TruePlanning® *Space Missions (TPSM)*

Validation Testing

NASA Cost Symposium 2015
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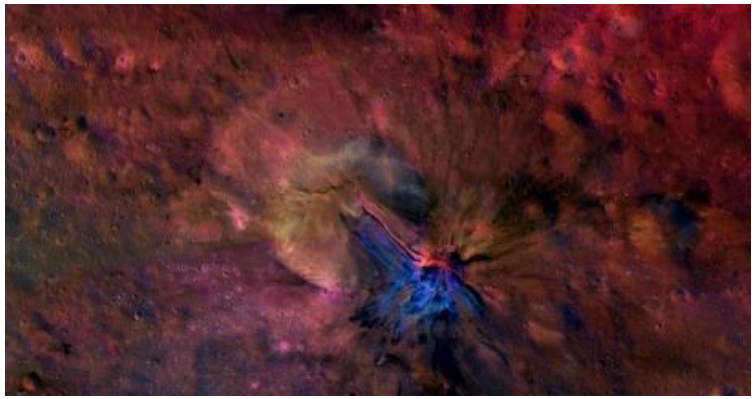
PRICE Systems LLC

Outline

1. **TPSM Overview**
2. **Validation Study Approach**
3. **Preliminary Results**
   a) Mission-level
   b) WBS-specific:
      - *WBS 5 - Payload*
      - *WBS 6 - S/C Subsystems*
      - *WBS 10 - I&T*
      - *WBS 1/2/3 - PM/SE/MA*
      - *WBS 4/7/9 - GDS/MOS/Science*
4. **Findings / Observations**



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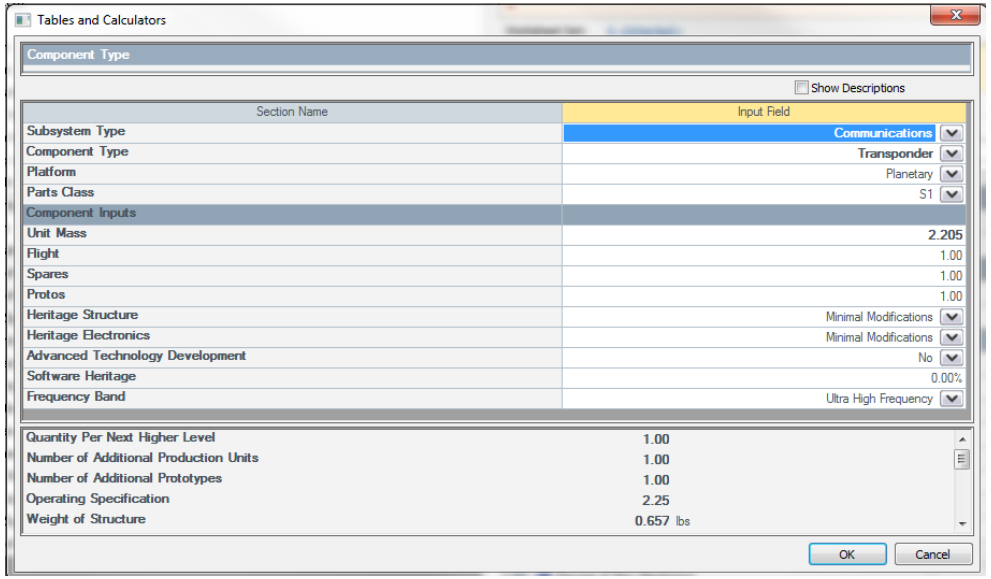
Space Missions Model Overview

- Cost estimating for Formulation through Implementation for robotic Earth and Space Science Missions
- Used supporting NASA mission analyses for 25 years
  - 1989: initially developed to support NASA's Discovery Program
  - Applied to Mars Pathfinder and NEAR
  - 1991: Major modification to incorporate PRICE H
  - Used for NASA's first Discovery AO (Announcement of Opportunity) evaluation in 1994
  - Periodic updates from 1994-2014

Space Missions Implementation

- Implementation of PRICE TruePlanning® for Hardware specifically tailored for estimation of Space Missions



Subsystem / Component
STRUCTURE & MECHANISMS
Primary Structure
Secondary Structure
Shielding
Solar Array Substrate/Structure
HGA Structure
Electronics Boxes
Mechanisms
Motor/Actuator
Booms
ROBOTIC ARM
Robotic Arm - Limb
Robotic Arm - Joint/Actuator
THERMAL CONTROL
MLI, Paints, Coatings
Heaters, RHUs, Thermostats
Radiators/Louvers
Heat Pipes
Cryocooler
PROPULSION
Propulsion Lines/Valves/Fittings
Pressure Regulator
Tanks
Thrusters
ELECTRIC PROPULSION
Ion Thruster *
Power Processing Unit *

Subsystem / Component
GUIDANCE, NAVIGATION, & CONTROL
Star Tracker
Sun Sensor
Reaction Wheel
Torque Rod
Gimbals
IMU-Gyro
Actuators
Radar Altimeter *
COMMUNICATIONS
Transponder
Transmitter
Amplifier
Misc RF Electronics
HGA
MGA/LGA
Waveguide/Comm Cabling
COMMAND & DATA HANDLING
Command/Data Processing
Solid State Memory
POWER
Power Management and Distribution
Solar Cells/Electrical
Pyrotechnics
Batteries
Harness

Subsystem / Component
ENTRY & DESCENT
Themal Protection System *
Parachute *
OPTICS
Optical Bench
Optics
Gratings
Filter Wheel
Optics Filters/Misc
SENSOR SYSTEMS
Laser *
Sensors-Detectors
CCD Detectors
Magnetometer
TOF Spectrometer
ESA sensor
Photodiode
Bolometer
Ion Source
Gamma Sensor
Neutron Sensor
Dust Detector
Readout Electronics

- Component-Level Cost Estimating Methodology
  - Spacecraft/Instrument component types cover all space subsystem functions
  - Flight Element (Spacecraft) and Instrument Estimates are built up from a user-defined combination of subsystem and component-level estimates
  - Space Mission Component level inputs drive the inputs for the PRICE TruePlanning® model for Hardware

