Cost and Risk Estimating and Analysis in a Concurrent Engineering Environment

TEAMX
Jet Propulsion Laboratory

AIAA
Economics Technical Committee Workshop

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Team X Cost Estimation Process

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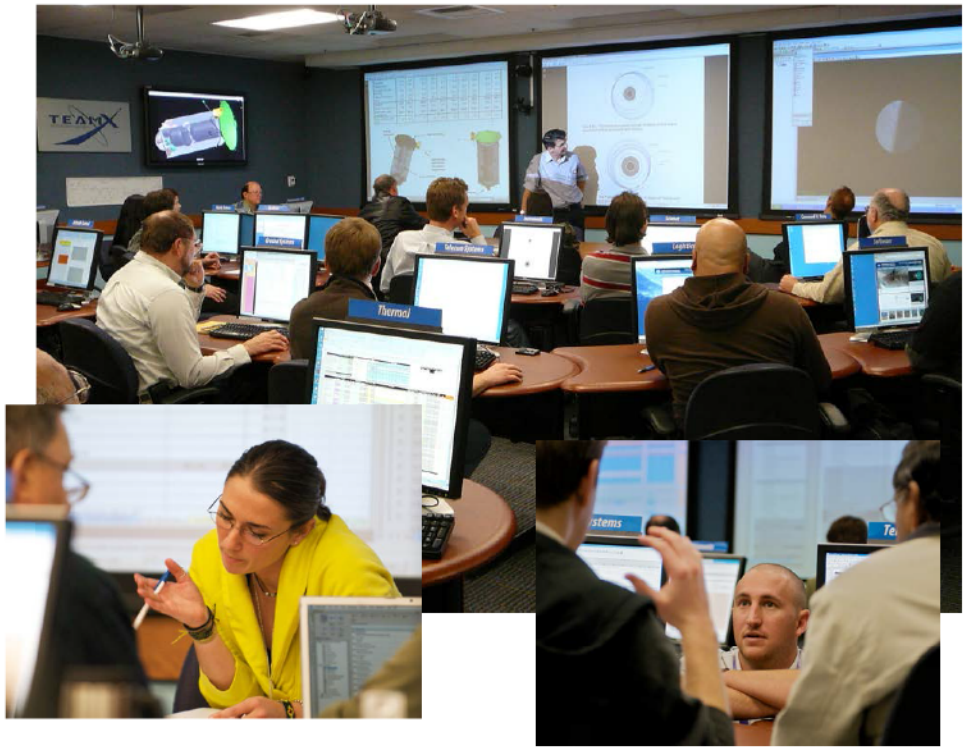
What is Team X?

Team X is a concurrent engineering team for rapid design and analysis of space mission concepts



Within this setting cost is a tradable parameter, like mass, power, etc.

- **Developed in 1995 by JPL to reduce study time and cost**
- **More than 1100 studies completed**
- **Institutionally endorsed**
- **Emulated by many institutions**

Team X profiled in *Time* magazine, October 2005
Previous New York Times article

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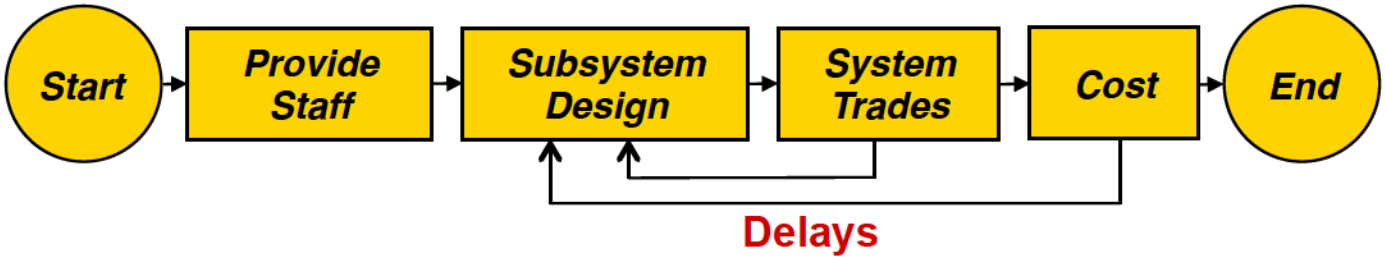
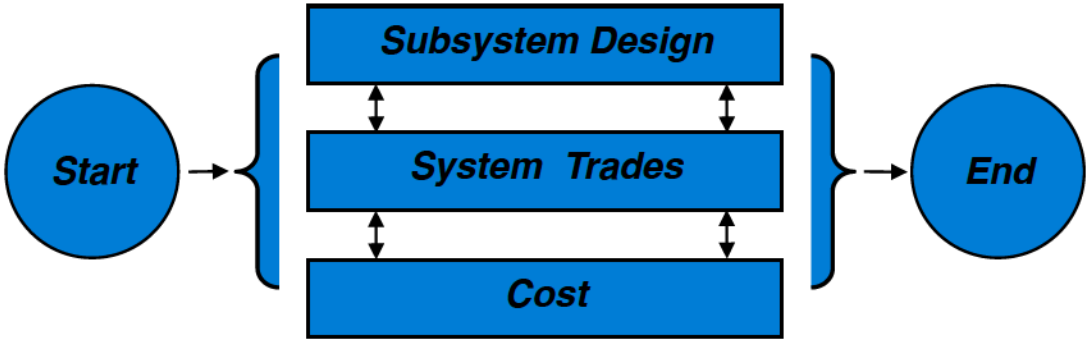
Concurrent Engineering – What is it?

