Exploring the of Results of two Methodologies for Unmanned Space Estimation:

Space Missions Catalog – 2015

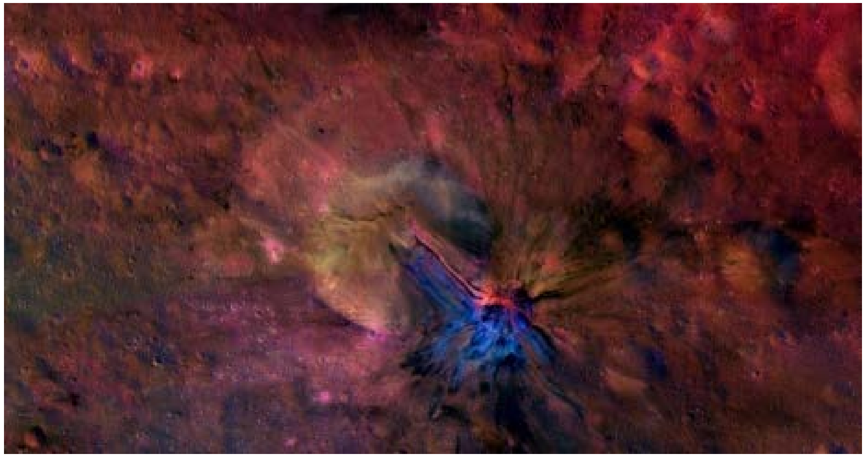
Hardware Catalog – 2016

ICEAA
2017 Portland Meeting

June 6-9, 2017

Outline

1. **Introduction**
2. **Overview of Projects**
3. **Validation Models**
   a) Space Missions Catalog
   b) Hardware Catalog
4. **Study Results**
   a) Mission-level
   b) WBS-specific:
      - *WBS 5 - Payload*
      - *WBS 6 - S/C Subsystems*
      - *WBS 1/2/3 - PM/SE/MA*
      - *WBS 10 - I&T*
5. **Lessons Learned**



Abstract

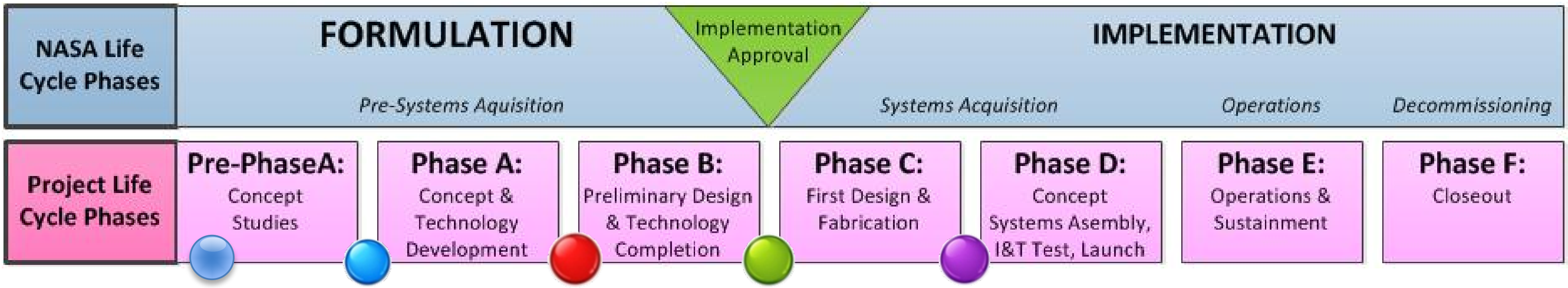
Independent validations of two separate predictive analytics methodologies were performed over the last two years

In both cases, common detailed assessments of past missions' integrated technical and programmatic requirements were used to mimic a grass-roots bottom-up methodology

This presentation compares the process and top-level results from both approaches as well as explores lessons learned

PRICE®

Typical Needs: Integrating Estimation and Decision-Support into Business Process



Bid/No Bid ; RFP Response

Fast dynamic support of go-forward action without sacrifice of accuracy

AoA & Tech Trades

Well structured / defined models supporting cost estimates for conceptual systems

Cross-Check/ Benchmark

Data-driven defensible estimates, leveraging knowledge bases and new requirements

Affordability Analysis

Post-processing supports quick turn-around analysis, sensitivity analysis, and risk analysis for SRR and PDR decisions

Design To Cost

Rapid reconfiguration of product breakdown structure allows for design to cost, CAIV, and value engineering analysis

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Understanding Space Projects well: The What, Why and How of Estimating Cost

The WHAT: Know the ACTUAL cost.	Know how much past space projects have cost Understand cost normalization (as spent vs. constant, inflation, accounting rules …) Understand cost breakdown structure and cost objects
The WHY: Know what drives the cost.	Know which are the cost drivers Understand the different cost drivers and their impact Understand cost driver behavior over time (dependent on technology?)
The HOW: Know how to control cost.	Know how to use (or build, if needed) a cost model Understand how to model a space project Measure, make visible impacts on cost, and look for trends Identify targets for cost reduction

We cannot reduce the cost of space activities if we do not understand space project cost!