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Space Missions Mapping to NASA WBS

- Development Phases:
  - **Design:** these costs come directly from the TruePlanning ®Hardware model
  - **Fabrication:** these costs come directly from the TruePlanning ® Hardware Model
  - **Assembly Integration and Test:** these costs are a function of the Design & Fabrication costs
  - **Launch Operations:** these costs are a function of Design and Fabrication costs
- Project Support Functions:
  - Project Management
  - Mission Analysis
  - System Engineering
  - Safety and Mission Assurance
  - Science/Technology
  - Mission Operation System (MOS)
  - Assembly and Integration Support
  - System Test
  - Ground Support Equipment

These costs apply to all phases

Milestones: ATP → CDR→SIR→ Ship

WBS	Design	Fab	I&T	Launch Ops
1) Project Management				
2) Systems Engineering (w/ Mission Analysis)				
3) Mission Assurance				
4) Science/ Technology				
5) Payload (w/ details by subsystem)				
6) Spacecraft (w/ details by subsystem)				
7&9) MOS/GDS Dev				
10) System I&T (w/ Ground Support Equip)				

Space Missions estimated costs align with the NASA WBS and provide phasing details

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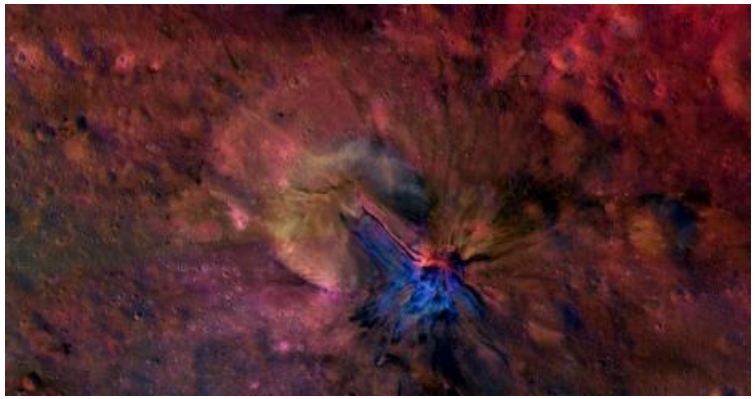

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Space Missions Validation Approach

- A validation using 12 recent NASA robotic Earth and Space Science Missions has been conducted
  - CADRe used as primary data source for technical, programmatic, and cost
- An Excel I/F has been developed to facilitate the effort
  - Excel more readily interfaces with technical data sources
  - Currently accommodates 5 separate Flight Systems (S/C) and 10 Instrument Elements
  - Incorporates significant flexibility for subsystem definitions and component allocations
  - Allows changes to technical, schedule, and programmatic drivers that are typically defined in project documentation (and are not necessarily TPSM-specific)
  - The I/F also helps maintain consistency between estimates

Space Missions Excel Interface

- The Excel I/F has 4 separate input areas
  - The first 2 include mass breakdowns for each instrument and s/c subsystem with component-type specific characterization for each item

MISSION NAME														
PAYLOAD MASTER EQUIPMENT LIST														
		# OF UNITS			FLIGHT HARDWARE MASSES			OTHER COMPONENT INFORMATION		TPSM COST MODEL INPUTS				
Subsystem/Component	Unit Mass, Current Best Estimate (CBE)	Flight Units	Flight Spares	EMs & Proto-types	Total Mass, CBE	Contingency %	Total Mass w/ Contingency	Description (Vendor, Part #, Heritage Basis)	Other characteristics/issues (volume, power, other component-specific items)	Heritage	New or Advanced Tech	Subsys	Comp	Type
Instrument Item #1														

  - Programmatic inputs are also captured (Fees/Burdens are added outside TPSM)

	Phase B start	PDR [1]	CDR	Deliver to System I&T	Ship to Launch Site	Launch	On-Orbit Chect-Out (L+30d)
Project	1/2/2003	10/14/2003	6/15/2004	2/1/2005	4/6/2007	9/27/2007	10/27/2007
Flight Element #1	1/2/2003	10/14/2003	6/15/2004	2/1/2005	4/6/2007	9/27/2007	

  - "External Impact" costs are added outside TPSM on a case-by-case basis

	Platform ("EO" or "P")	Parts Class (S,S1,B,B 1,B2,D)	Internati onal ("Y" or "N")	Contracti ng Fee	Contract Monitor Burden	# of Flight Units	Notes	Mission Class
Flight Element #1	P	S1	N			1		Class A/B

Missions Used for TPSM Validation

- The preliminary validation included 12 recent missions
  - Candidates covering Earth Science have been identified and will be included in future validation efforts
  - An Excel I/F file and TPSM PRICE file have been created for each mission

#	MISSION	Launch Date	Lead Org PM	Lead Org Flt Sys	NASA Program
1	MAVEN	11/18/13	GSFC	LMA	Planetary
2	IRIS	6/27/13	GSFC	LMMS	Astrophysics/SMEX
3	NuSTAR	6/13/12	JPL	OSC	Astrophysics/Explorer
4	GRAIL	9/10/11	JPL	LMA	Planetary/Discovery
5	Juno	8/5/11	JPL	LMA	Planetary/New Frontiers
6	WISE	12/14/09	JPL	BATC	Astrophysics/Explorer
7	IBEX	10/19/08	SwRI	OSC	Astrophysics/Explorer
8	Dawn	9/27/07	JPL	OSC/JPL	Planetary/Discovery
9	AIM	4/25/07	LASP	OSC	Heliophysics
10	STEREO	10/26/06	GSFC	APL	Heliophysics
11	NEW HORIZONS	1/19/06	APL	APL	Planetary/New Frontiers
12	MESSENGER	8/3/04	APL	APL	Planetary/Discovery
		Earth Sci	Heliophy		
		Astrophy	Planetary		

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Adjustments Performed Outside TPSM

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

Difficulties Comparing Cost 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 TPSM WBS 1/2/3/10 estimate
- Programmatic differences also affect comparisons
  - Issues related to NIAT, Full Cost Accounting, and other programmatic issues/initiatives may not be adequately captured in this preliminary validation

