

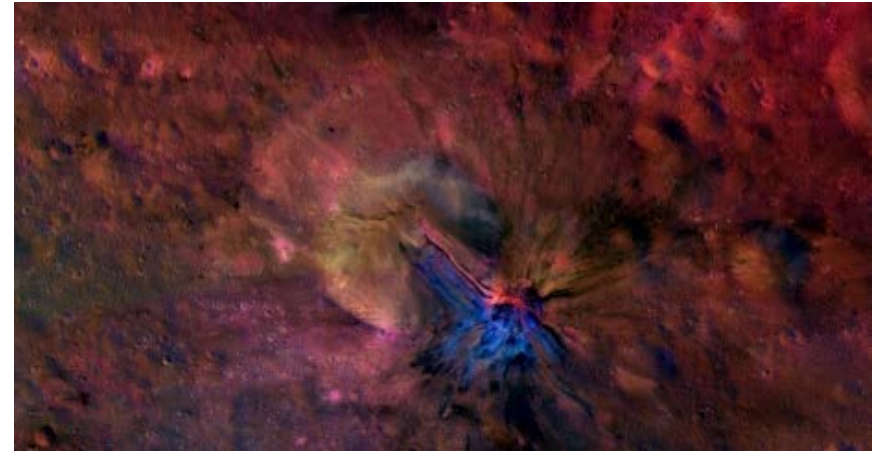


**Exploring the of Results of two Methodologies
for Unmanned Space Estimation:
Space Missions Catalog – 2015
Hardware Catalog – 2016**