Traditional Method – Serial



Concurrent Engineering – Parallel

- Diverse specialists working in real time, in the same place, with shared data, to yield an integrated design



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Team X Cost Estimation Process

Methodology

- Provide expected mission costs by level 2 and level 3 WBS elements.
  - Estimates are predominantly grass roots model-based (a few are parametric and wrap factors). They provide fast, accurate turnaround, and are endorsed by the doing organization.
  - Models are owned by the doing organizations.
- Accumulates costs from Team X subsystem chairs.
- Cost engineering station generates systems engineering, management, mission assurance, and reserves.
- As part of the study system evaluation, system design trades involving cost are performed.
- WBS estimates, cost profiles, and cost risk estimates are generated.

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Cost Tools and Use

- Team X uses tools that are predominantly quasi grass roots models. They are the responsibility of and are owned by the performing technical organizations at JPL. They usually generate expected resource expenditures that are accumulated to dollar amounts.
- Rates and factors are provided by the JPL financial organization.
- Reserves are calculated to meet JPL Design Principles.
- L/V costs come from AO information. Can also be provided by customer.
- A risk estimate capability based on the work of MCR is also generated. It will take into account both estimation and technical uncertainty for each subsystem. The 5 x 5 risk chart is used by the risk station.
- S-curve capability exists and will be discussed.

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Cost Tools and Use

- The responsible organizations update and validate their models to keep them current.
- The updated models are reviewed and approved by a Change Control Board (CCB).
- The cost models are subject to a Configuration Management (CM) system.

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Team X Risk Process

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Overview of Risk in a Concurrent Engineering Team

- **Risk process is highly subjective.**
- **Limited data available to drive scoring.**
- **Dependent on the person sitting in the risk chair.**
- **Risk in a concurrent engineering team is very different from risk on a project.**
  - Focus is on risk identification and initial assessment, not risk management.
- **In many cases the identified 'risk' item is primarily an issue that needs to be addressed in a proposal or analyzed further.**
  - Less precise because driven by limited time to determine the answer.
  - Difficult to use the standard techniques.

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Risk Mental Models

Risk Identification

- In the early stages of the lifecycle it is difficult to distinguish between an Issue, Concern, or Risk.
- Everyone applies some type of risk threshold.
  - Normal risks are not worth writing down as as they are part of the 'risk' of doing business.
- Risk identification is very dependent upon immediate experience. If a person is constantly involved in high-risk projects, their risk threshold may become higher than usual. If they were recently burned by a particular failure, they will overstate the existence of a related risk.
  - Risk Chair becomes the 'Normalizer'.

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Overview of Key Findings: Risk Scoring

- **Scoring is a fuzzy hybrid of qualitative and quantitative assessment.**
  - Some researchers describe risk assessment in the early life-cycle as 'pre-quantitative risk'.

- **Rather than thinking about risk quantitatively, engineers appear to have a better sense of levels of risk.**
  - A representation of the thought process might be:
    - This is something to keep an eye on (green risk).
    - This is something that I am very worried about and it could cause total mission loss (red risk).
    - This is something to worry about and it might be even worse than I realize since there is limited information currently available (yellow risk).

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Subsystem Role Correlation with Risks

- **Leading' subsystems**
  - Science, Instruments, and Mission Design make decisions with the greatest impact on the science requirements and are mainly concerned with uncertainties in a given environmental capability.

- **Reactive' subsystems**
  - ACS, Propulsion, Power, Telecom, CDS and Thermal, are dominated by redundancy/critical failure concerns, which are indicative of their design role to reliably fulfill mission requirements set by the leading subsystems.

- **Software, GDS, and Structures appear to be exceptions**

  - Software is primarily concerned with re-use assumptions. Both Software and GDS have few risks because the design and implementation can be modified during operations. For the Structures subsystem critical failure and uncertainty in assumptions both appear appear to be major risk categories.
    - Fitting within a mass envelope is a primary concern because there is considerable mass uncertainty during conceptual design.

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Risk Mental Models for Expert Engineers

- **Expert engineer risk mental models**
  - Include a focused mental checklist of a few questions.
  - Repeatable systematic model with simple structure, leading to consistent risk identification in various settings.

Mental Checklist	
ACS	Instrument
• How well do I need to know where I am? • How well do I have to point? • How do I meet the above requirements?	• Who *is building the mission?* • What *are they trying to do?* • Where *are they going?* • When *is the mission?* • Why *are they doing this?* • How *are they implementing it?* • How *much will it cost?*
If there is uncertainty about the answer to these questions above a personal threshold, an issue is noted.	

Attempt to reduce uncertainty by gathering information from people, databases, and other external information sources.