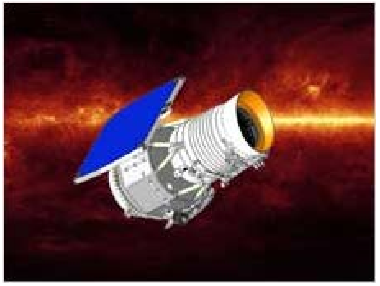
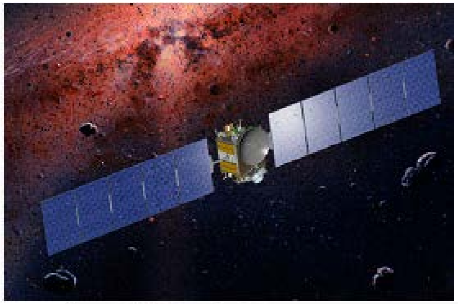
 |

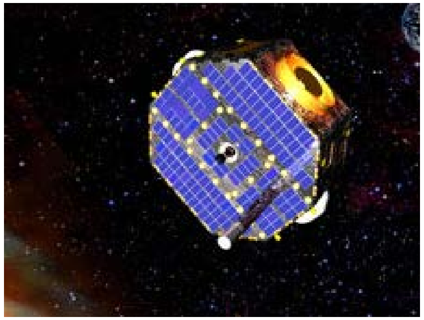
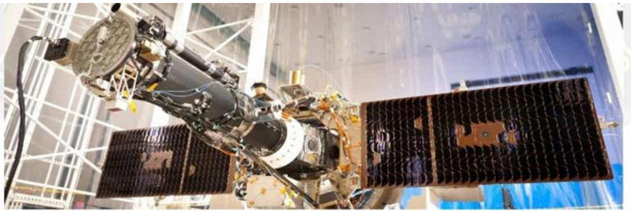
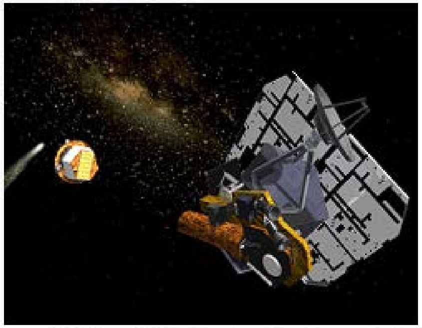
Two Projects Conducted

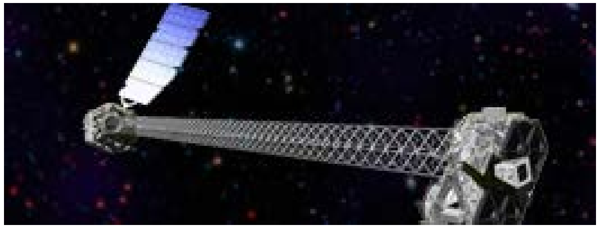
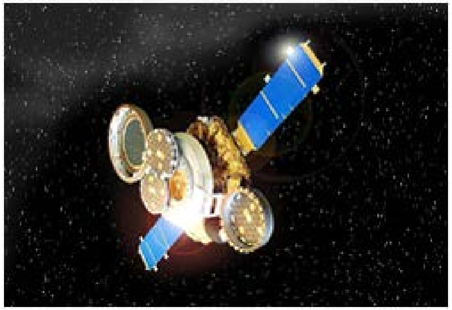
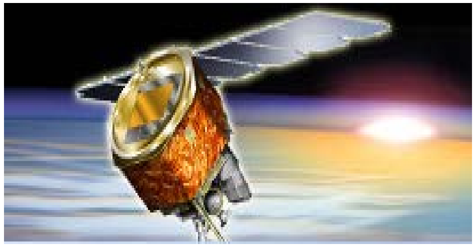
- Studies
  - Space Missions Catalog Validation (2015)
  - Hardware Catalog Validation (2016)
    {using enhanced Equipment-Type Calculator}
- Team
  - Bruce Fad
  - Chris Price
  - Pete Stanley
  - John Swaren
  - Melissa Winter
- Partners
  - Mark Jacobs
  - Shawn Hayes

13 Past Unmanned Missions

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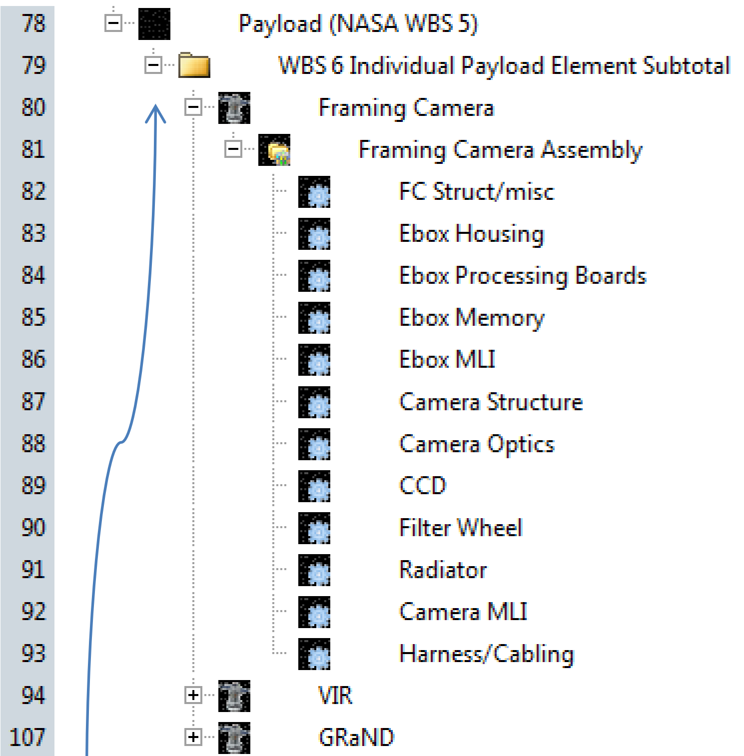
Missions Used for Validation Studies