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**



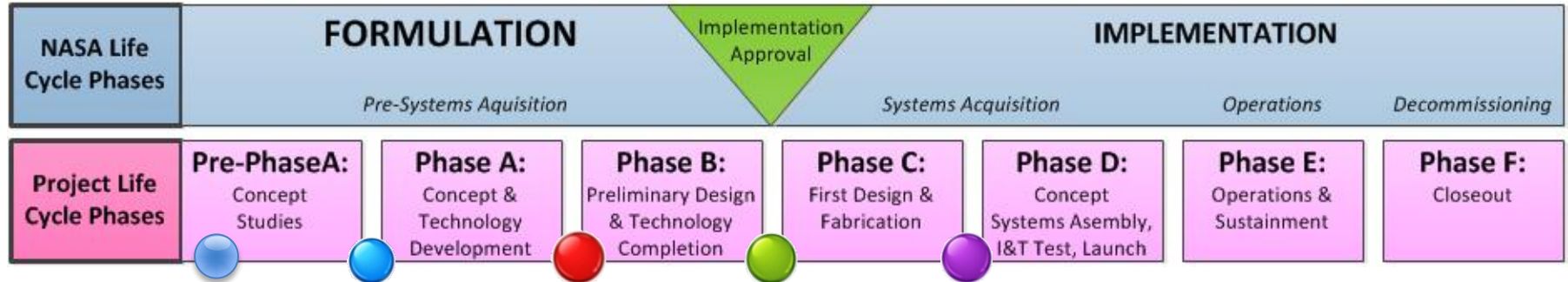
Abstract

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

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

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

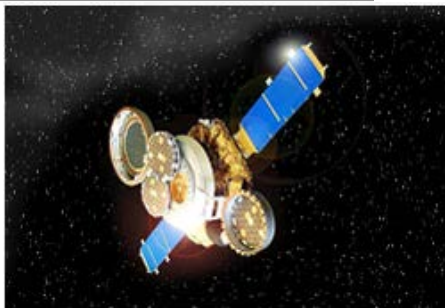
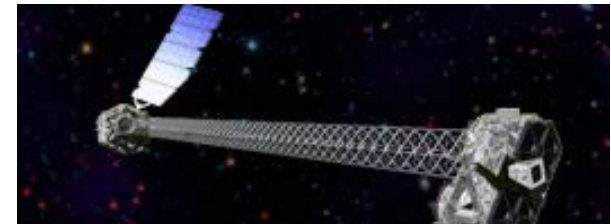
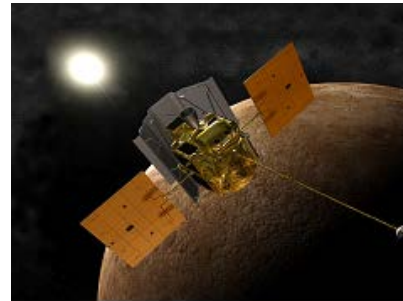
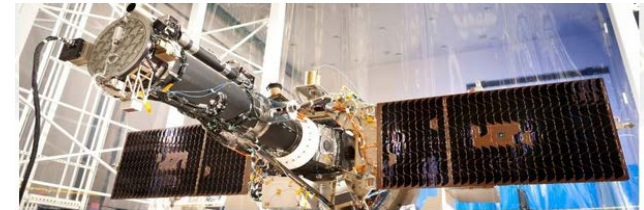
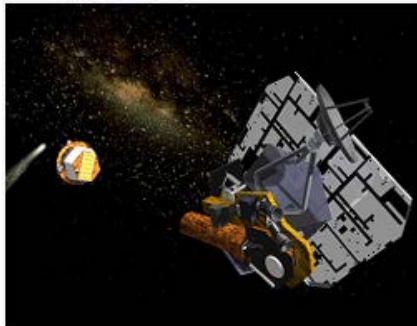
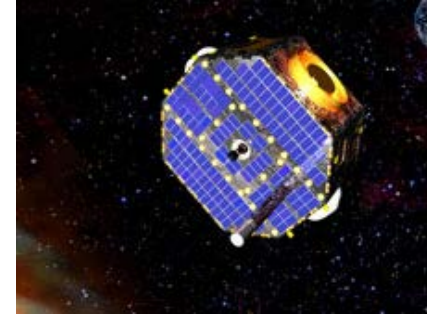
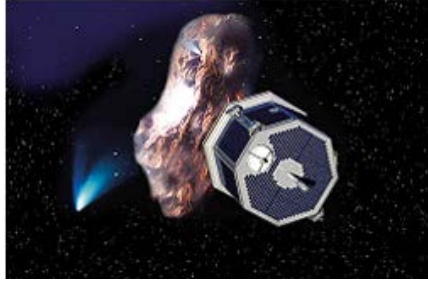
- Bruce Fad
- Chris Price
- Pete Stanley
- John Swaren
- Melissa Winter

