# A Quantitative Approach to Perform Expert Elicitation for Space Communication System Design and Risk Analysis: Methodology and Experimental Results

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# Outline

- Research context and motivation
- Why expert opinion?
- Expert opinion methodology
  - Probabilistic Thinking
  - Calibration
  - Elicitation
- Experimental results
  - Students
  - JPL Engineers
- Conclusions

# Research context

- The expert elicitation methodology presented is part of Ms. Babuscia PhD dissertation on "Statistical Risk Estimation for Communication System Design"
- Spacecraft are composed of different subsystems and there exist multiple relationships among them
- The design of spacecraft is a time evolving process during which a lot of changes can happen
- Different studies reveal that during the design:

"*Significant* ***deviations from expected mass, power, cost*** *or performance for any element of the spacecraft.*"

- Communication system is a key driver in spacecraft sizing (mass fraction up to 28%), in some applications (commercial satellites, relay satellites for space exploration, small satellites)
- The causes of deviations divided into two main categories:
  - Deviations due to lack of human interaction
  - Deviations due to **lack of knowledge**

# Research motivation and objective

- A lot of work done to overcome lack of human interaction among engineers, (facilities like JPL TeamX or ESA CDF).

Engineers in the Project Design Center during one of the daily TeamX sessions. Courtesy of: (TeamX) [4].

Engineers during one of ESA CDF sessions. Courtesy of: (CDF). **[5]**

- **Less work done to overcome the lack of knowledge**
- Current approach based on margins (contingency) which can lead to:
  - Solutions that are too conservative (less efficient)
  - Solutions that are too risky

Consequence: redesign

## Research objective:

**What?**

- Develop a mathematical approach to quantify the likelihood that a design of a space communication system would meet the spacecraft and mission constraints when the design matures

**Why?**

To reduce/avoid the cost of redesign

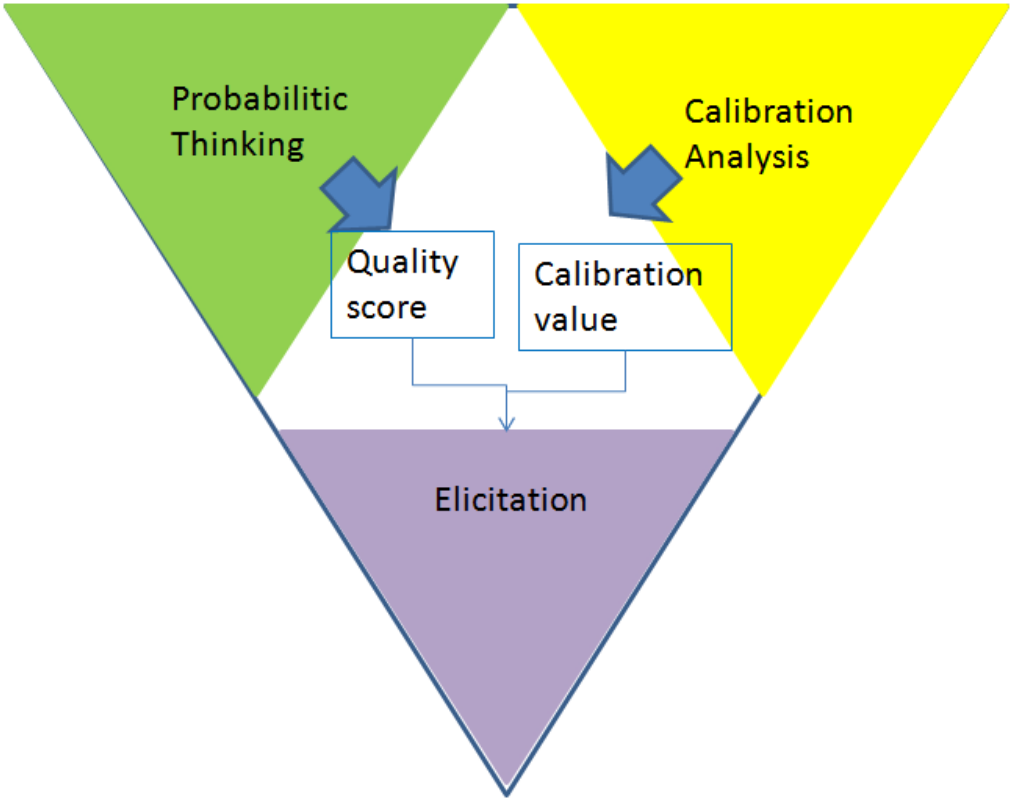
# Why expert opinion?