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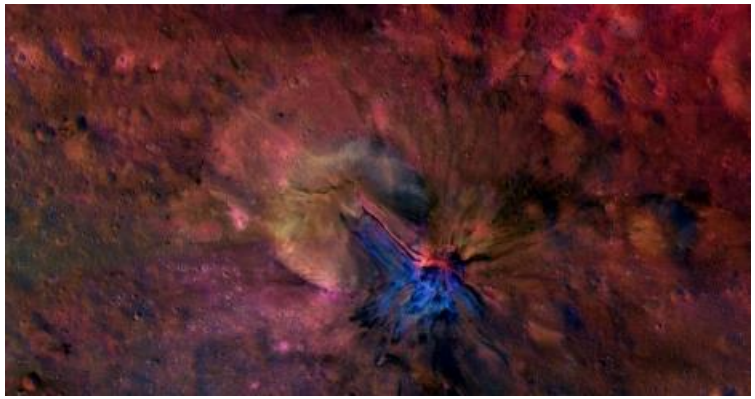

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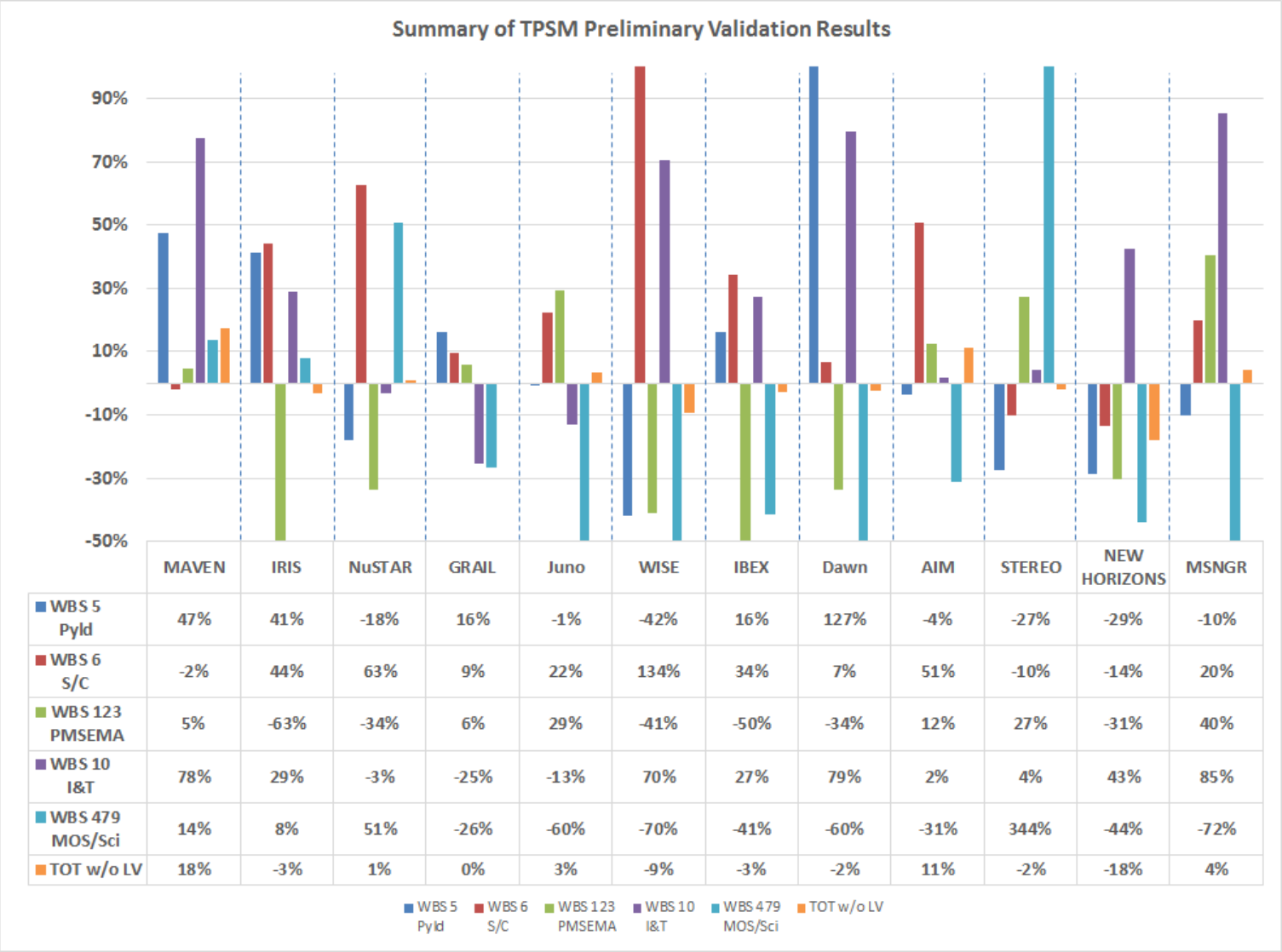
TPSM Validation – Results Summary



	MAVEN	IRIS	NuSTAR	GRAIL	Juno	WISE	IBEX	Dawn	AIM	STEREO	NEW HORIZONS	MSNGR
WBS 5 Pyld	47%	41%	-18%	16%	-1%	-42%	16%	127%	-4%	-27%	-29%	-10%
WBS 6 S/C	-2%	44%	63%	9%	22%	134%	34%	7%	51%	-10%	-14%	20%
WBS 123 PMSEMA	5%	-63%	-34%	6%	29%	-41%	-50%	-34%	12%	27%	-31%	40%
WBS 10 I&T	78%	29%	-3%	-25%	-13%	70%	27%	79%	2%	4%	43%	85%
WBS 479 MOS/Sci	14%	8%	51%	-26%	-60%	-70%	-41%	-60%	-31%	344%	-44%	-72%
TOT w/o LV	18%	-3%	1%	0%	3%	-9%	-3%	-2%	11%	-2%	-18%	4%