■ Partners

- Mark Jacobs
- Shawn Hayes



13 Past Unmanned Missions



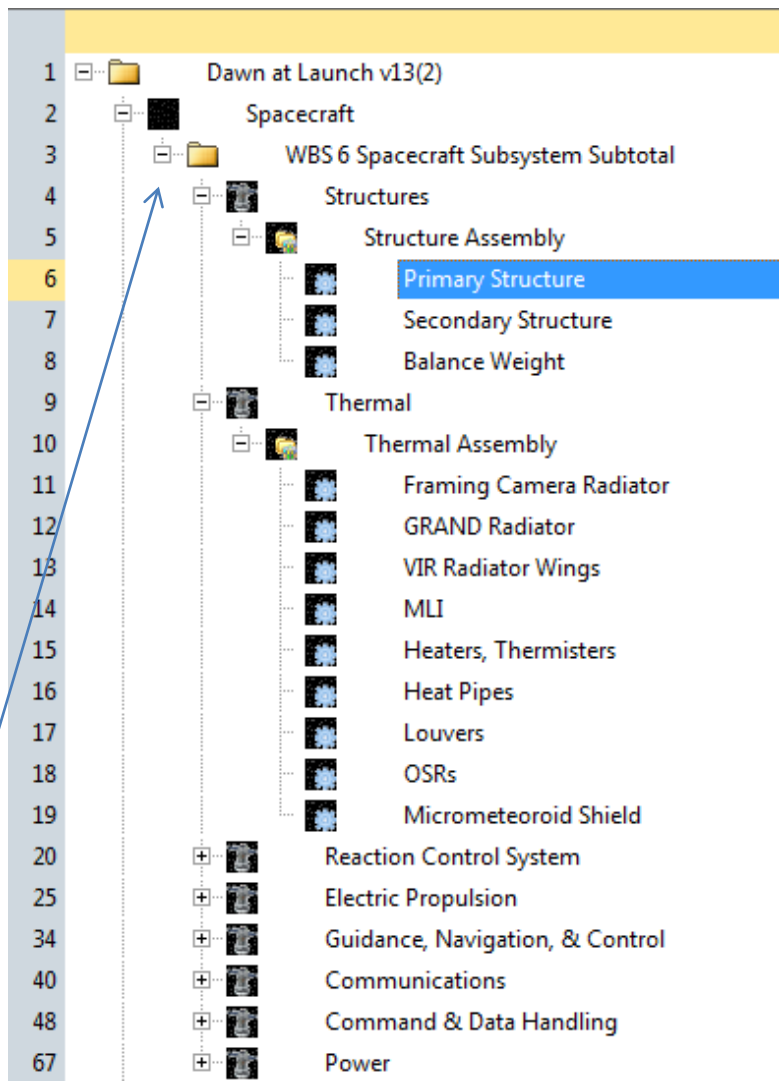
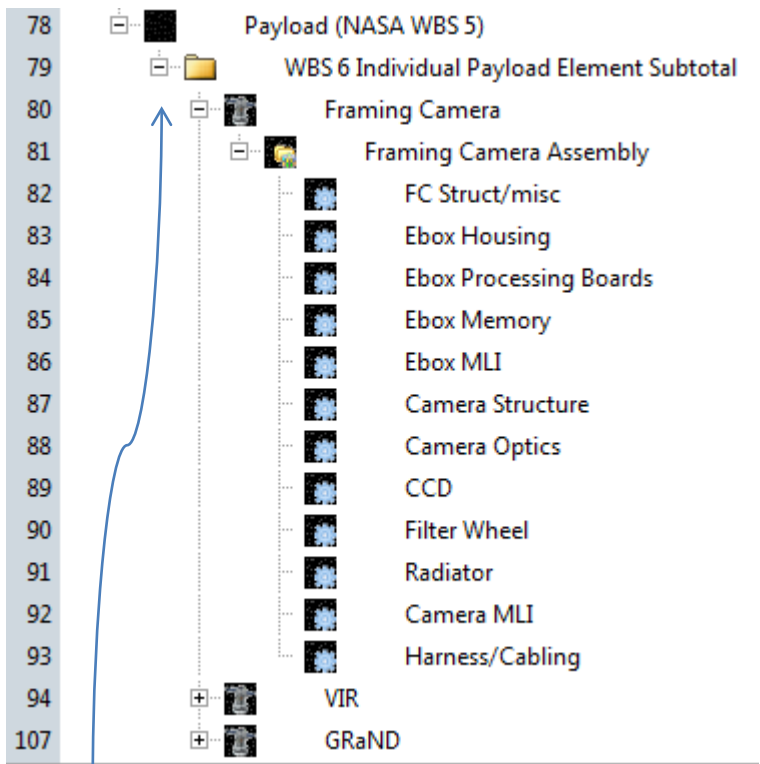
Missions Used for Validation Studies

- 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	Planetary/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

Flight configuration

Launch configuration

Reaction Wheels

Antennas

Max-Planck-Institut für Sonnensystemforschung (MPS)
Deutsches Zentrum für Luft und Raumfahrt
Institut für Raumfahrtforschung (DLR DFVLR)

Gamma Ray and Neutron Detector (GRaND)

Star Trackers

Framing Cameras (FC)

MASTER EQUIPMENT LIST Template

Instrument	Subsystem/Component	Current Estimate
GRaND	BGO Crystal - det	0.75
	BGO R/O electr	0.50
	CZT - det	0.50
	CZT - R/O electr	0.50
	PMTs	0.50
	Plastic Scintillators	0.50
	Microcontoller	0.50
	Memory	0.50
	HVPS	0.50
	Misc PMAD	0.50
	Structure	1.90
Instrument #3 Total		