- To assess the likelihood of exceeding design constraints, 2 possible statistical approach can be used:
  - Frequentist approach: data
  - Subjective approach: expert opinion

- Expert opinion approach is generally preferred in the following cases:
  - Limited amount of empirical data
  - Completely new components/technology
  - When the main driver in mass and power is given by the technological evolution of the components (example: processors)

# Expert model: Objectives and Philosophy

- Objectives
  - Develop a process to incorporate expert opinion in the risk analysis framework.
  - Develop a methodology with relative metrics to calibrate expert opinion and to quantify its quality
  - Identify a technique to compose multiple expert opinions into an unique estimate
- Philosophy
  - Expert interview in 3 parts
    - Probabilistic thinking
    - Calibration
    - Elicitation



# Expert model: probabilistic thinking

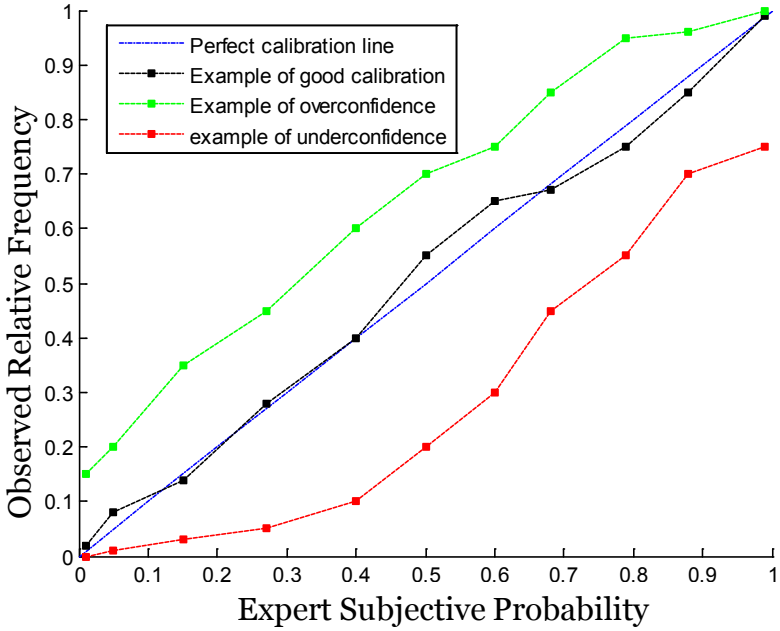
- Tversky and Kahneman discovered that when people judge probabilities they often use heuristics which can cause systematic deviations from the optimal solutions (biases).
- Our probabilistic thinking interview aims to discover through specific questions how sensible are the experts to those biases.
- 16 questions (20-30 minutes time).
- Biases analyzed: judgment by availability, judgment by representativeness, law of small numbers, anchoring, coherence, hindsight bias.
- Probabilistic Thinking can be used by any other scientist in any other field of research to assess if the expert is able to model phenomena in a probabilistic way.
- Total score and Quality index:

$$S = \sum_{i=1}^{16} s_i \qquad 0 \le S \le 100 \qquad Q = \frac{S}{100} \qquad 0 \le Q \le 1$$

Linda is 31 years old, single, outspoken and very bright. She majored in philosophy. As a student, she was deeply concerned with issues of discrimination and social justice and also participated in anti-nuclear demonstrations. Please tick the most likely alternative:
1. Linda is a bank teller
2. Linda is a bank teller and is active in the feminist movement.