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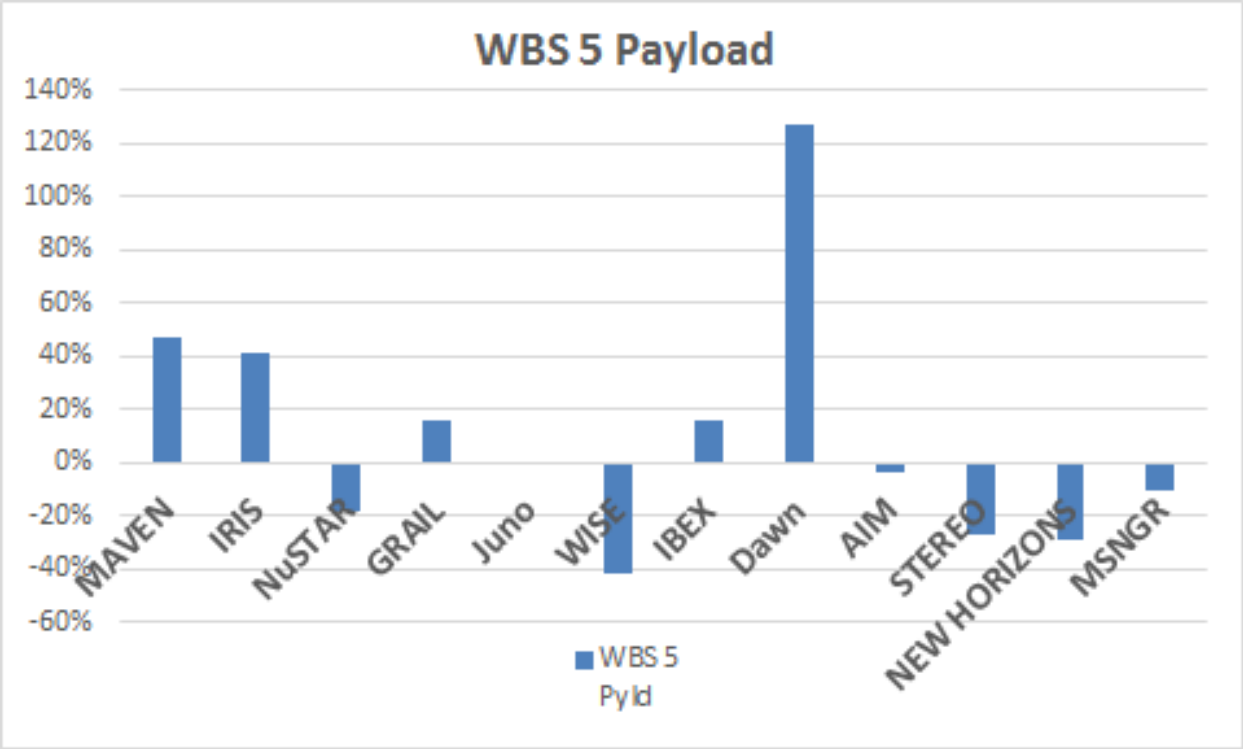
TPSM Validation –Payload Results



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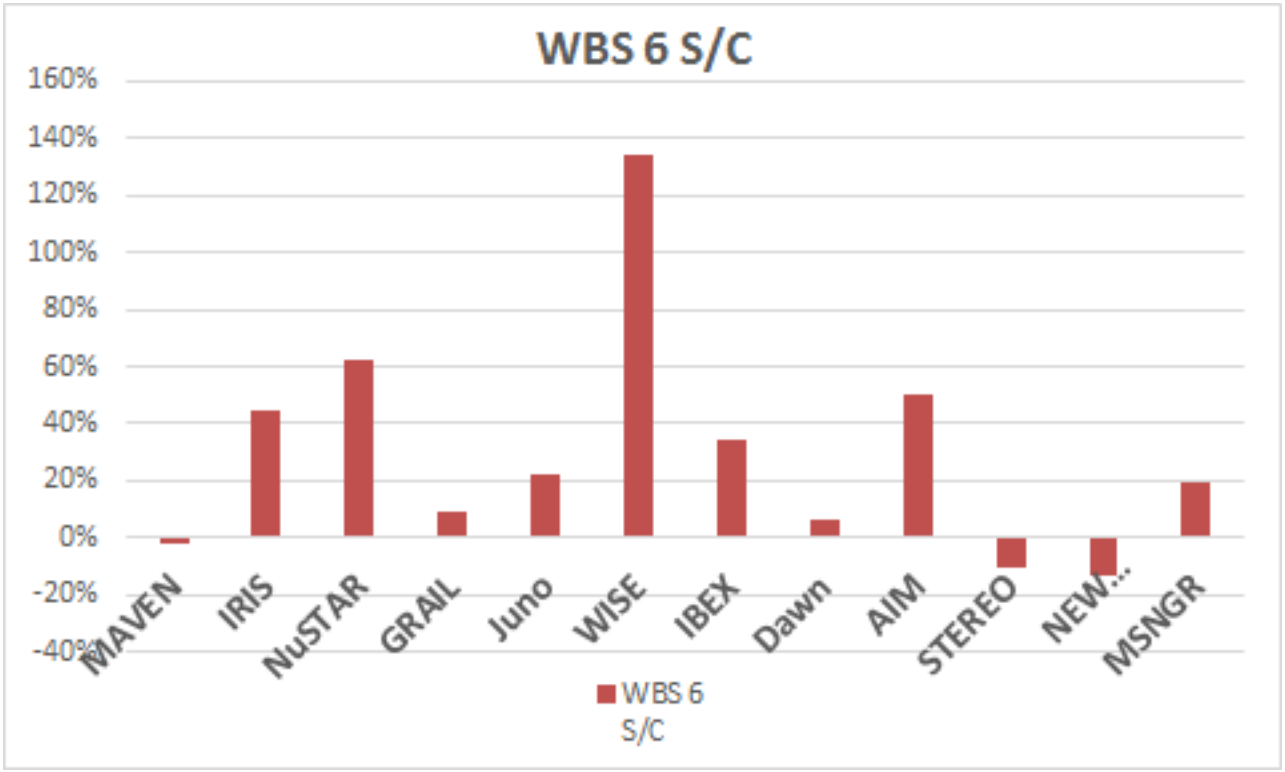
TPSM Validation – S/C Subsystem Results