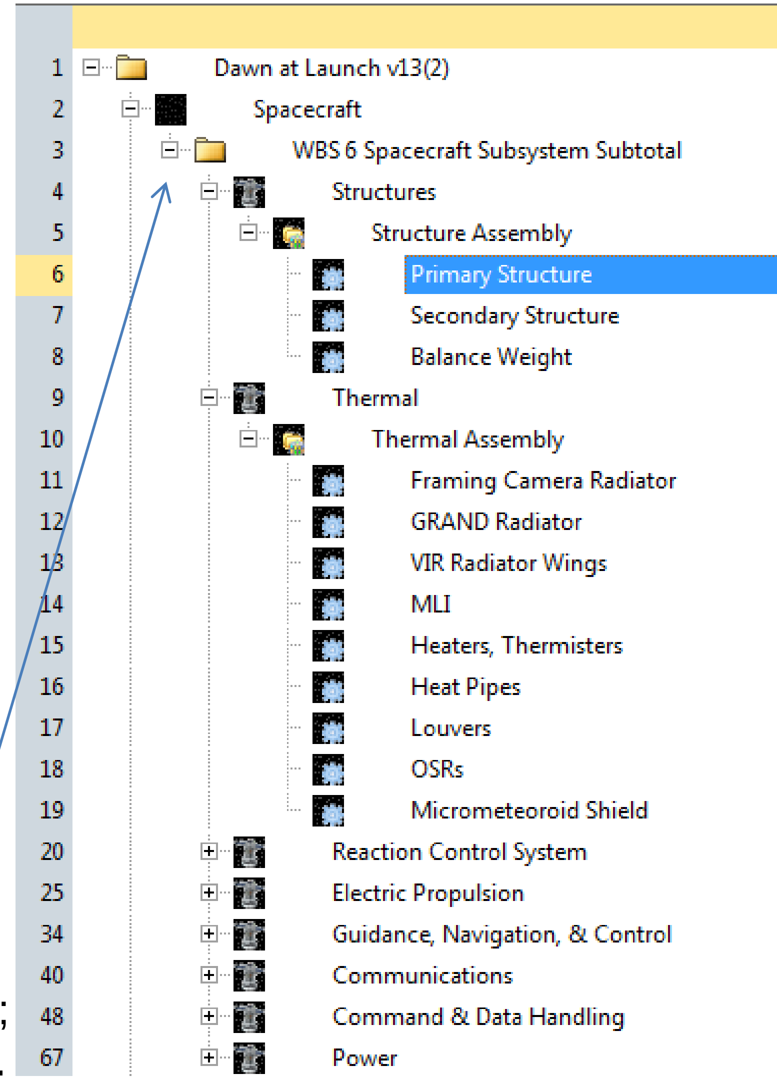
- 13 recent NASA robotic Earth and Space Science Missions

MISSION	NASA Program Type
Mission #1	Planetary
Mission #2	Astrophysics/SMEX
Mission #3	Astrophysics/Explorer
Mission #4	Planetary/Discovery
Mission #5	Planetary/New Frontiers
Mission #6	Astrophysics/Explorer
~~Mission #7~~	~~Astrophysics/Discovery~~
Mission #8	Astrophysics/Explorer
Mission #9	Planetary/Discovery
Mission #10	Heliophysics
~~Mission #11~~	~~Astrophysics/Explorer~~
Mission #12	Heliophysics
Mission #13	Planetary/New Frontiers
Mission #14	Planetary/Discovery
~~Mission #15~~	~~Astrophysics/Explorer~~
Mission #16	Planetary/Discovery
Earth Sci	Heliophy
Astrophy	Planetary