# Expert model: calibration

- Calibration is focused on the specific nature of the problem, and it tries to check if the expert tends to underestimate or overestimate quantities.
- Calibration needs to be reformulated if a researcher wants to perform an expert elicitation in a different field
- It is done in term of point estimation
- 17 questions (20-30 minutes)




- Calibration question

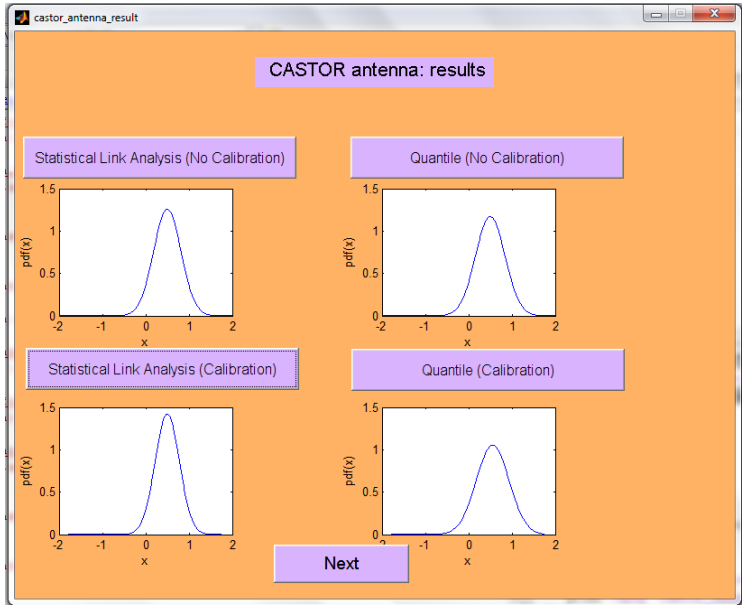
A rigid antenna in band X has a gain of 62dB. What is the expected mass value?

- Single calibration index and total index

$$c_i = \frac{e_i - r_i}{r_i} \qquad C = \frac{\sum_i c_i}{n} \quad -1 \le C \le 1$$