Uncertainty that is non-reducible in given time or with given resources noted as a **RISK**

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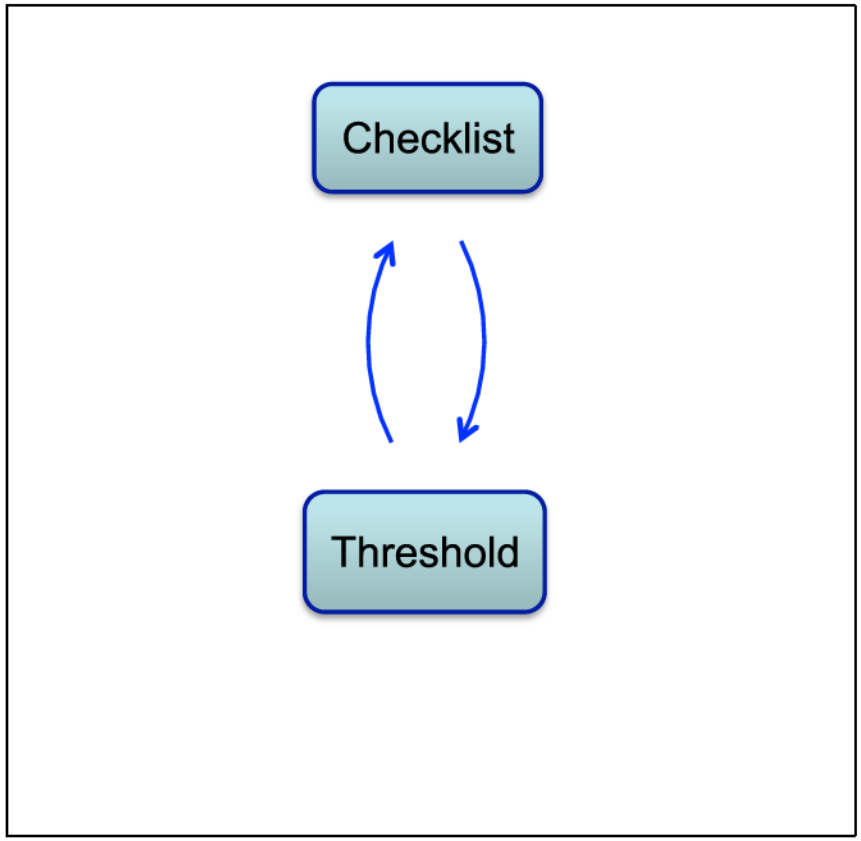
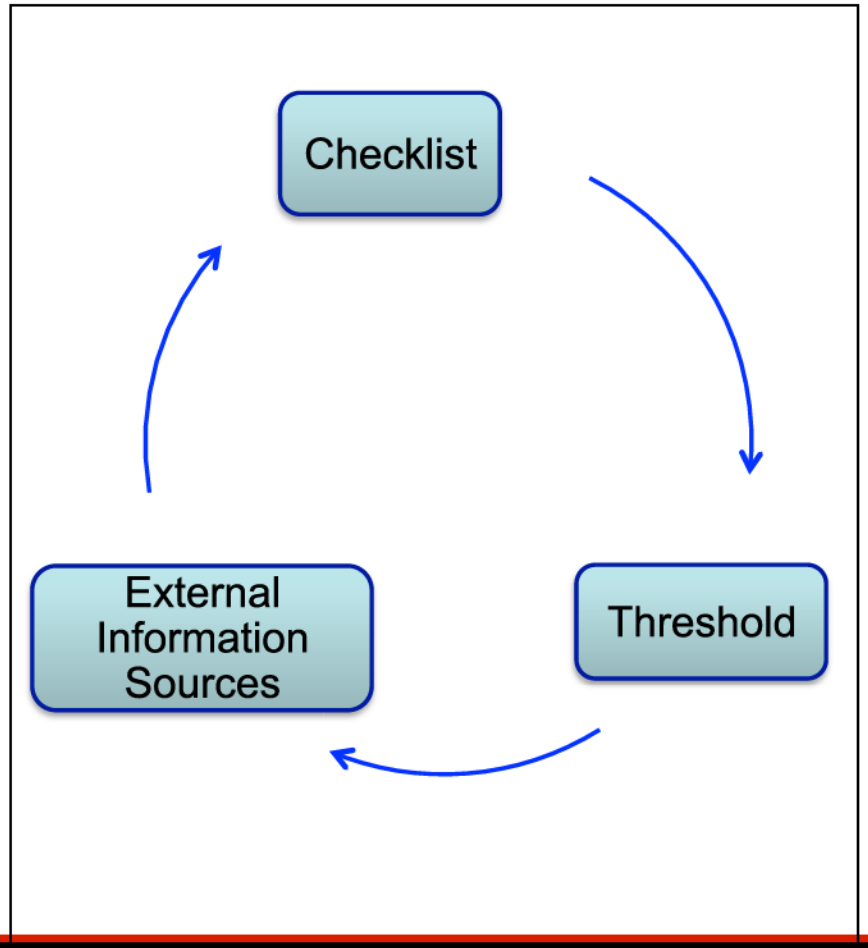
Mental Model Loops