- CADRe used as source for technical, programmatic and cost data

Modeling with Space Missions Catalog

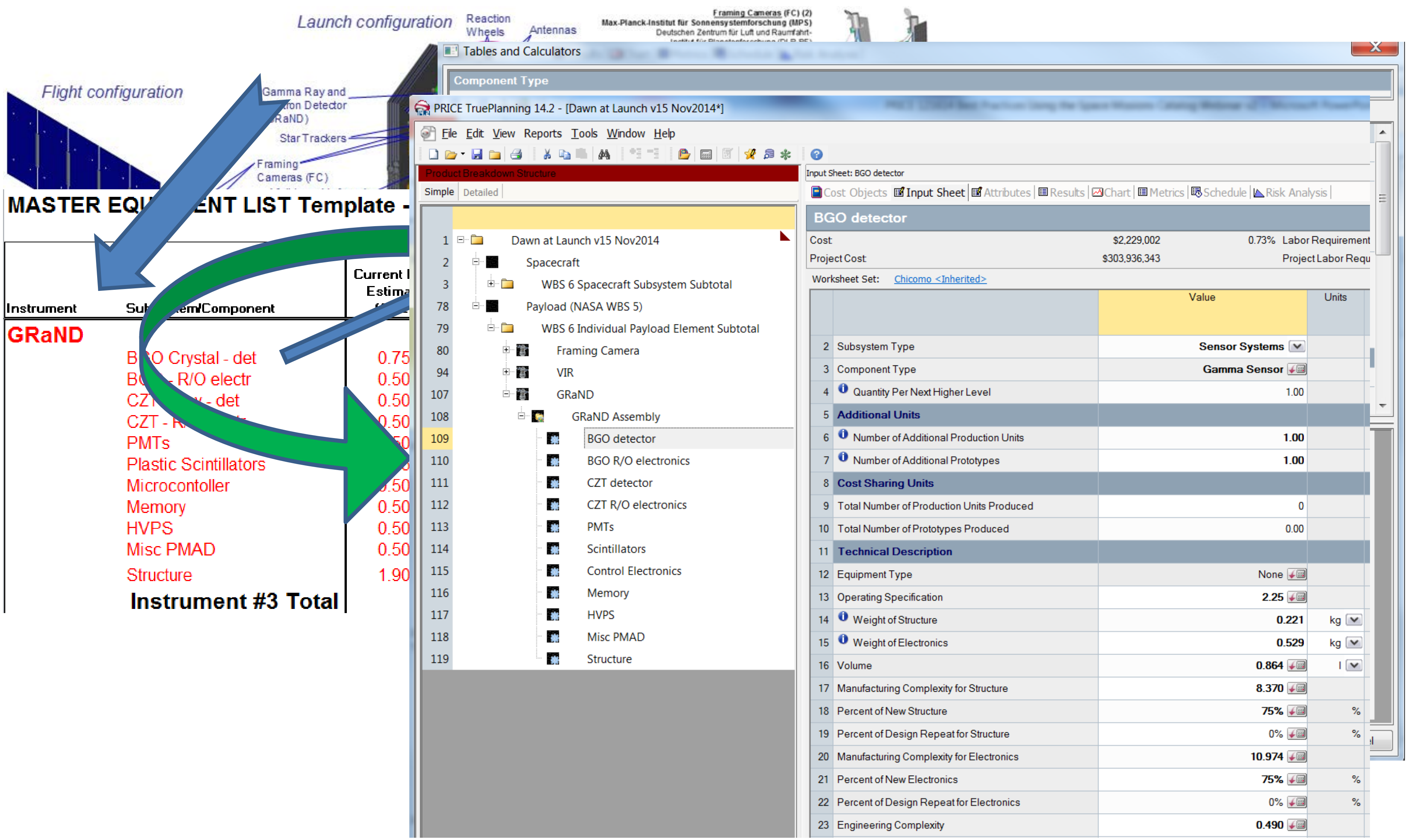




Use Folder to collect Subsystems;
Instruments need Subsystem/Assembly pairings

Overall Bus Subsystem, but no Assembly at top-level;
Bus subsystems need Subsystem/Assembly pairings.

Estimate to Level IV: Spacecraft Bus Components and Payload Instruments



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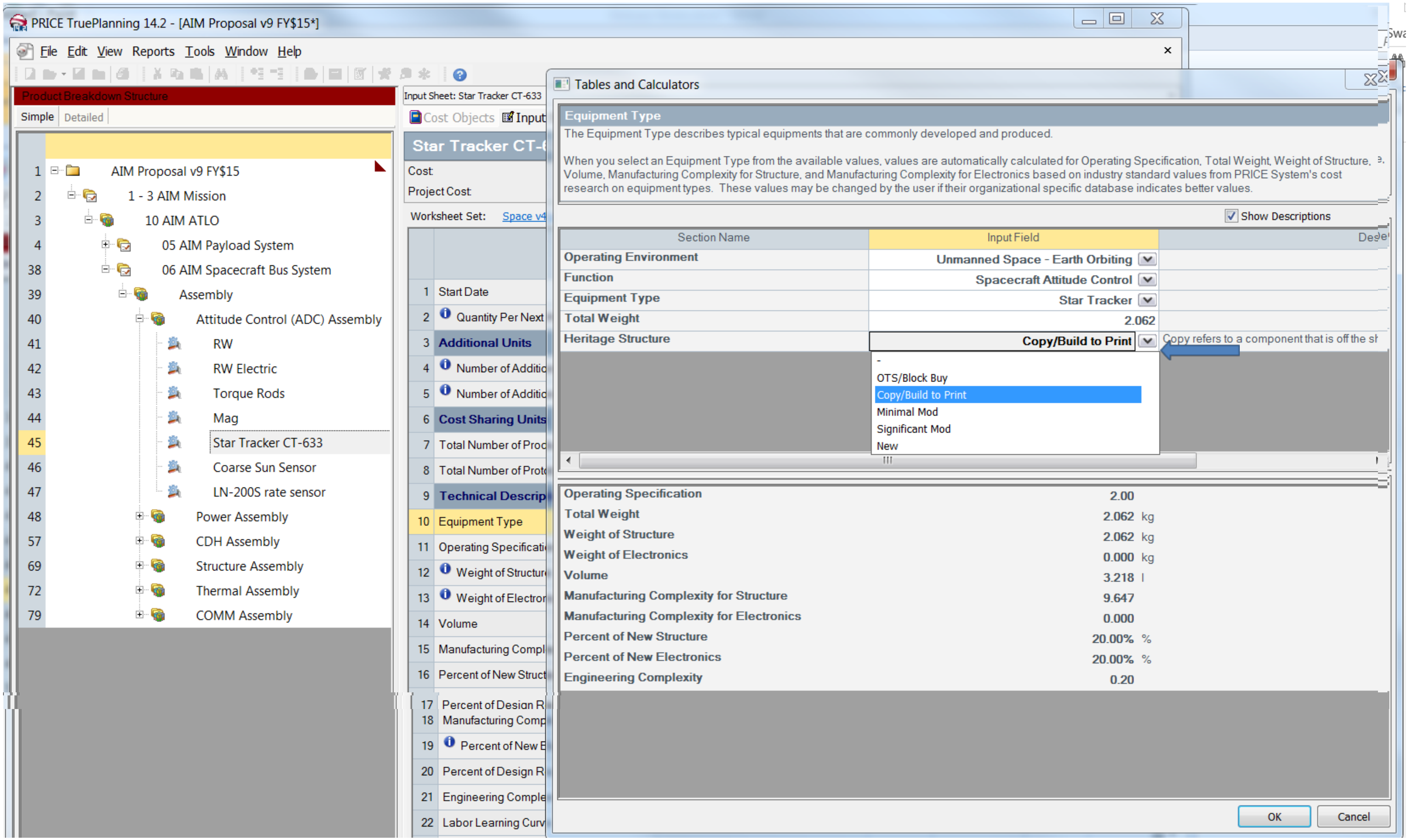
Space Missions Calculator