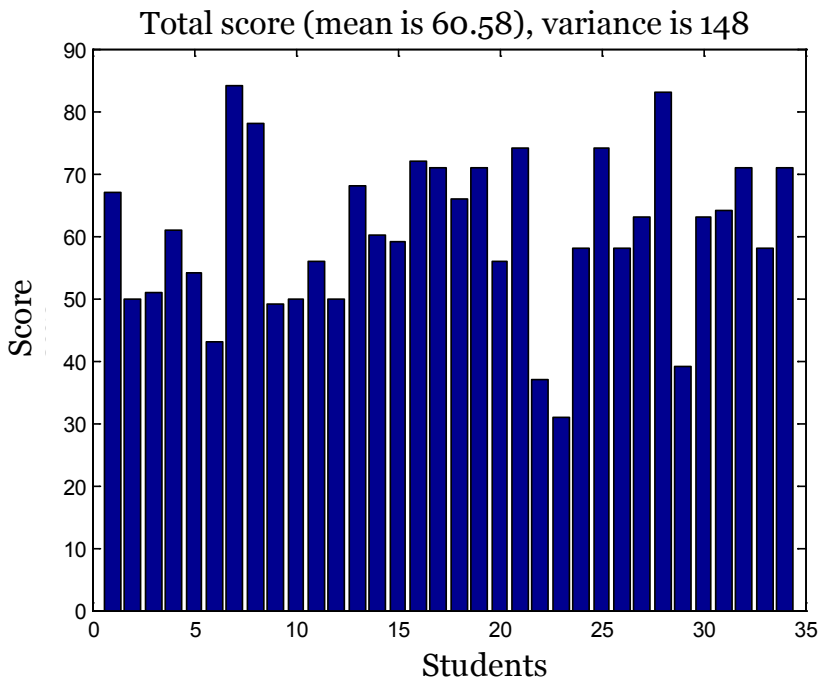
# Expert model: expert elicitation

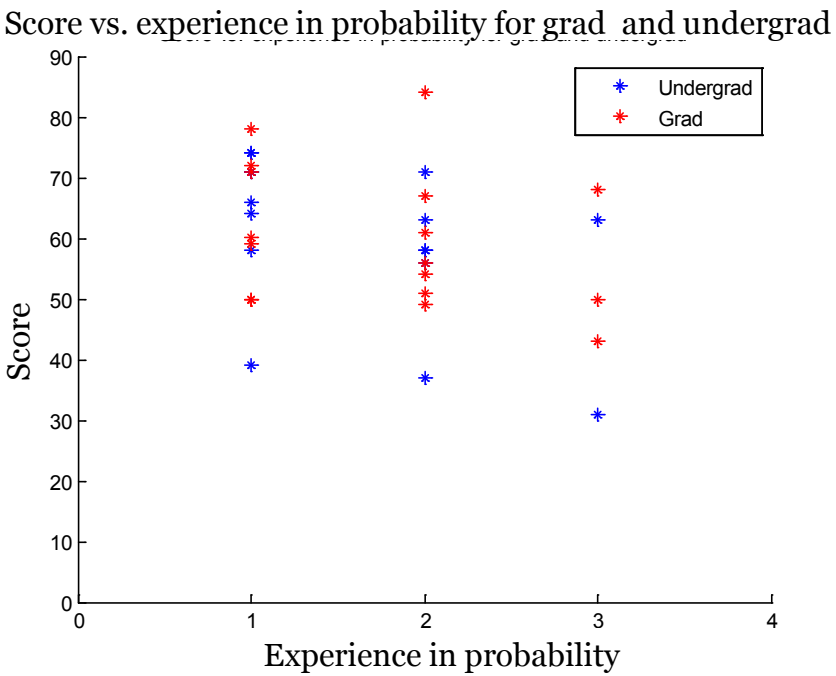
- In this phase the expert elicit the quantities in which we are really interested (the risks for our components of exceeding caps)
- *C* is used to translate the distributions on the x-axis
- *S* is used to weight the sum of expert opinions
- 9 questions (30 minutes)
- 2 techniques used:
  - Approach derived from Statistical Link Analysis
    - Inputs: adverse tolerance, favorable tolerance, shape of the distribution
    - Possible shapes: normal, triangular, uniform
    - Possibility to update the parameters
  - Quantile method
    - Inputs: quantile (50, 16), shape
    - Possible shapes: normal, triangular, uniform
    - Possibility to update the parameters



# Expert model results with students

Interview process approved by COUHES (Committee On the Use of Humans as Experimental Subjects) on the 8th March 2011
Interviews conducted through April 2011
17 grad students and 17 undergrad students interviewed (only part 1: Probabilistic Thinking)