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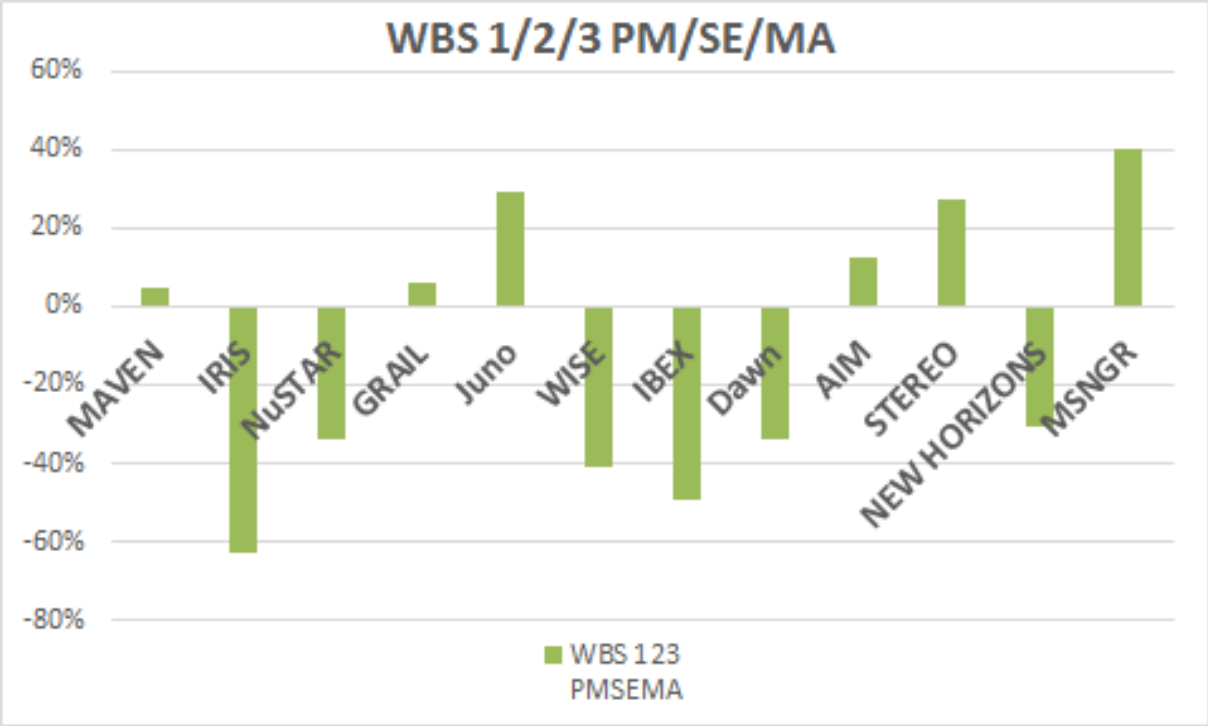
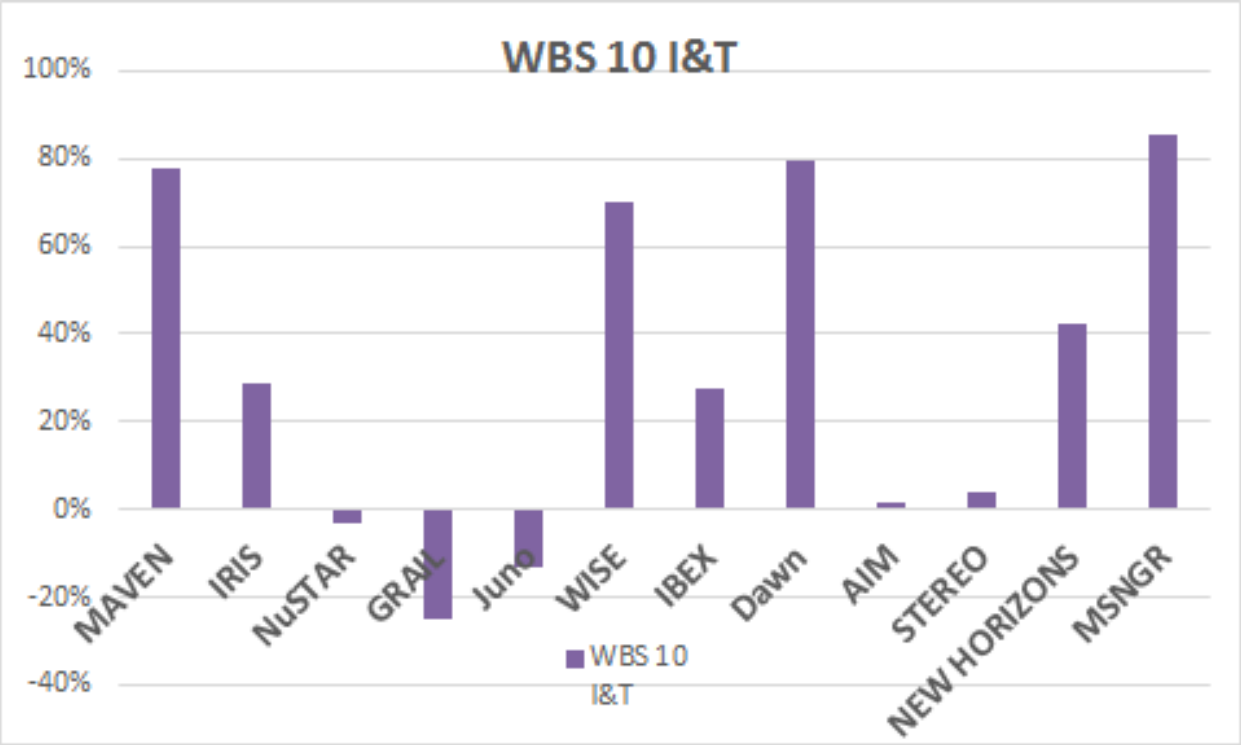
TPSM Validation – PM/SE/MA Results