Knowledge Based Wizard



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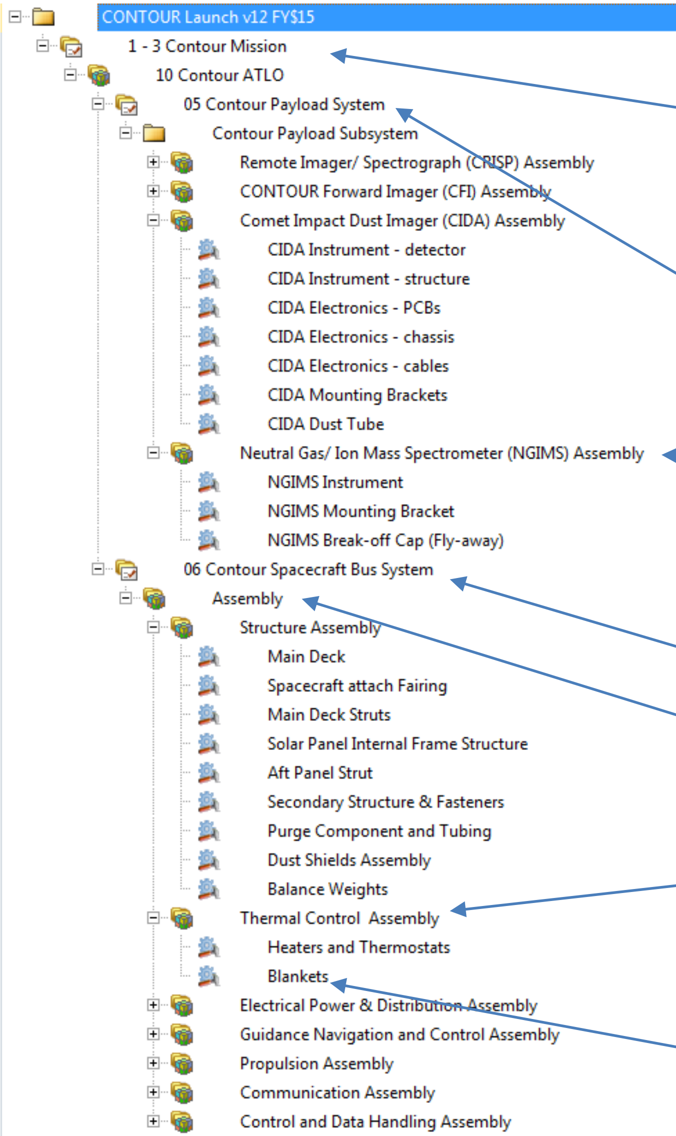
Modeling with Hardware Catalog



- Top Level
  - System & Assembly Object
  - Missions PMO & ATLO
- Payload Level
  - System Object for Payload PMO
  - Assembly Object at each Payload Summary for Integration
- Spacecraft Level
  - System Object for S/C PMO
  - Assembly Object for S/C I&T
  - Assembly Objects at each Subsystem Level for I&T
- Component Level
  - Hardware Objects

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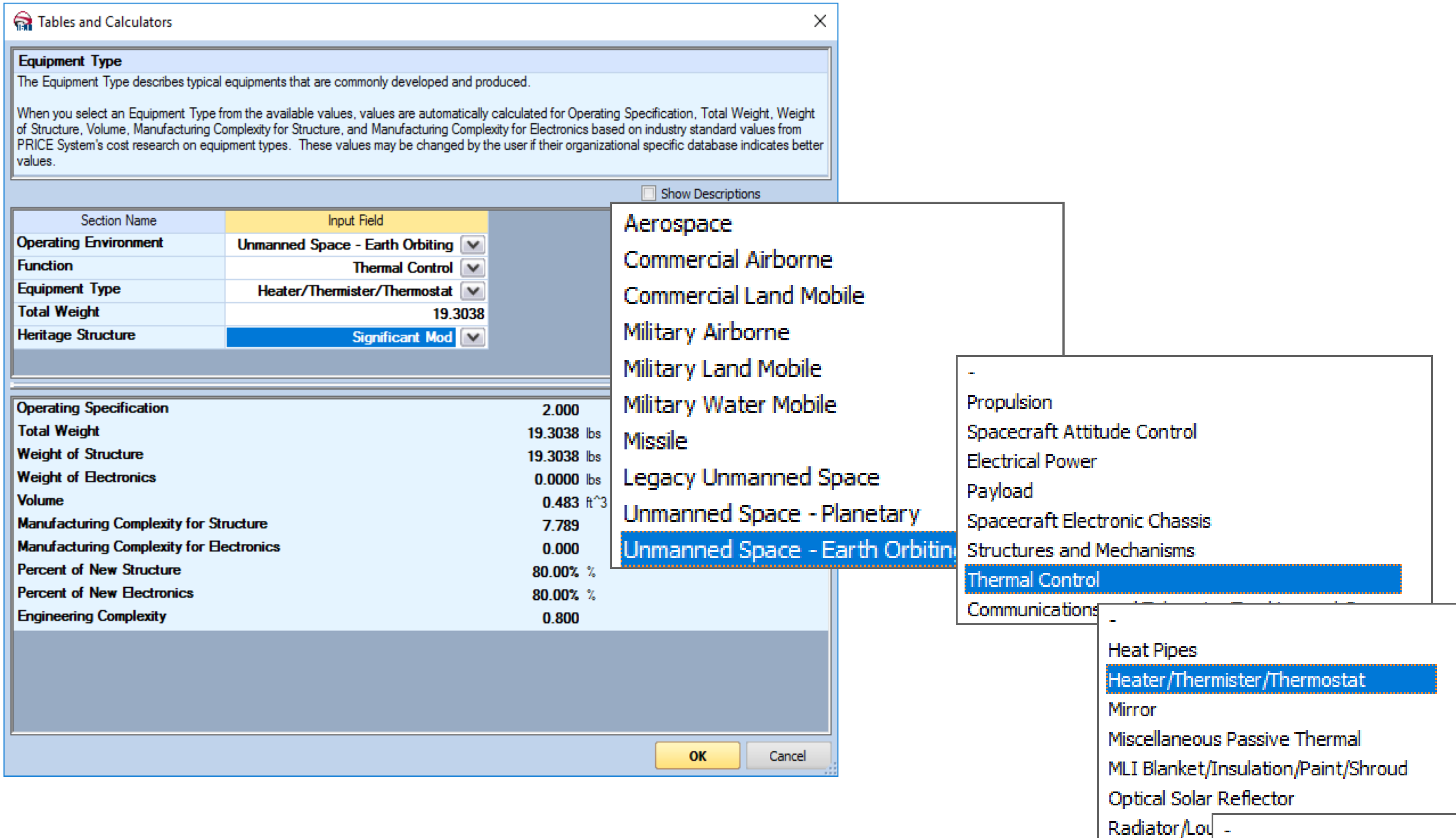
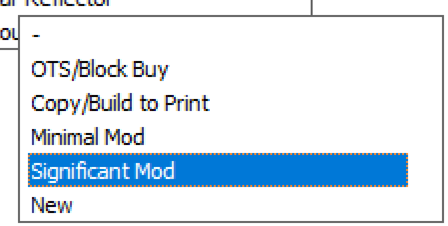
Hardware Knowledge Based Wizard