- **Mental Model Loop 1**



- **Mental Model Loop 2**



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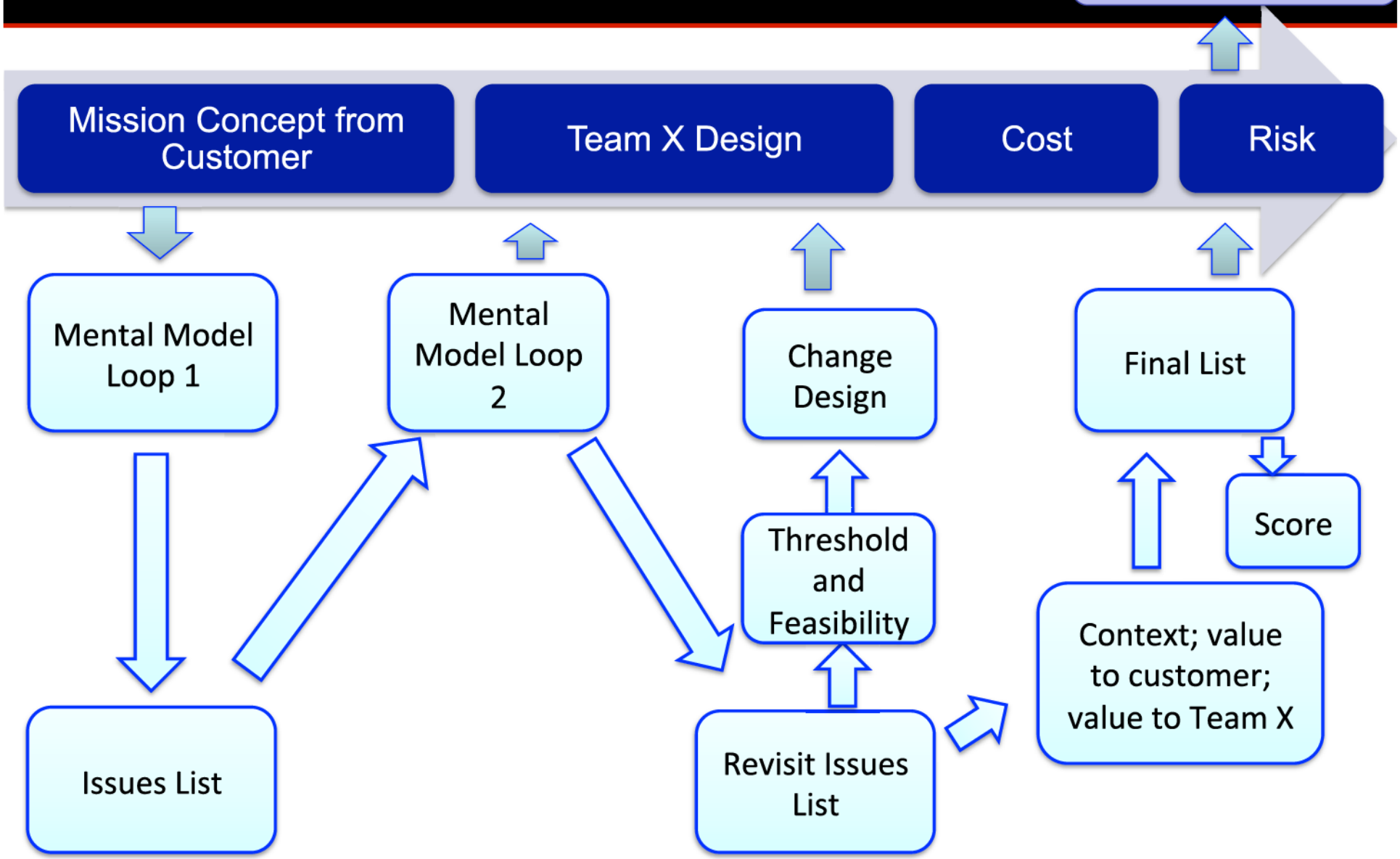
Team X Risk Mental Model



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Example Risk Checklist: Propulsion

Propulsion	Implementation	Mission
Organizational		
Outside development of mission parts/contractor relations		
Multiple collaborating implementing organizations		
Technology Development and Heritage		
Low TRL /New Technology		
Lack of experience with technology at JPL		
Scaling of existing technology (significant increase in size, power, mass)		
Technology inheritance from future missions		
Optimistic heritage assumptions		
Reliance on availability of residual hardware (such as Galileo heat shield, or SEP from DAWN)		
Availability of commercial parts		
Redundancy/Critical Failure		
Lack of Redundancy		
Dependencies on other flight systems within the mission		
Inability to test certain components in a relevant environment		
Very long mission (impact on component reliability)		
Environmental		
Harsh environment		
Unknown environment		
Environmental contaminants		
Subsystem Specific		
Restricted configuration to avoid contamination of other subsystems		
Meeting deorbit maneuver fuel requirements		
Unbalanced Thrusters		

- Checklist of common risks developed for each subsystem, through review of a subset of prior Team X studies.
- Checklists validated during interviews with Team X subsystem chairs.
- Use of checklists during Team X studies revealed:
  - Lists were useful to Risk chair.
  - Subsystem chairs felt the general lists were long, should be tailored to the specific study.
  - Would be easier to use if built into tool.

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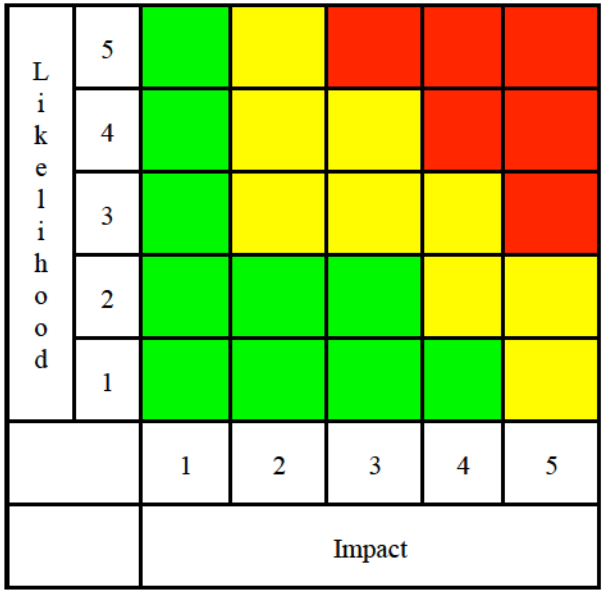
Old Risk Scoring Guidance