PRICE TruePlanning 14.2 - [Dawn at Launch v15 Nov2014*]

Product Breakdown Structure

- Dawn at Launch v15 Nov2014
 - Spacecraft
 - WBS 6 Spacecraft Subsystem Subtotal
 - Payload (NASA WBS 5)
 - WBS 6 Individual Payload Element Subtotal
 - Framing Camera
 - VIR
 - GRaND
 - GRaND Assembly
 - BGO detector
 - BGO R/O electronics
 - CZT detector
 - CZT R/O electronics
 - PMTs
 - Scintillators
 - Control Electronics
 - Memory
 - HVPS
 - Misc PMAD
 - Structure

Input Sheet: BGO detector

Cost Objects | Input Sheet | Attributes | Results | Chart | Metrics | Schedule | Risk Analysis

BGO detector

Cost	\$2,229,002	0.73%	Labor Requirement
Project Cost	\$303,936,343		Project Labor Requ

Worksheet Set: [Chicomo <Inherited>](#)

	Value	Units
2 Subsystem Type	Sensor Systems	
3 Component Type	Gamma Sensor	
4 Quantity Per Next Higher Level	1.00	
Additional Units		
6 Number of Additional Production Units	1.00	
7 Number of Additional Prototypes	1.00	
Cost Sharing Units		
9 Total Number of Production Units Produced	0	
10 Total Number of Prototypes Produced	0.00	
Technical Description		
12 Equipment Type	None	
13 Operating Specification	2.25	
14 Weight of Structure	0.221	kg
15 Weight of Electronics	0.529	kg
16 Volume	0.864	l
17 Manufacturing Complexity for Structure	8.370	
18 Percent of New Structure	75%	%
19 Percent of Design Repeat for Structure	0%	%
20 Manufacturing Complexity for Electronics	10.974	
21 Percent of New Electronics	75%	%
22 Percent of Design Repeat for Electronics	0%	%
23 Engineering Complexity	0.490	

Space Missions Calculator

Knowledge Based Wizard

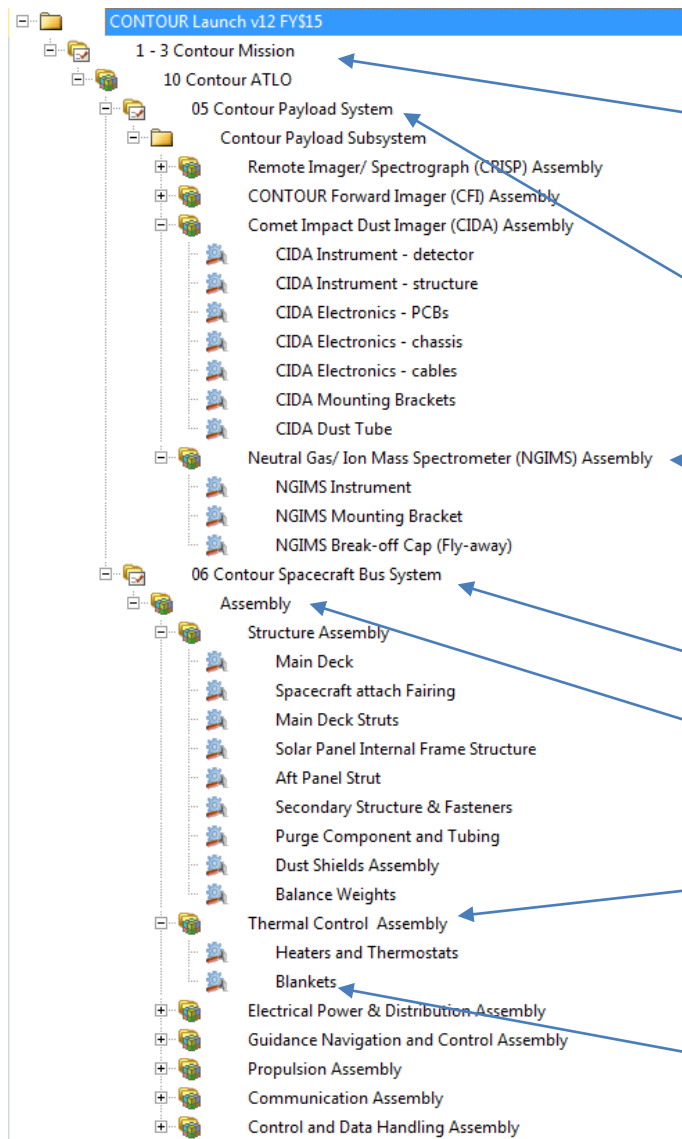
The screenshot displays the PRICE TruePlanning 14.2 software interface. On the left, a 'Product Breakdown Structure' tree shows a hierarchy starting with 'AIM Proposal v9 FY15', leading to '1 - 3 AIM Mission', '10 AIM ATLO', '05 AIM Payload System', and '06 AIM Spacecraft Bus System'. Under '06 AIM Spacecraft Bus System', an 'Assembly' is expanded to show 'Attitude Control (ADC) Assembly', which includes components like 'RW', 'RW Electric', 'Torque Rods', 'Mag', 'Star Tracker CT-633', 'Coarse Sun Sensor', and 'LN-200S rate sensor'. Other assemblies shown include 'Power Assembly', 'CDH Assembly', 'Structure Assembly', 'Thermal Assembly', and 'COMM Assembly'.