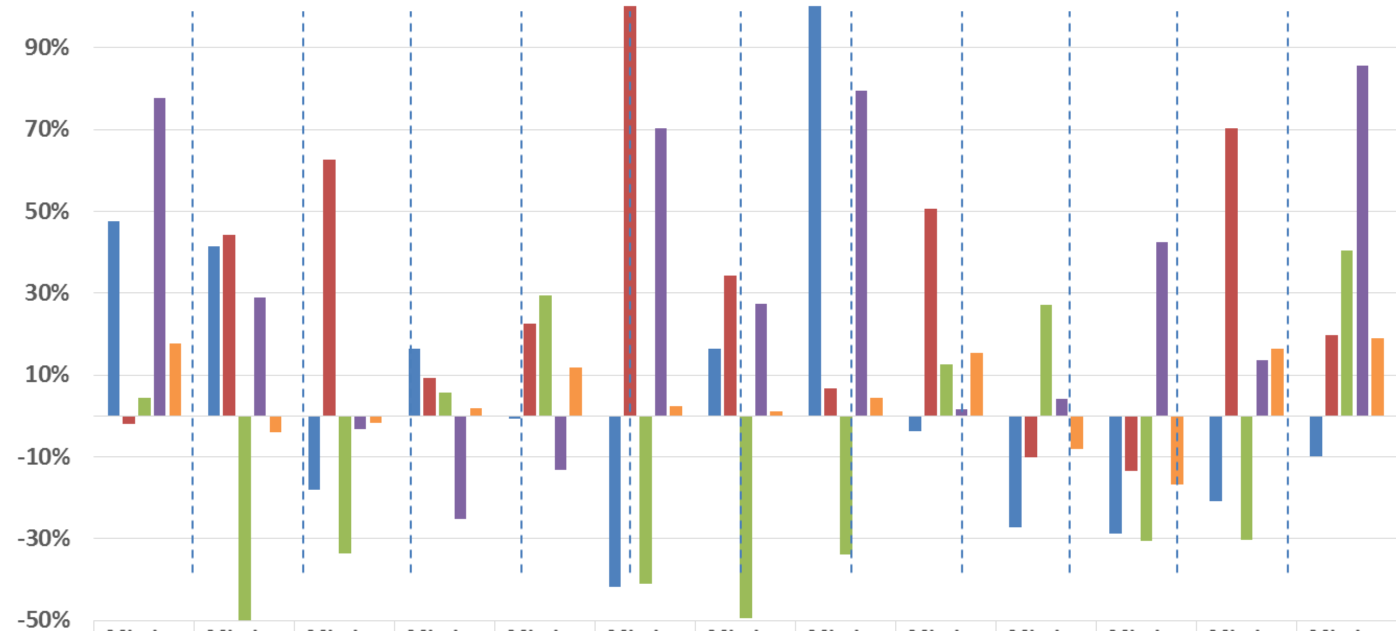


Over 520 data-driven analytics recently added independent of the Space Missions Catalog

Study Results:
Space Missions Catalog (2015)
Hardware Catalog (2016)

Space Missions Catalog – Validation Results (2015)

Summary of TPSM Preliminary Validation Results



	Mission #1	Mission #2	Mission #3	Mission #4	Mission #5	Mission #6	Mission #8	Mission #9	Mission #10	Mission #12	Mission #13	Mission #14	Mission #16
WBS 5 Pyld	47%	41%	-18%	16%	-1%	-42%	16%	127%	-4%	-27%	-29%	-21%	-10%
WBS 6 S/C	-2%	44%	63%	9%	22%	134%	34%	7%	51%	-10%	-14%	70%	20%
WBS 123 PMSEMA	5%	-63%	-34%	6%	29%	-41%	-50%	-34%	12%	27%	-31%	-30%	40%
WBS 10 I&T	78%	29%	-3%	-25%	-13%	70%	27%	79%	2%	4%	43%	14%	85%
TOT w/o LV	18%	-4%	-2%	2%	12%	2%	1%	4%	15%	-8%	-17%	16%	19%