<u>Likelihood of Occurrence</u>

Very High (>10%)
High (>5%)
Medium (>1%)
Low (>0.5%)
Very Low (>0.1%)



<u>Loss of Mission Objectives</u>

Mission Failure (100%)
Significant (90%)
Moderate (50%)
Small (10%)
Minimal (1%)

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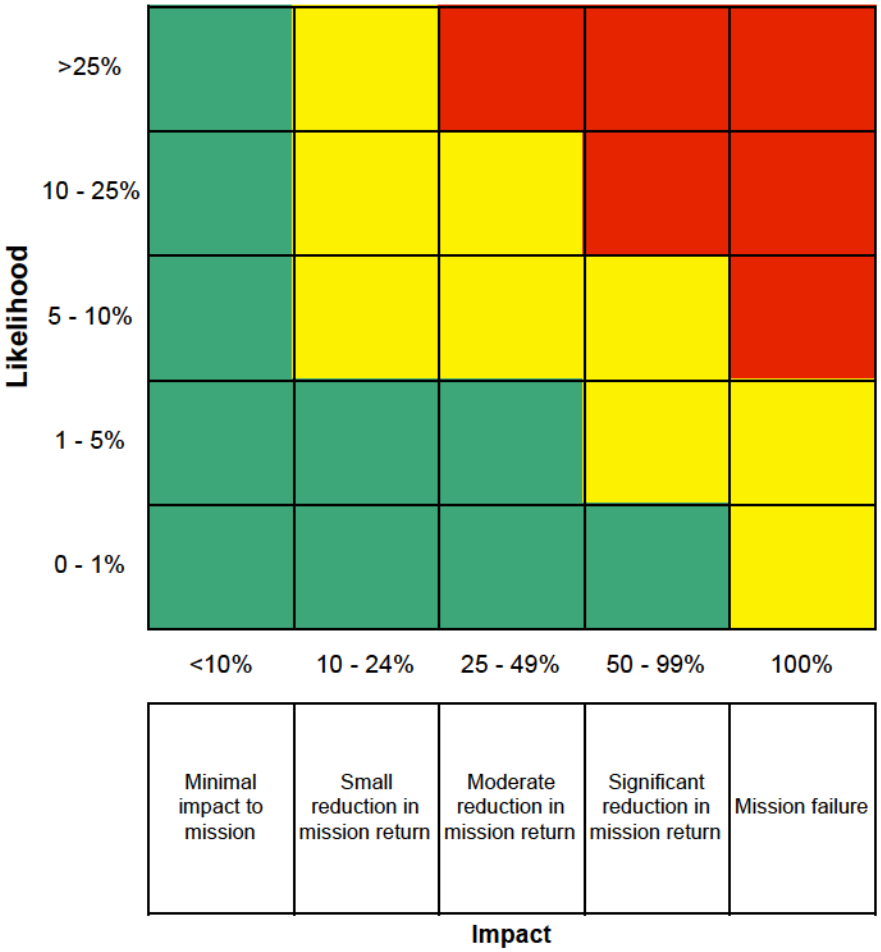
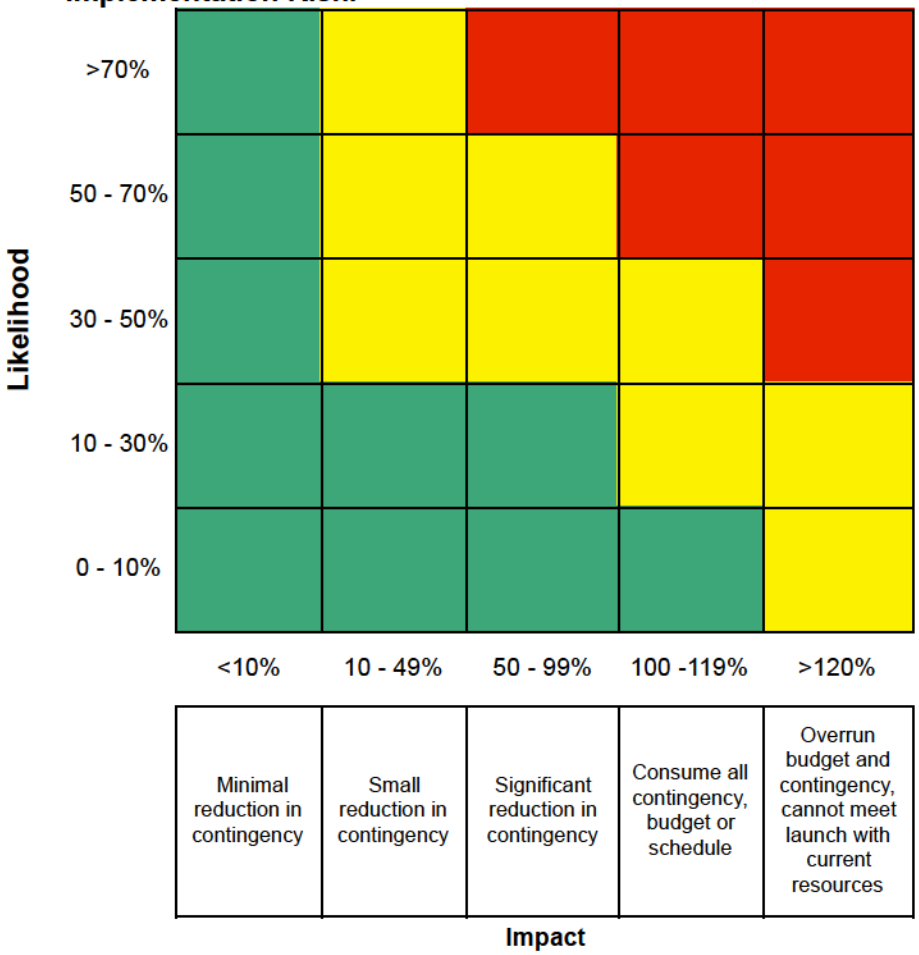
New Risk Scoring Guidance