TPSM Validation – I&T Results



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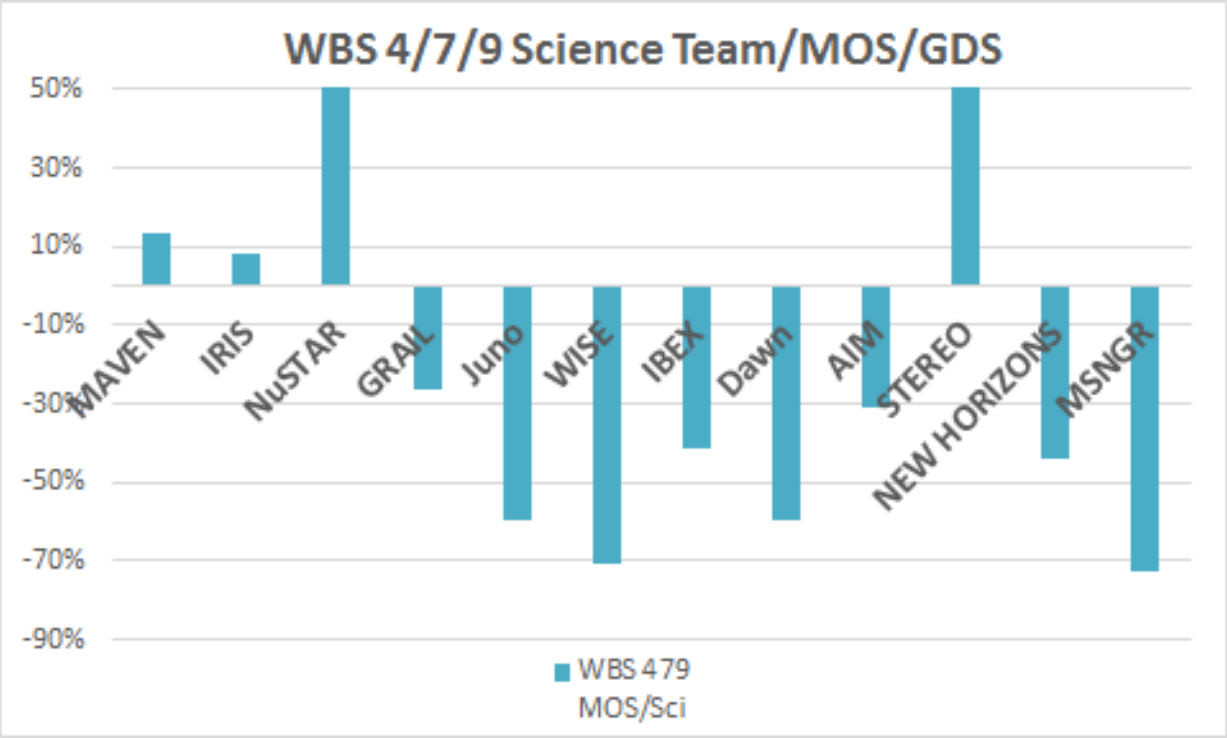
TPSM Validation – GDS/MOS/Science Results