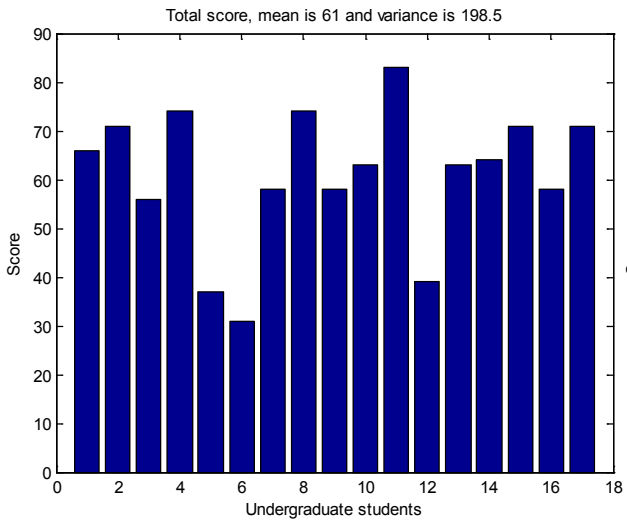


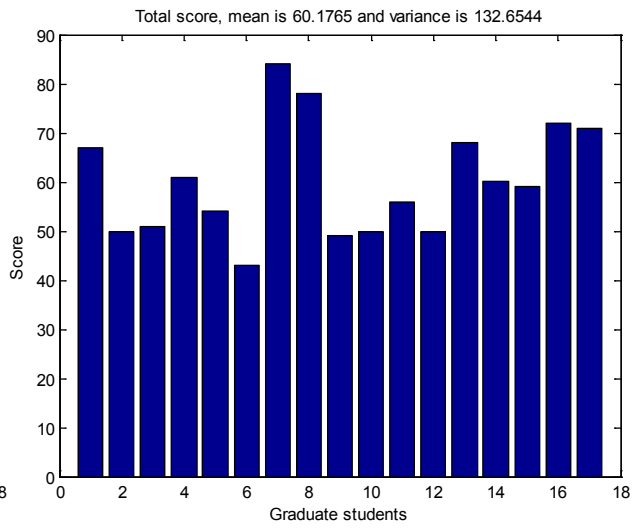



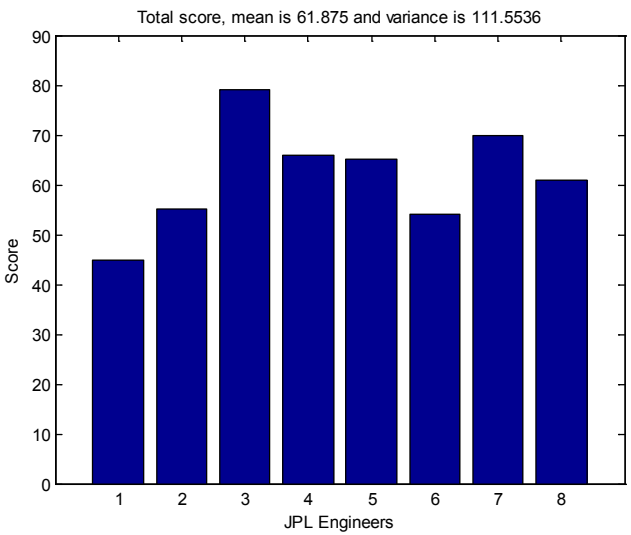
# Expert model: test with JPL Engineers

- Currently in progress…. 8 interviews performed
- The test will show:
  - How much experts are sensitive to biases/heuristics;
  - How probabilistic thinking can be used to compose multiple expert opinions in an unique estimate;
  - How calibration helps to improve experts` assessments
  - Whether expert elicitation process can or cannot improve risk assessment (the missions that will be used for expert elicitation are MIT missions for which we know initial and final design values).

# Comparison of general score for Part 1 across the three populations: undergraduate students, graduate students, engineers