WBS 5 Pyld | WBS 6 S/C | WBS 123 PMSEMA | WBS 10 I&T | TOT w/o LV

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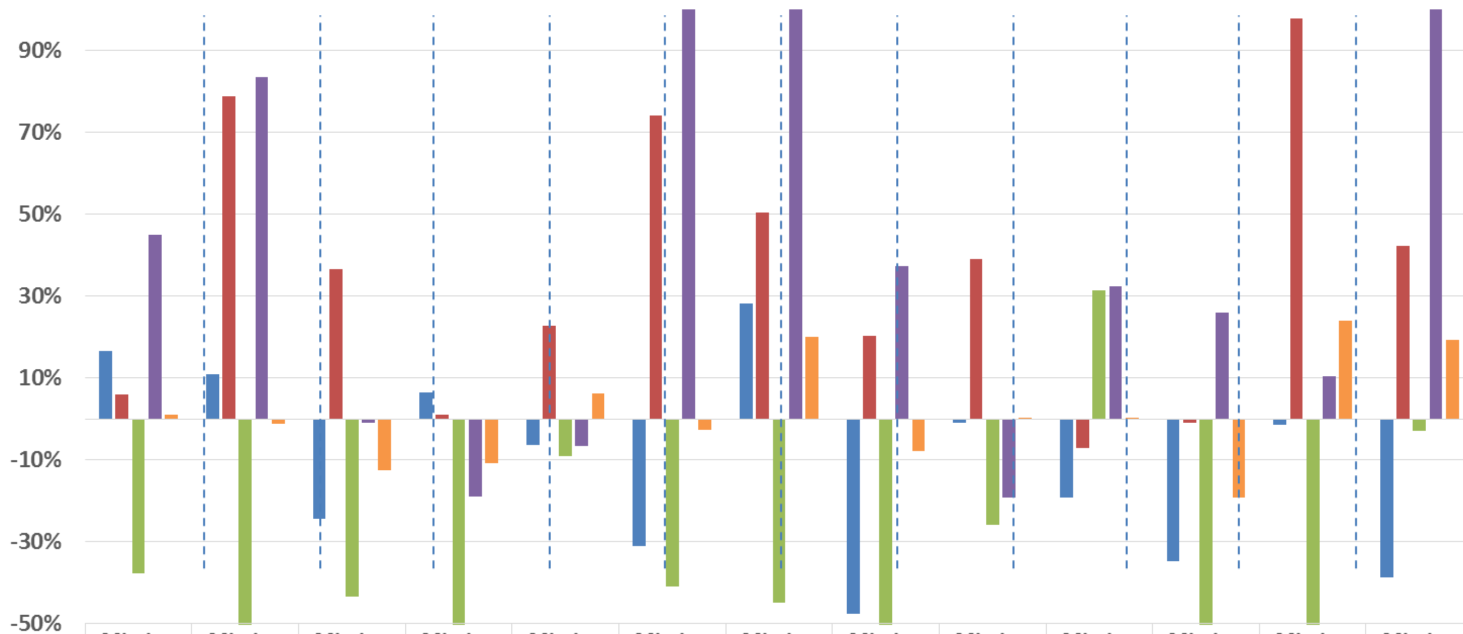
Hardware Catalog – Validation Results (2016)

Summary of TP-HW Preliminary Validation Results



	Mission #1	Mission #2	Mission #3	Mission #4	Mission #5	Mission #6	Mission #8	Mission #9	Mission #10	Mission #12	Mission #13	Mission #14	Mission #16
WBS 5 Pyld	17%	11%	-24%	7%	-6%	-31%	28%	-48%	-1%	-19%	-35%	-1%	-39%
WBS 6 S/C	6%	79%	37%	1%	23%	74%	51%	20%	39%	-7%	-1%	98%	42%
WBS 123 PMSEMA	-38%	-68%	-43%	-52%	-9%	-41%	-45%	-64%	-26%	32%	-61%	-54%	-3%
WBS 10 I&T	45%	84%	-1%	-19%	-6%	110%	140%	37%	-19%	33%	26%	10%	153%
TOT w/o LV	1%	-1%	-12%	-11%	6%	-3%	20%	-8%	0.4%	0.5%	-19%	24%	19%

WBS 5 Pyld WBS 6 S/C WBS 123 PMSEMA WBS 10 I&T TOT w/o LV

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Space Missions Catalog Validation – Results Summary (2015)

(adjTPSM - adjActual)/ adjActual	WBS 5 Pyld	WBS 6 S/C	WBS 123 PMSEMA	WBS 10 I&T	**TOT w/o LV**
Mean	7%	33%	-12%	30%	**5%**
sd	47%	42%	31%	36%	**11%**
cv	6.20	1.28	2.49	1.19	**2.31**
Avg.Abs.	31%	37%	31%	36%	**9%**
sd	32%	37%	17%	31%	**7%**
cv	1.05	0.99	0.53	0.86	**0.76**

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Hardware Catalog Validation – Results Summary (2016)

(adjTPHW - adjActua)/ adjActual	WBS 5 Pyld	WBS 6 S/C	WBS 123 PMSEMA	WBS 10 I&T	**TOT w/o LV**
Mean	-11%	36%	-36%	46%	**1%**
sd	23%	33%	28%	59%	**13%**
cv	2.16	0.93	0.78	1.28	**9.55**
Avg.Abs.	20%	37%	41%	53%	**10%**
sd	15%	32%	20%	52%	**9%**
cv	0.73	0.86	0.49	0.99	**0.89**

