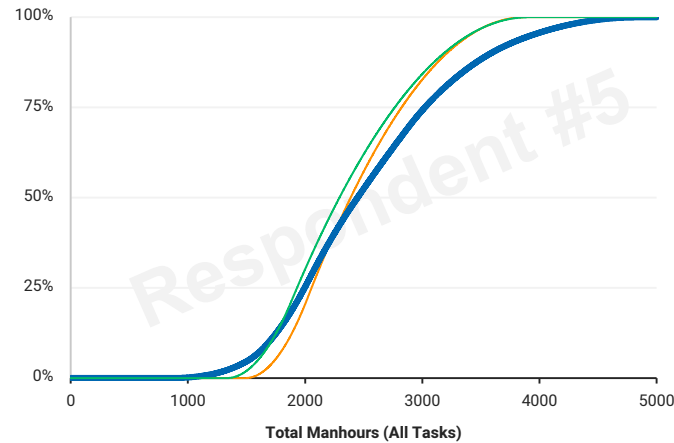
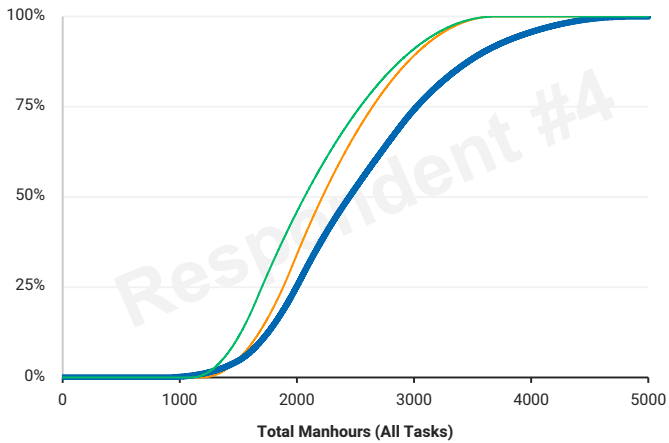
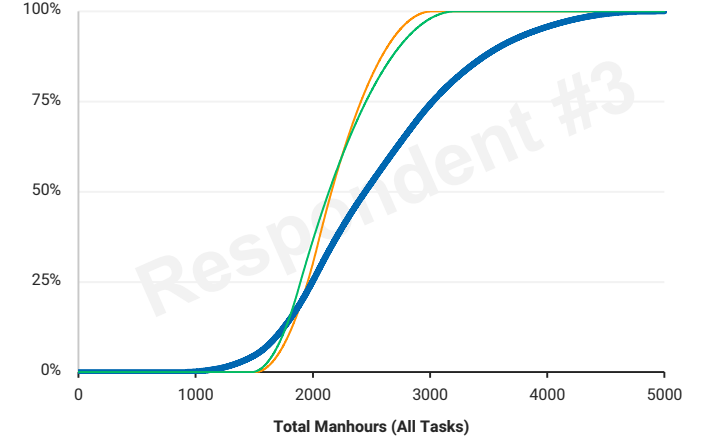
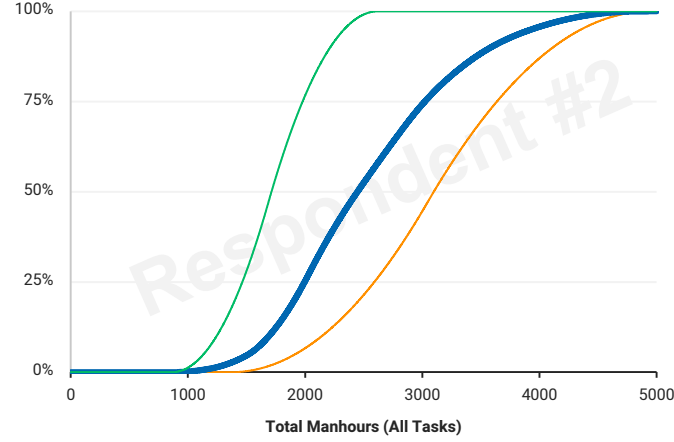
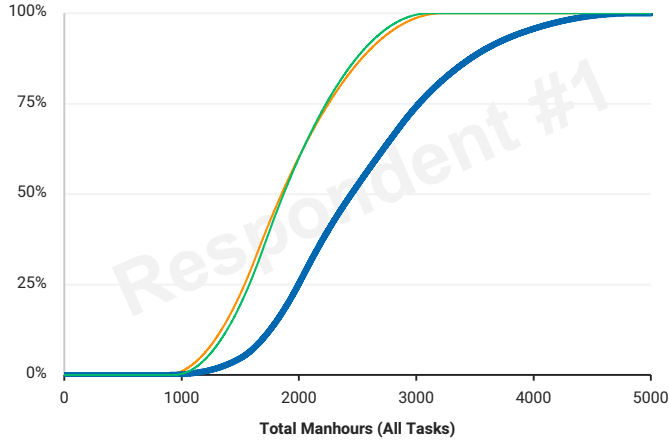