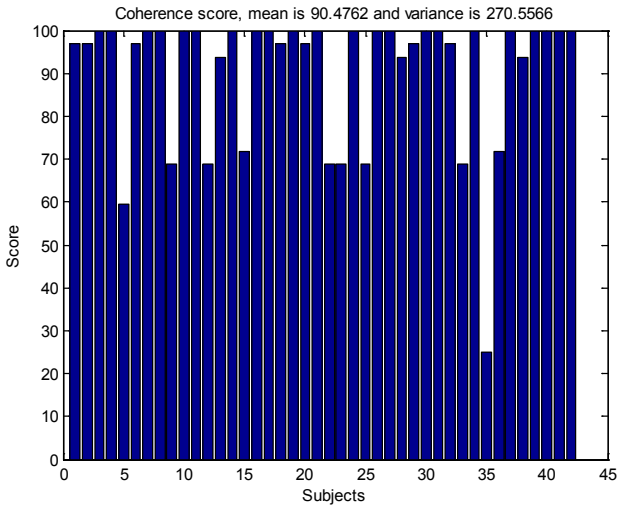


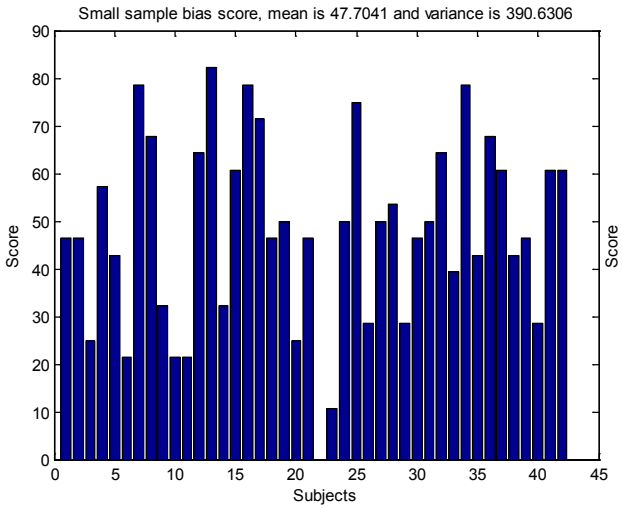



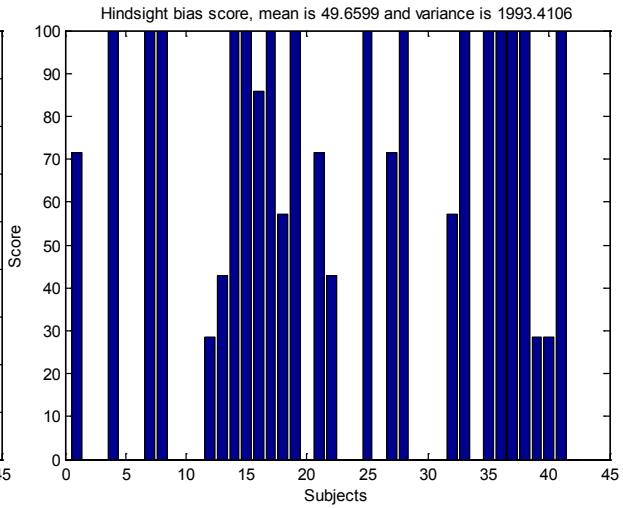



# Additional 7 sub-indices mapped

•**Coherence:** check whether the expert respects the basic coherency laws of probabilities
•**Hindsight bias:** can happen when people are asked to assess their a priori probability of an event that has actually occurred
•**Small sample bias:** people sometime forget that size of a sample affects the probability of obtaining certain results
•**Judgment by availability**: used when an expert judges the probability of an event according to the ease with which similar events or instances that come to mind
•**Judgment by representativeness**: instead of evaluating the conditional probability, a Person might judge on the base of the similarity between events
•**Awareness of underlying conditional probabilities**: the case in which people don`t consider how underlying events can condition probabilities
•**Judgment by anchoring and adjustments**: the case when people are asked to estimate a quantity, they start with an initial estimate ("anchor"), and then they just adjust it



# Expert model lessons learned

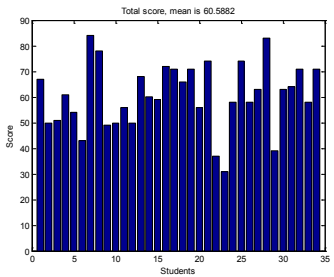
**STUDENTS**

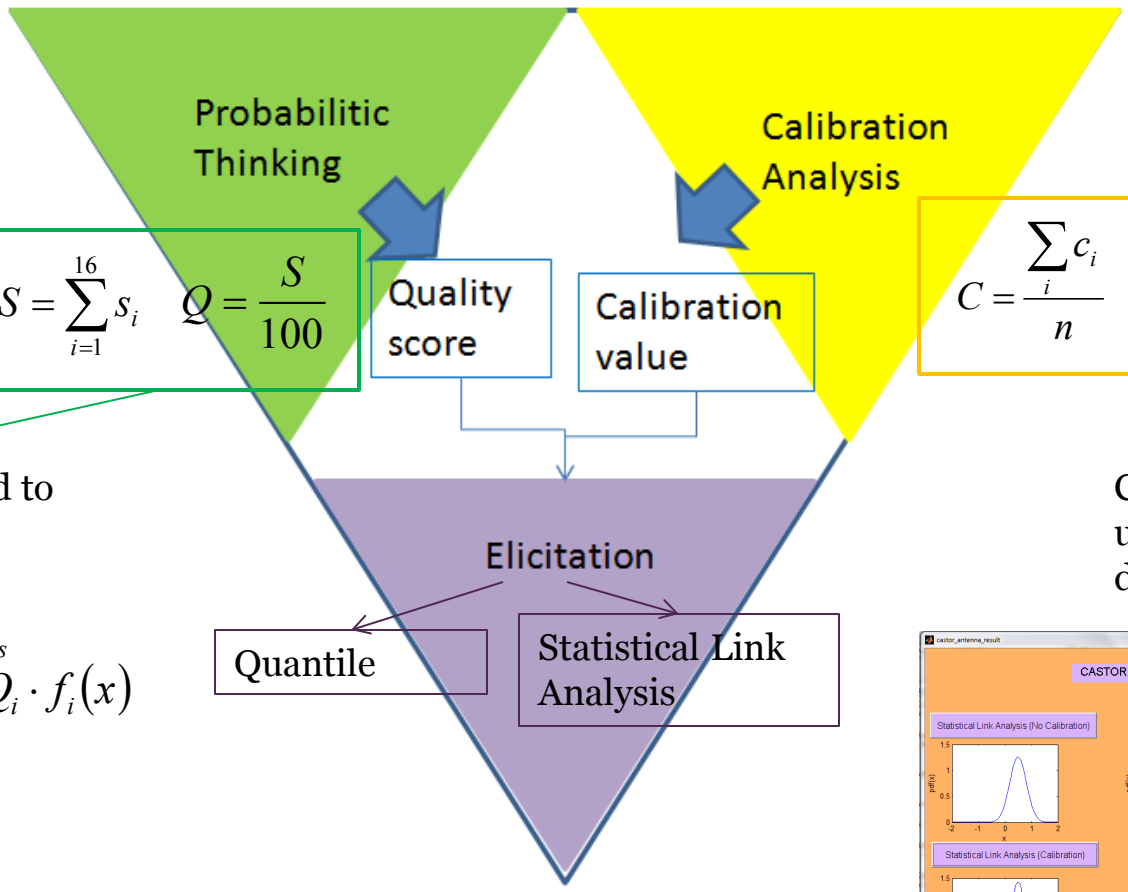
- **Duration:** most of the time around the 30 minutes, with some exception.
- **Question formulation:** some unclear questions needed to be restated.
- **Scoring system:** adjusted to reflect better the variability across the answers.
- **Over thinking:** some students tend to over think about each question trying to identify what the interviewer was looking for. This results in wrong answers
- **Coaching:** in some cases coaching helped students, in some others it caused more over thinking and it didn`t improve the score
- **Lack of courage in the answers:** some students identified successfully the biases and mentioned them during the interview, but then they picked the wrong answers. When interrogated on the motivation for their final selection, they replied that they didn`t have enough proofs/confidence to support their initial intuition. In other words, they trusted more their biases than their intuition.