Space Missions Catalog Validation (2015) – Results Summary

(adjTPSM - adjActual)/ adjActual	WBS 5 Pyld	WBS 6 S/C	WBS 123 PMSEMA	WBS 10 I&T	**TOT w/o LV**
Mission #1	47%	-2%	5%	78%	**18%**
Mission #2	41%	44%	-63%	29%	**-4%**
Mission #3	-18%	63%	-34%	-3%	**-2%**
Mission #4	16%	9%	6%	-25%	**2%**
Mission #5	-1%	22%	29%	-13%	**12%**
Mission #6	-42%	134%	-41%	70%	**2%**
Mission #8	16%	34%	-50%	27%	**1%**
Mission #9	127%	7%	-34%	79%	**4%**
Mission #10	-4%	51%	12%	2%	**15%**
Mission #12	-27%	-10%	27%	4%	**-8%**
Mission #13	-29%	-14%	-31%	43%	**-17%**
Mission #14	-21%	70%	-30%	14%	**16%**
Mission #16	-10%	20%	40%	85%	**19%**
Mean	7%	33%	-12%	30%	**5%**
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Hardware Catalog Validation (2016) – Results Summary

(adjTPHW - adjActua)/ adjActual	WBS 5 Pyld	WBS 6 S/C	WBS 123 PMSEMA	WBS 10 I&T	**TOT w/o LV**
Mission #1	17%	6%	-38%	45%	**1%**
Mission #2	11%	79%	-68%	84%	**-1%**
Mission #3	-24%	37%	-43%	-1%	**-12%**
Mission #4	7%	1%	-52%	-19%	**-11%**
Mission #5	-6%	23%	-9%	-6%	**6%**
Mission #6	-31%	74%	-41%	110%	**-3%**
Mission #8	28%	51%	-45%	140%	**20%**
Mission #9	-48%	20%	-64%	37%	**-8%**
Mission #10	-1%	39%	-26%	-19%	**0.4%**
Mission #12	-19%	-7%	32%	33%	**0.5%**
Mission #13	-35%	-1%	-61%	26%	**-19%**
Mission #14	-1%	98%	-54%	10%	**24%**
Mission #16	-39%	42%	-3%	153%	**19%**
Mean	-11%	36%	-36%	46%	**1%**
sd	23%	33%	28%	59%	**13%**
cv	2.16	0.93	0.78	1.28	**9.55**
Avg.Abs.	20%	37%	41%	53%	**10%**
sd	15%	32%	20%	52%	**9%**
cv	0.73	0.86	0.49	0.99	**0.89**

Validation Study Comparison-Observed Error Band

Error-Band					
Delta Analysis		**2016 Validation**		**2015 Validation**	
		TRUE-HW		**TPSM**	
Mean		**1%**		**5%**	
St. Dev.		**13%**		**11%**	
Coeff. Var.		**9.55**		**2.31**	
% Delta = (PRICE Estimate) – (Actual "As Built") / Actual "As Built" x 100%					

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Validation Study Comparison-Absolute Error Band

Error-Band					
Delta Analysis		2016 Validation		2015 Validation	
		Hardware Catalog		Space Missions Catalog	
Avg.Abs.		**10%**		**9%**	
St. Dev.		**9%**		**7%**	
Coeff. Var.		**0.89**		**0.76**	
% Delta = (PRICE Estimate) – (Actual "As Built") / Actual "As Built" x 100%					

Lessons Learned: Normalizing Assumptions

- Adjustments Performed Outside Models
  - Typical fee/burden arrangements were accounted for in estimates where applicable
  - Adjustments were mission-unique
- Removed: Contributed Hardware
- Removed: External Impacts
  - Covers costs for items identified in Actuals as beyond scope (or outside a project's ability to control)
- Items Not Accounted For:
  - Launch Vehicle and Education & Public Outreach costs were not included
  - Pre-launch DSN/Ground Network costs were not included in the TPSM value, although may be part of MOS Project costs (relatively small with minor impact)

Lessons Learned: Difficulties Comparing Results

- Most projects have their own way of covering management, systems engineering, mission assurance, and I&T functions
  - Similar PM/SE/MA/I&T functions may be carried in WBS 1/2/3/10 by one project and in WBS 5/6 in another, skewing results
  - Some I&T allocations needed to be estimated if cost detail was not available
  - Comparisons include all Project PM/SE/MA/I&T functions against the WBS 1/2/3/10 estimate
- Programmatic differences also affect comparisons
  - Issues related to IAT, Full Cost Accounting, and other programmatic issues/initiatives may not be fully captured

Final Thoughts: Tool Comparison

- Space Missions Catalog
  - Allocates costs to Design, Fabrication, AI&T and Launch Opns phases
  - Estimates System-level "wrap" support functions: project management, mission analysis, system engineering, safety & mission assurance, science/ technology, MOS, A&I support, system test, GSE
  - Allows for distinction between Mission Classes: A/B vs C/D
  - Has dedicated CER models for Laser, Thermal, Electric Propulsion, Ion Thruster, Radar Altimeter and Parachute
  - Based on NASA-mission calibrations
- Hardware Catalog
  - Supports use of previously calibrated input drivers
  - Supports existing post-processors for system-level wrap functions
  - Works with other System, Assembly and Hardware objects
  - Based on combination of data sources: PRICE Knowledge Network, spacecraft bus component calibrations and PRICE-proprietary tools

Questions?