- **Translation of impact and likelihood ratings into Red-Yellow-Green for NASA 5x5 risk matrix**

Mission Risk:



Implementation Risk:



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Team X Integrated Cost-Risk Process

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Team X Customer Requests

- Team X has been asked for S-curves by various studies over the years (Probabilistic range estimates are required as per NPR 7120.5E).
- For various reasons previous attempts at generating S-curves have not succeeded.
  - Too many inputs.
  - Too slow – can lock up Excel.
  - Results did not pass the laugh test – steep S-curves where for a few dollars more, likelihood of meeting cost goal increases significantly.
- New method was developed and has been successfully used which we will discuss shortly.

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Team X Cost Estimation Process

- **Risk Assessment on Team X has four primary elements that enable the generation of a cost distribution and support risk analysis**
  - Parametric Mission Cost Model (PMCM) - that can assess mission cost independently of Team X studies. It has been shown to give estimates that are in close agreement with Team X estimates.
  - NASA Instrument Cost Model (NICM) –model that is used across NASA to estimate instrument costs
  - Technical Risks are identified by the subsystem chairs and with final scores scrubbed by the Risk Chair
  - Launch slip model

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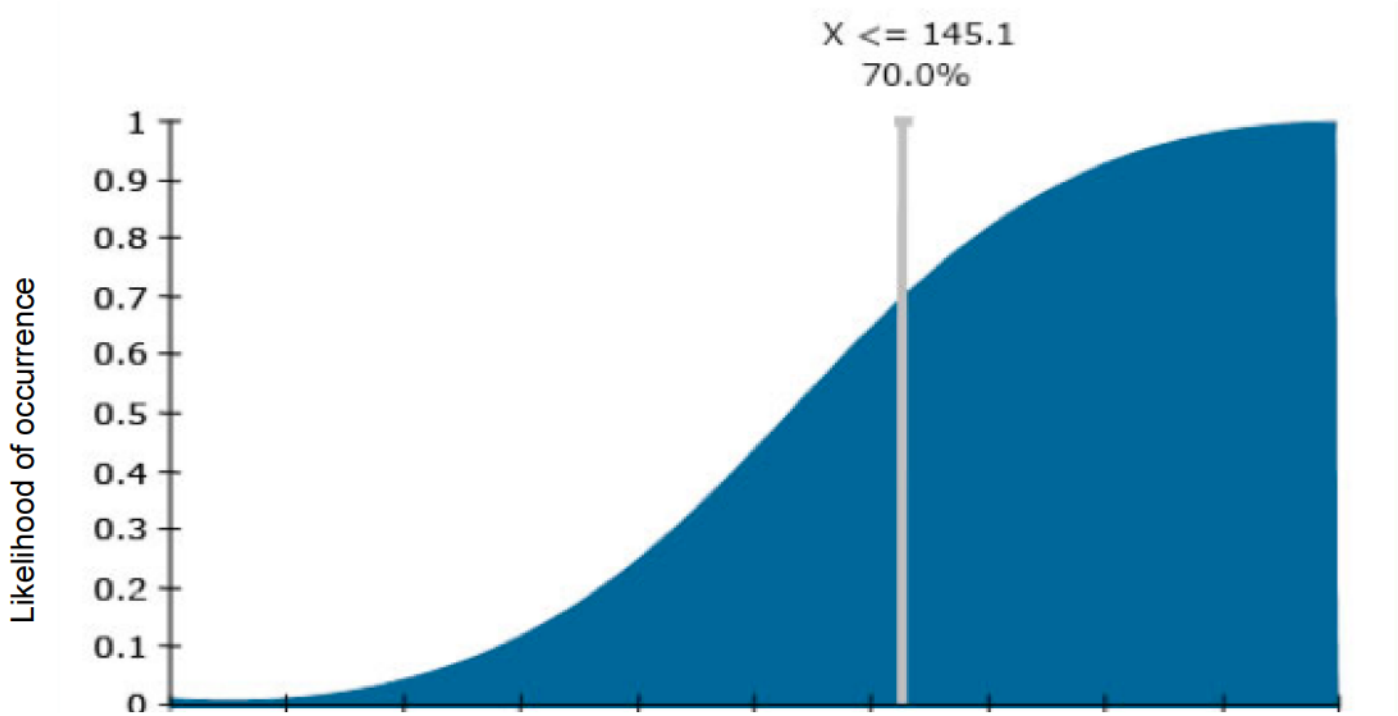
Team X Cost Estimation Process

An S-curve provides the likelihood of occurrence vs the probability of not to exceed cost.