The central 'Worksheet Set: Space v4' shows a table with columns for 'Section Name' and 'Input Field'. The 'Equipment Type' row is highlighted, and a dropdown menu is open, showing options: 'Copy/Build to Print' (selected), 'Minimal Mod', 'Significant Mod', and 'New'. A tooltip for 'Copy/Build to Print' states: 'Copy refers to a component that is off the shelf'. Below the table, a 'Tables and Calculators' dialog box displays calculated values for the selected 'Equipment Type':

Operating Specification	2.00
Total Weight	2.062 kg
Weight of Structure	2.062 kg
Weight of Electronics	0.000 kg
Volume	3.218 l
Manufacturing Complexity for Structure	9.647
Manufacturing Complexity for Electronics	0.000
Percent of New Structure	20.00% %
Percent of New Electronics	20.00% %
Engineering Complexity	0.20

The bottom of the dialog box has 'OK' and 'Cancel' buttons.

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

Hardware Knowledge Based Wizard

Tables and Calculators

Equipment Type
The Equipment Type describes typical equipments that are commonly developed and produced.

When you select an Equipment Type from the available values, values are automatically calculated for Operating Specification, Total Weight, Weight of Structure, Volume, Manufacturing Complexity for Structure, and Manufacturing Complexity for Electronics based on industry standard values from PRICE System's cost research on equipment types. These values may be changed by the user if their organizational specific database indicates better values.

Show Descriptions

Section Name	Input Field
Operating Environment	Unmanned Space - Earth Orbiting
Function	Thermal Control
Equipment Type	Heater/Thermister/Thermostat
Total Weight	19.3038
Heritage Structure	Significant Mod

Operating Specification	2.000
Total Weight	19.3038 lbs
Weight of Structure	19.3038 lbs
Weight of Electronics	0.0000 lbs
Volume	0.483 ft ³
Manufacturing Complexity for Structure	7.789
Manufacturing Complexity for Electronics	0.000
Percent of New Structure	80.00% %
Percent of New Electronics	80.00% %
Engineering Complexity	0.800

OK Cancel

- Aerospace
- Commercial Airborne
- Commercial Land Mobile
- Military Airborne
- Military Land Mobile
- Military Water Mobile
- Missile
- Legacy Unmanned Space
- Unmanned Space - Planetary
- Unmanned Space - Earth Orbiting