**ENGINEERS**

- **Duration:** between 90 minutes and 120 minutes.
- **Question formulation/Software:** question were mostly clear. Software had some problem , but overall was good
- **Scoring system:** ok for part 1, some analysis on the other parts need to be performed.
- **Coaching:** not too much implemented

# Expert model summary



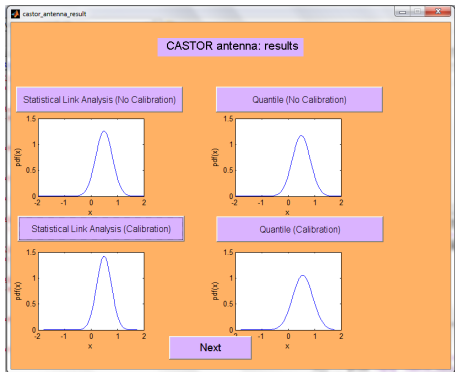

$$S = \sum_{i=1}^{16} s_i \qquad Q = \frac{S}{100}$$

$$C = \frac{\sum_i c_i}{n} \qquad c_i = \frac{e_i - r_i}{r_i}$$

Quality score is used to perform experts` composition

Calibration score is used to shift the distributions

$$f_{tot}(x) = \frac{1}{\sum Q_i} \sum_{i=1}^{n_experts} Q_i \cdot f_i(x)$$



# Conclusions

- In this paper we present a quantitative approach to perform expert elicitation for space communication system design and risk analysis
- The methodology includes a three parts interview process
- Experimental results on students show their sensitivity to different biases and a surprising lack of correlation between biases and exposure to probability
- A complete test of the methodology with JPL experts is in process
- This approach to expert elicitation can be easily translated to other aspects of spacecraft design: failure risk, cost risk,…