From NASA CEH

Not to exceed cost

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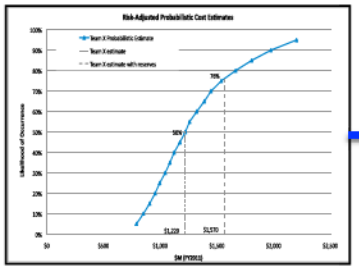
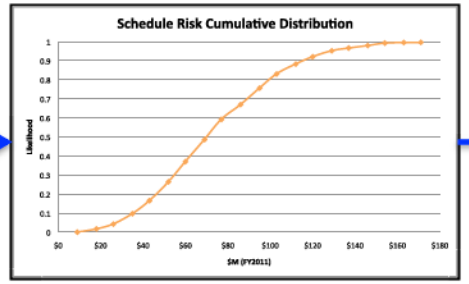
Risk-Adjusted Probabilistic Cost Estimate Methodology

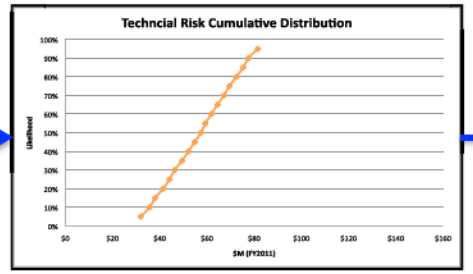


Estimate/Model Uncertainty

Convolve

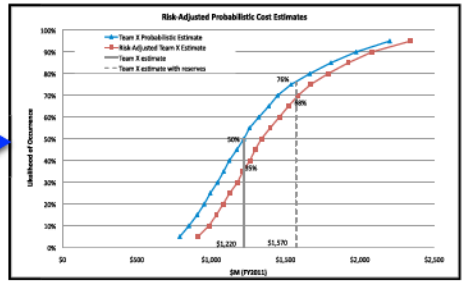
Estimated schedule risk based on inputs from Mission Design





Technical risks based on key risks that are based on risks identified by Team X

Yields



Risk-Adjusted Probabilistic Cost Estimate

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Risk-Adjusted Probabilistic Cost Estimate Methodology
Schedule Risk

- **Schedule distribution is derived from analysis and historical data**
  - Likelihood of slip is based on analysis of 19 historical JPL in-house and contracted missions.
  - Impact is based on Team X effort profiles and mission design determination of months between launch opportunities.
  - Launch opportunities identified by Mission Design.

Schedule Risk Defaults

Destination	Distribution Type	Schedule Slip (months)
Earth	Uniform	0-36 months
Planetary (non Mars/Jupiter)		
Jupiter		
Mars Orbiter		
Mars In-Situ		

Schedule Risk Inputs

Use Defaults?	No	
Type of Distribution	Bimodal	*See example charts below for help in selecting type of distribution*

Percent Probability	Distribution of Slip	Number of Months Slip				
		Low	Most Likely	High	Mean	Standard Deviation
90%	Uniform	0		0.75		
10%	Uniform	9		9.75		

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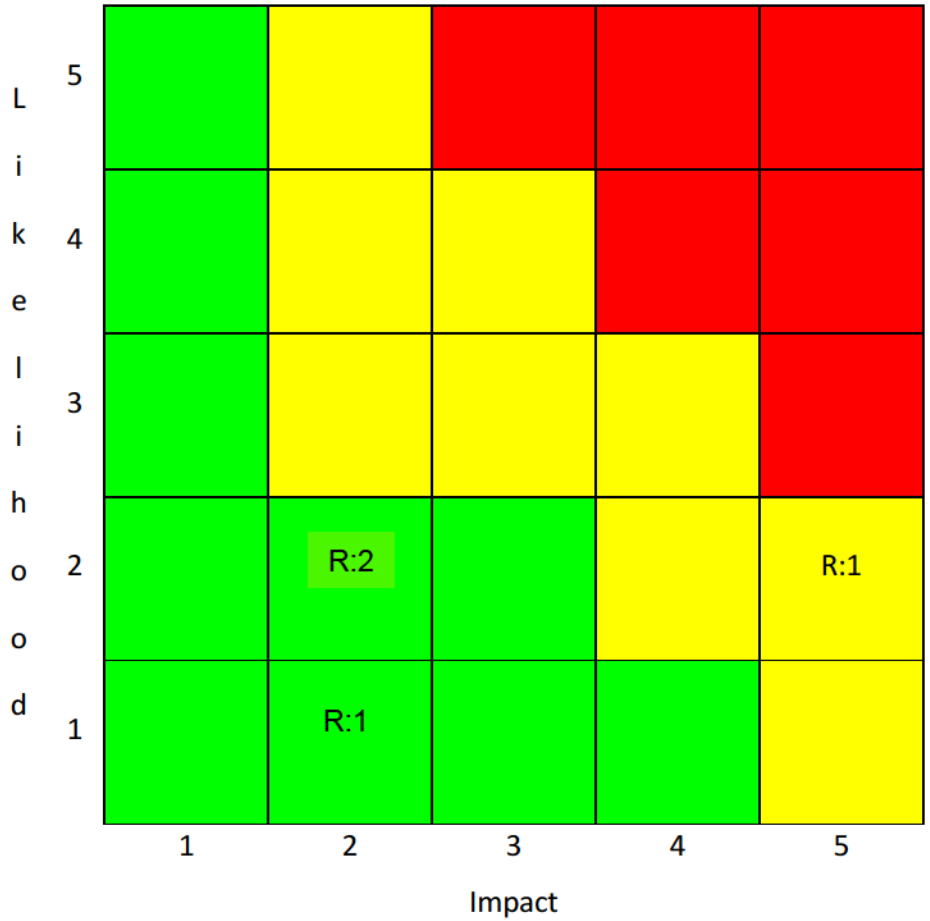
Implementation Risks
Risk Idenitification and Scoring