-
- Propulsion
- Spacecraft Attitude Control
- Electrical Power
- Payload
- Spacecraft Electronic Chassis
- Structures and Mechanisms
- Thermal Control
- Communications

-
- Heat Pipes
- Heater/Thermister/Thermostat
- Mirror
- Miscellaneous Passive Thermal
- MLI Blanket/Insulation/Paint/Shroud
- Optical Solar Reflector
- Radiator/Lou

-
- OTS/Block Buy
- Copy/Build to Print
- Minimal Mod
- Significant Mod
- New

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

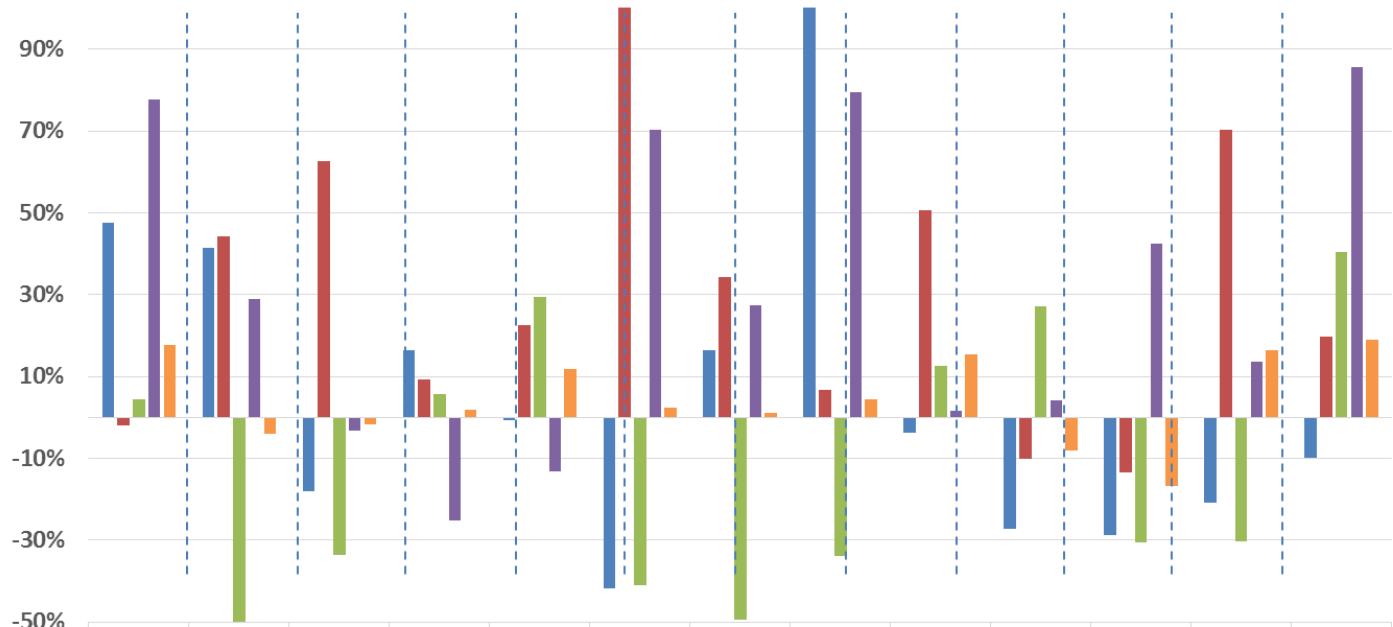
Study Results:

Space Missions Catalog (2015)

Hardware Catalog (2016)

Space Missions Catalog – Validation Results (2015)