# Thank you

# Questions

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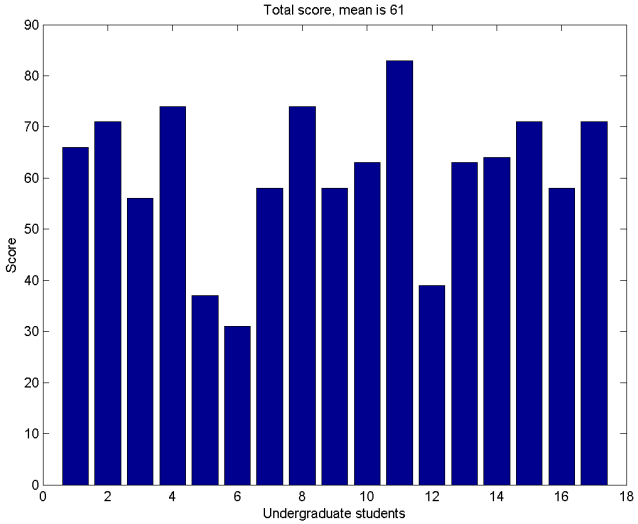
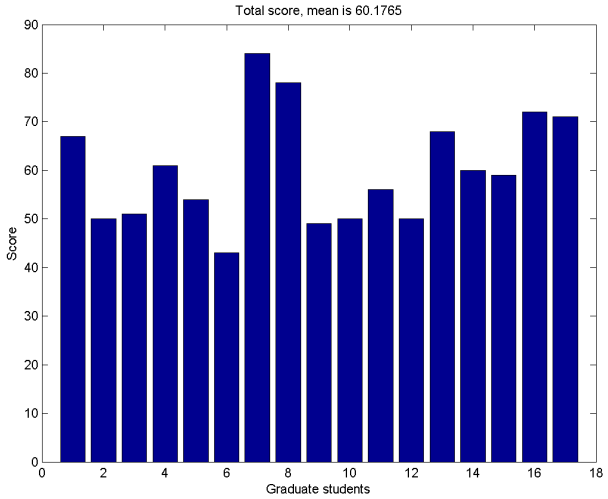
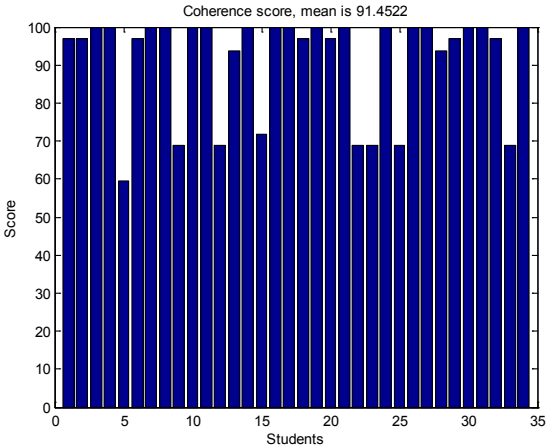
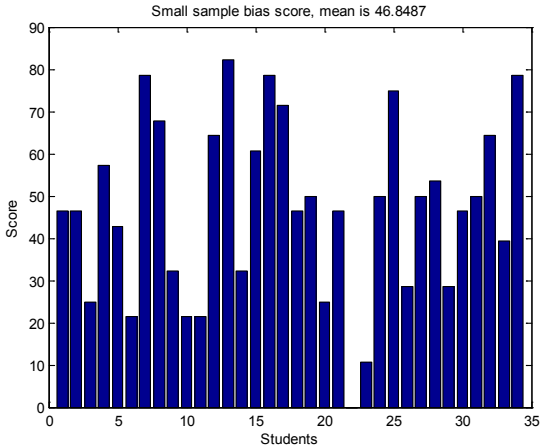
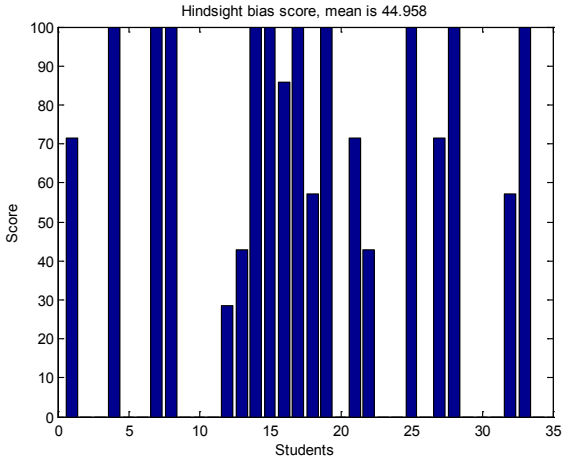
# Back up

# Interviews with students: more results

## Undergraduate vs. Graduate




## Partial indices: Coherence, Small sample bias, Hindsight bias