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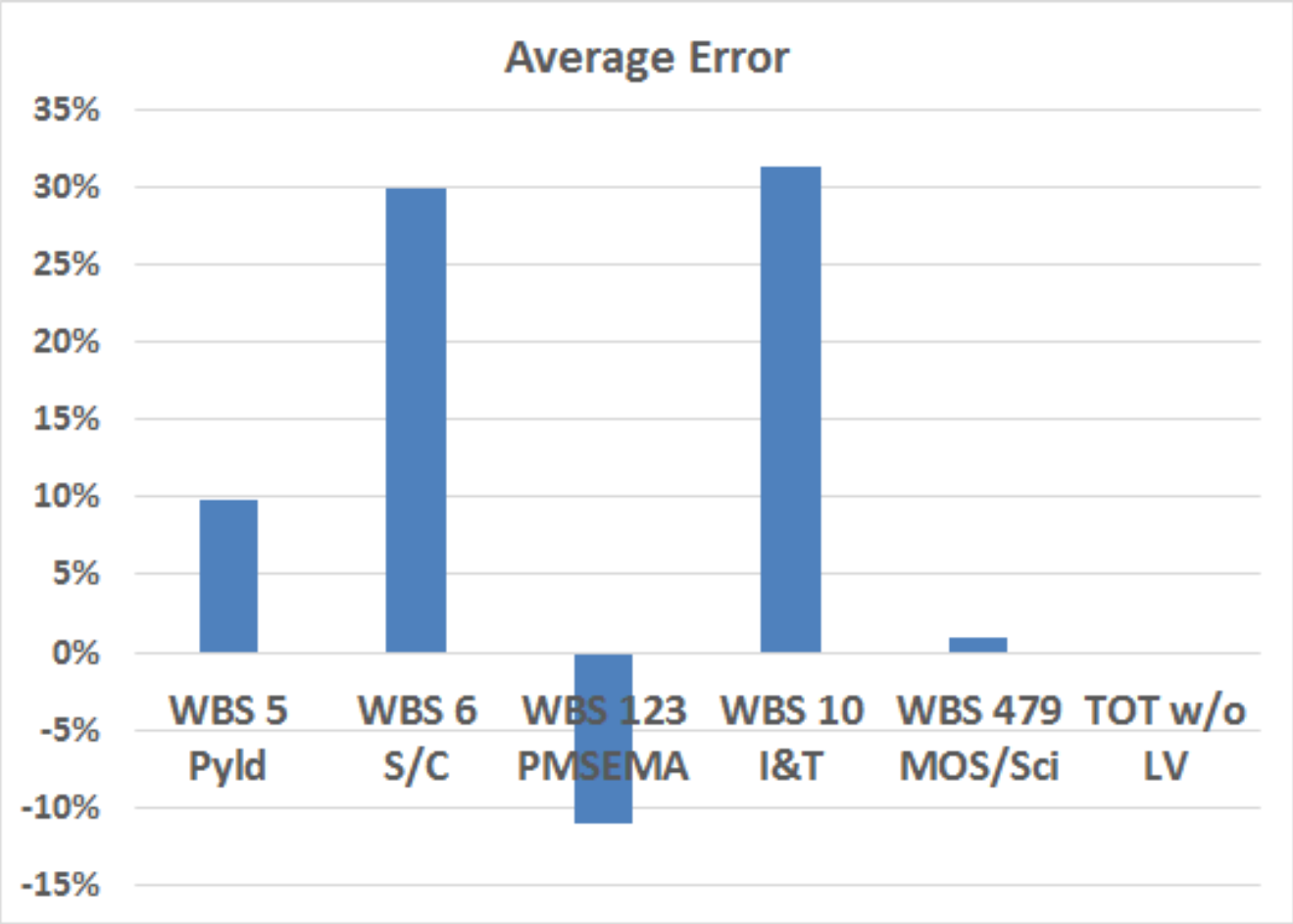
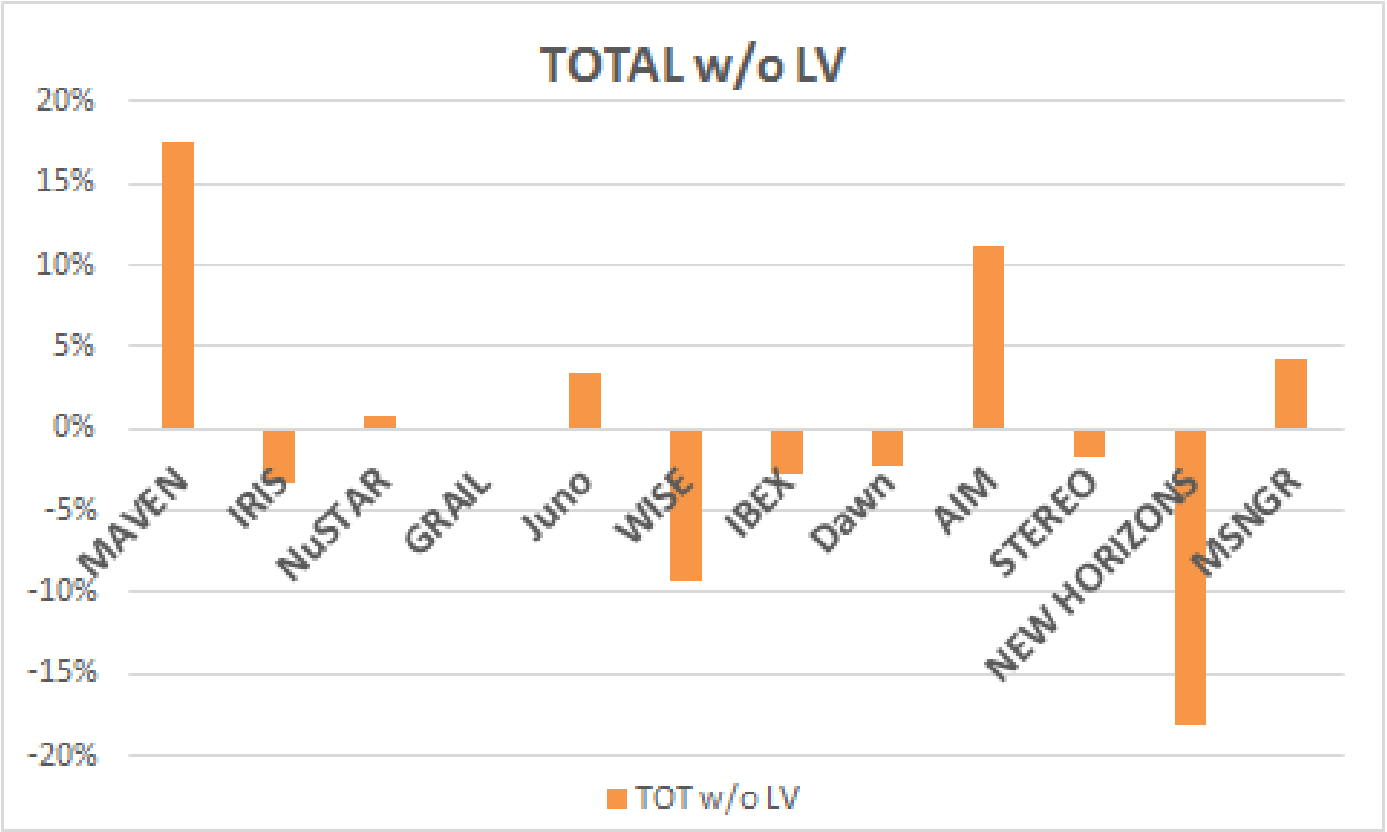
TPSM Validation – Average Error by WBS



TPSM Validation – Mission-level Results



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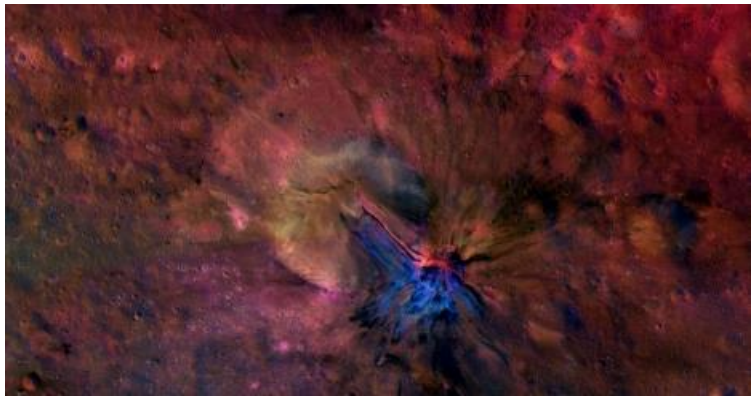

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TPSM Validation Findings & Observations

- Bottom-line results are very promising, with an average error of nearly 0% and most projects within +/-10%
  - Lower-level WBS differences are offsetting
  - Results for the Payload and S/C are +/- 20% (Avg. Error of ~5%)
  - Largest WBS differences were for Science Team + MOS/GDS; Since the Science Team is often passed-thru for the estimates, it is being considered for exclusion from future validation efforts
- Additional effort is needed to refine the validation run files and Excel I/F
  - Runs need to be reviewed to ensure accuracy for capturing inputs
  - More missions need to be added to the validation
  - An approach for allocating PM/SE/MA/I&T between WBS 1/2/3/10 and WBS 5/6 can facilitate result comparisons

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Wrap-up: More Information

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Learn more about TruePlanning® 2014

pricesystems.com/en-us/offerings/trueplanningframework.aspx

Call 1-800-43-PRICE or email: robert.becker@pricesystems.com

Request more information

pricesystems.com/en-us/requestinfo.aspx

Thank You!