Summary of TPSM Preliminary Validation Results

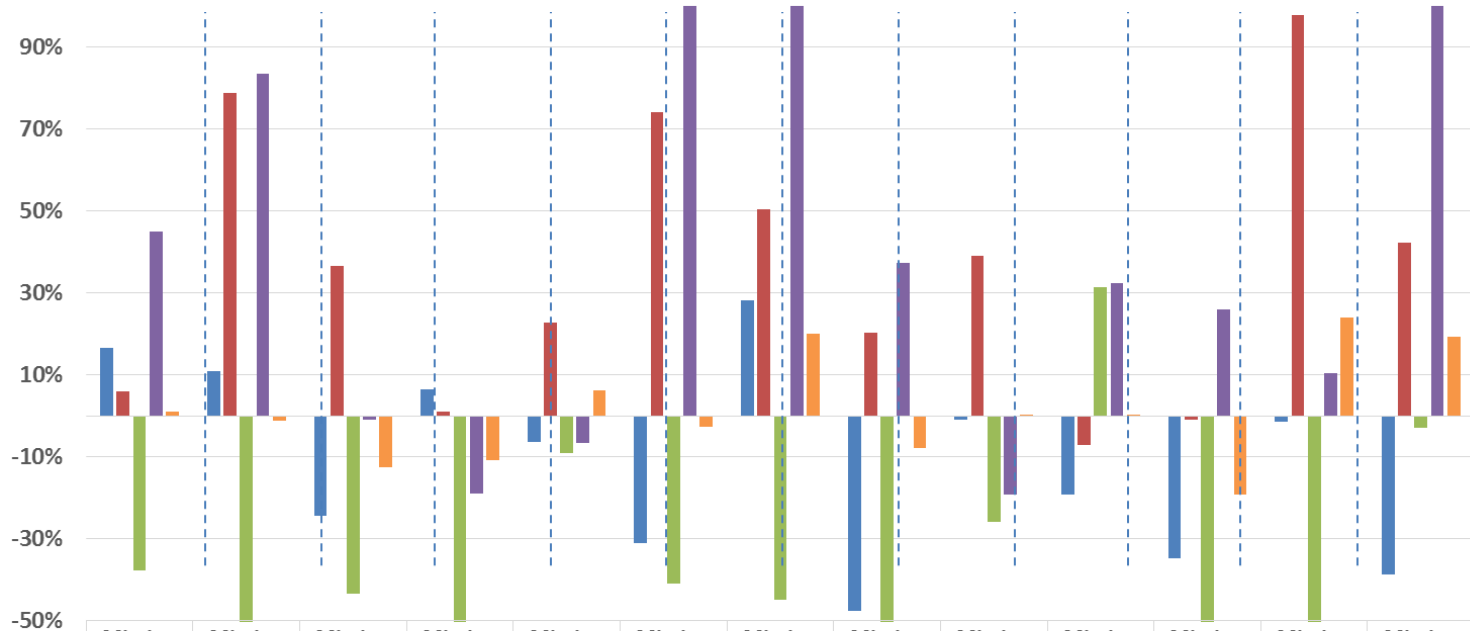


	Mission #1	Mission #2	Mission #3	Mission #4	Mission #5	Mission #6	Mission #8	Mission #9	Mission #10	Mission #12	Mission #13	Mission #14	Mission #16
■ WBS 5 Pyld	47%	41%	-18%	16%	-1%	-42%	16%	127%	-4%	-27%	-29%	-21%	-10%
■ WBS 6 S/C	-2%	44%	63%	9%	22%	134%	34%	7%	51%	-10%	-14%	70%	20%
■ WBS 123 PMSEMA	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

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

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

Hardware Catalog Validation – Results Summary (2016)

$(adjTPHW - adjActual) / adjActual$	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

<i>(adjTPSM - adjActual)/ adjActual</i>	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%
sd	47%	42%	31%	36%	11%
cv	6.20	1.28	2.49	1.19	2.31
Avg.Abs.	31%	37%	31%	36%	9%
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Hardware Catalog Validation (2016) – Results Summary

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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	
$\% \text{ Delta} = (\text{PRICE Estimate}) - (\text{Actual "As Built"}) / \text{Actual "As Built"} \times 100\%$					

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	
$\% \text{ Delta} = (\text{PRICE Estimate}) - (\text{Actual "As Built"}) / \text{Actual "As Built"} \times 100\%$					

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?