It can also be useful to look at the **coefficient of dispersion** at the **task level**

Across all tasks, the average coefficient of dispersion **dropped by over 20% between Game A and Game B**

A lower coefficient of dispersion at this level sheds insight into why **Game B overall showed greater consensus**

# Case Study | Individual Respondent Distributions



● Game A ● Game B ● Opinion Pool

# Case Study | Optimism Bias

- At the task level, we find that most participants were relatively centered in their estimates, though some individuals did show a **distinct optimism bias**
  - Estimation preferences were more prevalent in Game A, with four respondents trending optimistic (responding below the group mean 60% or more of the time)
  
- Only **two respondents showed an overall personal estimation bias** across both games (responding above or below the group mean more than 60% of the time)

Respondent	Game A		Game B		Overall Trend
	Below Group Mean	Above Group Mean	Below Group Mean	Above Group Mean	
#1	16	4	14	6	Optimistic
#2	12	8	11	9	-
#3	15	5	13	7	Optimistic
#4	12	8	10	10	-
#5	10	10	10	10	-
#6	9	11	9	11	-



- The results presented show **significant potential for identifying** (and potentially correcting) **additional cognitive bias** present in the expert elicitation process
- While not fully explored in this presentation, **evaluating the integral of personal respondent distributions** may provide substantive insight into:
  - Conservatism Bias
  - Leadership Bias
  - Group Think
  - Default Effect

**Measuring and resolving cognitive bias in expert elicitation is an intriguing field of future research**

## Case Study | Worth It?

- At first glance, it is **tempting to simply take the median of** the expert's point estimates
- As seen in the table below, the simplified approach provides substantially different results, with the end result varying by nearly 30%
  - This is because an aggregate median most likely estimate does not account for the distribution tails

	Sum of Median Most Likely	Opinion Pool Median Value	% Difference
Game A (All Tasks)	1894	2531	- 34%
Game B (All Tasks)	1669	2153	- 29%

- Considering the cost of a 30% delta in a cost, schedule, or risk estimate, this approach shows promise as a **low-overhead, high value-add method** for conducting expert elicitation



The proposed simplified approach captures many of the benefits of more thorough methods, while reducing process complexity





## Takeaways

## Takeaways | Conclusions

---

- Expert elicitation is a useful tool for developing estimates **when there exists insufficient data** or a **significant degree of uncertainty**
- Current expert elicitation approaches are **relatively complex**, require a **large number of roles/artifacts**, and can be **expensive to conduct properly**
- The proposed simplified approach incorporates many of the essential features of more thorough elicitation approaches while **reducing overhead requirements** and **decision gates**
- A case study using this new method to estimate turnaround time for a reusable spaceplane indicated **group consensus improved by almost 30%**

**The proposed approach shows great promise as a low-overhead,  
High value-add method for expert elicitation**



## Takeaways | Final Thoughts

---

- The primary goal of this approach is to **drive adoption of responsible expert elicitation methods**
  - While this method may not provide a more accurate or systematic approach than traditional techniques, it is less expensive and more accessible
- Perhaps the most intriguing finding of this study was that this approach may provide the means to **identify cognitive bias** present in the expert elicitation approaches
- If cognitive bias can be identified based on personal respondent distributions, they may also be able to **be measured** and **resolved**

**Future research from SpaceWorks on this topic will involve evaluating techniques for identifying, measuring, and resolving cognitive bias**

Authors:

## **Caleb Williams**

Lead Economic Analyst

[caleb.williams@spaceworks.aero](mailto:caleb.williams@spaceworks.aero)

## **Bill Doncaster**

Senior Systems Engineer

[bill.doncaster@spaceworks.aero](mailto:bill.doncaster@spaceworks.aero)

Illustrations by: **Davin Gerber, Lorena Carapaica**