- **Mission X is a relatively low risk mission compared to other similar space science missions.**
  - SC has relatively high heritage
  - Moderate number of instruments
- **There is one significant risk that needs to be addressed.**
  - ASRG performance and delivery date of flight is still highly uncertain.
  - Specific mitigations are not identified but the impact is based on a best estimate for the cost impact should the risk manifest.

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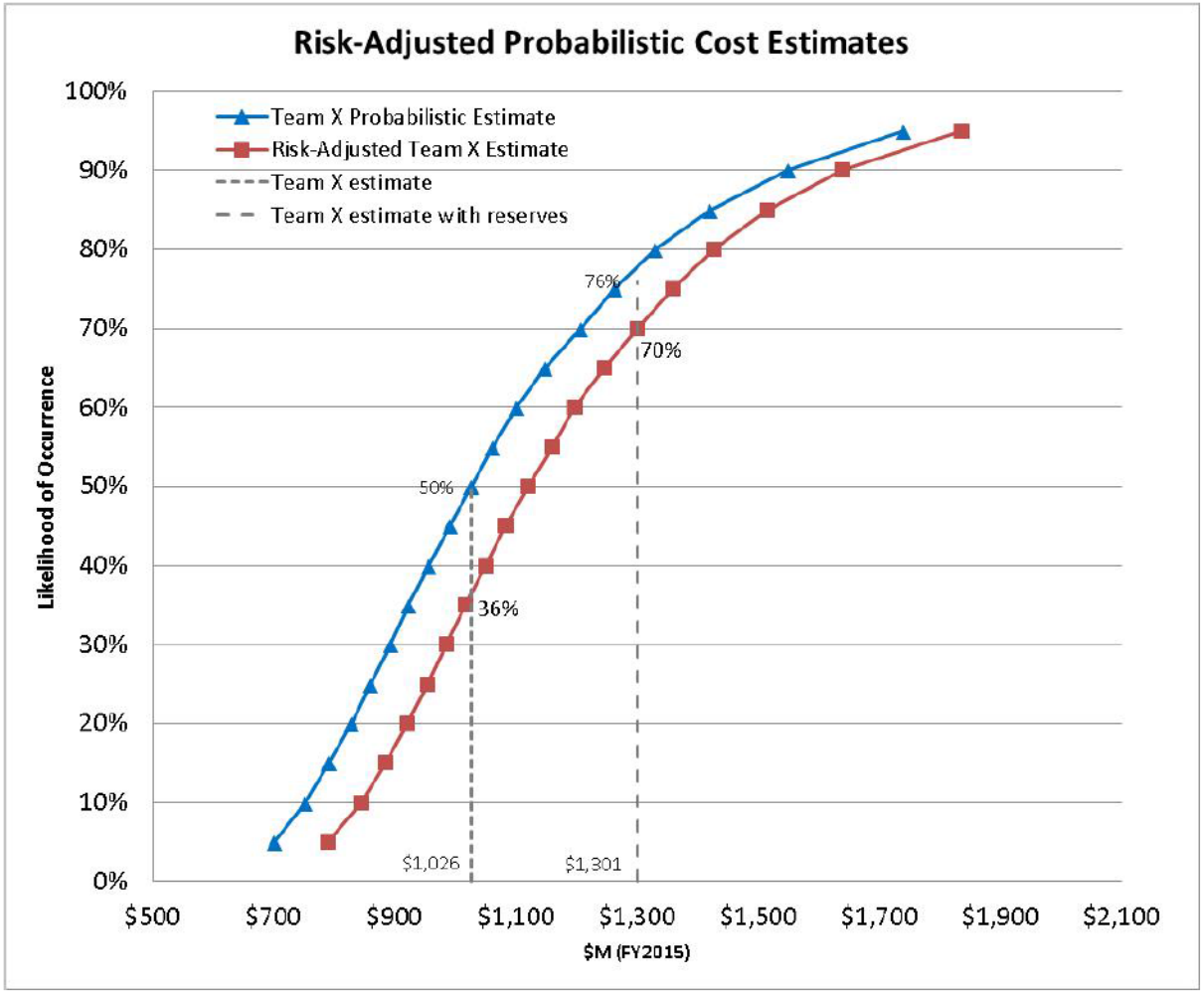
Risk-Adjusted Probabilistic Cost Distribution (S-Curve)
Example Mission



- **Estimate uses parametric cost model based on the Team X 50th-percentile estimate.**
- **Cost risk analysis indicates that proposed mission has a high likelihood of success.**
  - Estimated cost with reserves is 70% to 76%. Typical NASA goal is 70%.
  - Identified risks consume less than 1/3rd of planned reserves leaving sufficient reserves to cover 'unknown-unknowns'.
  - The 50th percentile team X estimate becomes 36% when the identified risks are taken into account.

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