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BACKUP

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Introduction - TruePlanning®

- TruePlanning® (TP) is an activity-based Resource Consumption Accounting (*RCA*) and Cost Analysis Tool
- TruePlanning® Estimation Framework consists of:
  - ***TrueAnalyst®*** is the application used by PRICE personnel to construct reusable activity-based RCA cost estimating models
  - ***TruePlanner®*** is the application which integrates the TP cost models with schedule and financial information through a robust software architecture and implementation called the TP Framework
  - ***SQL Database*** contains cost models and saved projects

TruePlanning® is an integrated set of cause and effect models. It identifies the primary cost drivers through statistical relationships and applies cost effects through the use of mathematically sound algorithms.

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TruePlanning® Methodology

- TruePlanning® is a set of Parametric Models executed using an Activity-Based Costing approach

- Parametric Modeling is:
  - An Operations Research Discipline
  - Relies on …
    - *Mathematical models of real life situations*
    - *The application of these models to new projects and technologies*
  - Relies heavily on historical data
    - *Data is reviewed and important cost drivers are identified*
    - *Regression analysis is used to determine cost estimating relationships*
    - *Results can then be refined with additional data and extrapolated to new projects, technologies and processes*

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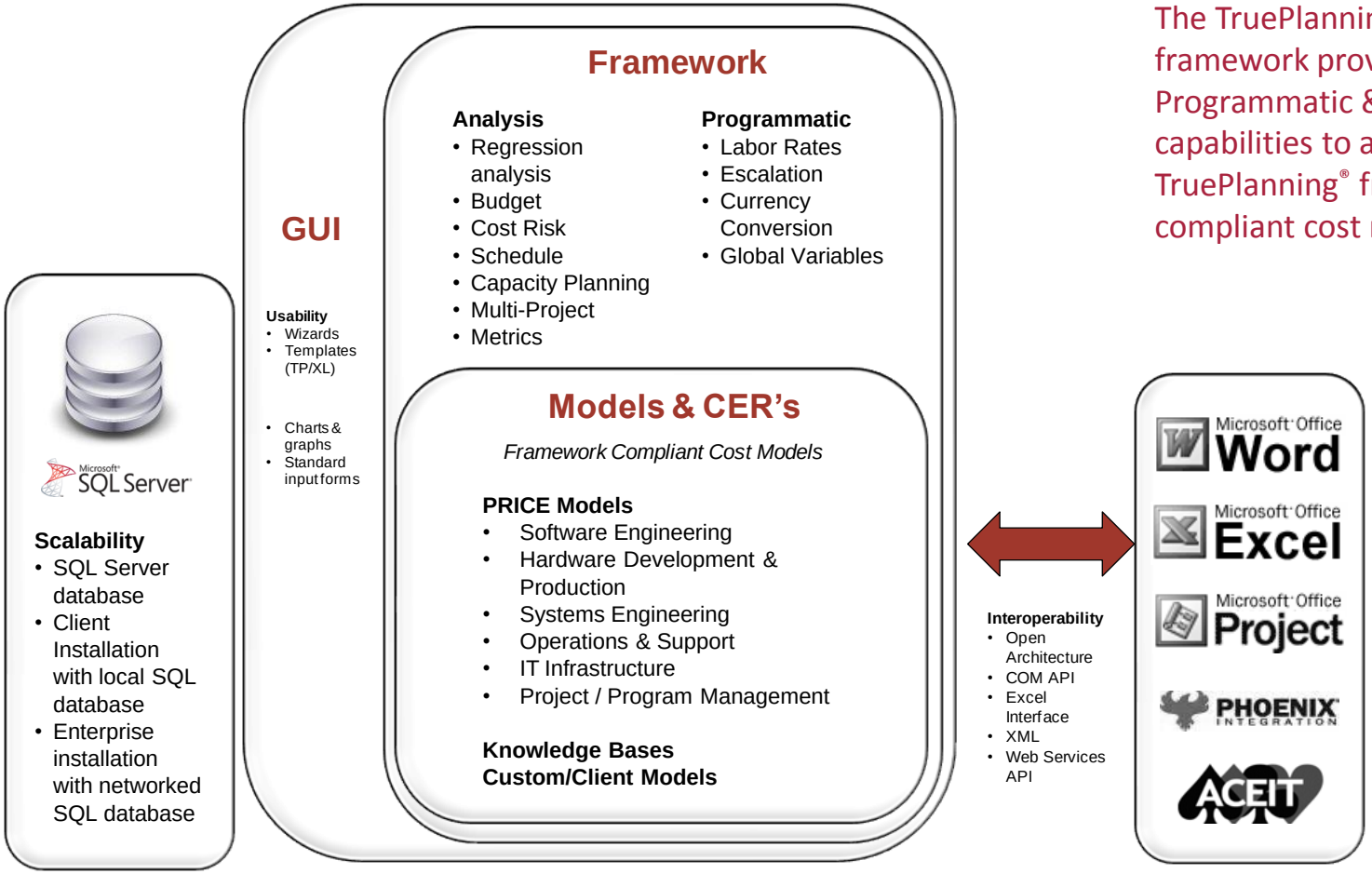
What is the TruePlanning® Framework?



The TruePlanning® framework provides Programmatic & Analysis capabilities to any TruePlanning® framework, compliant cost model.

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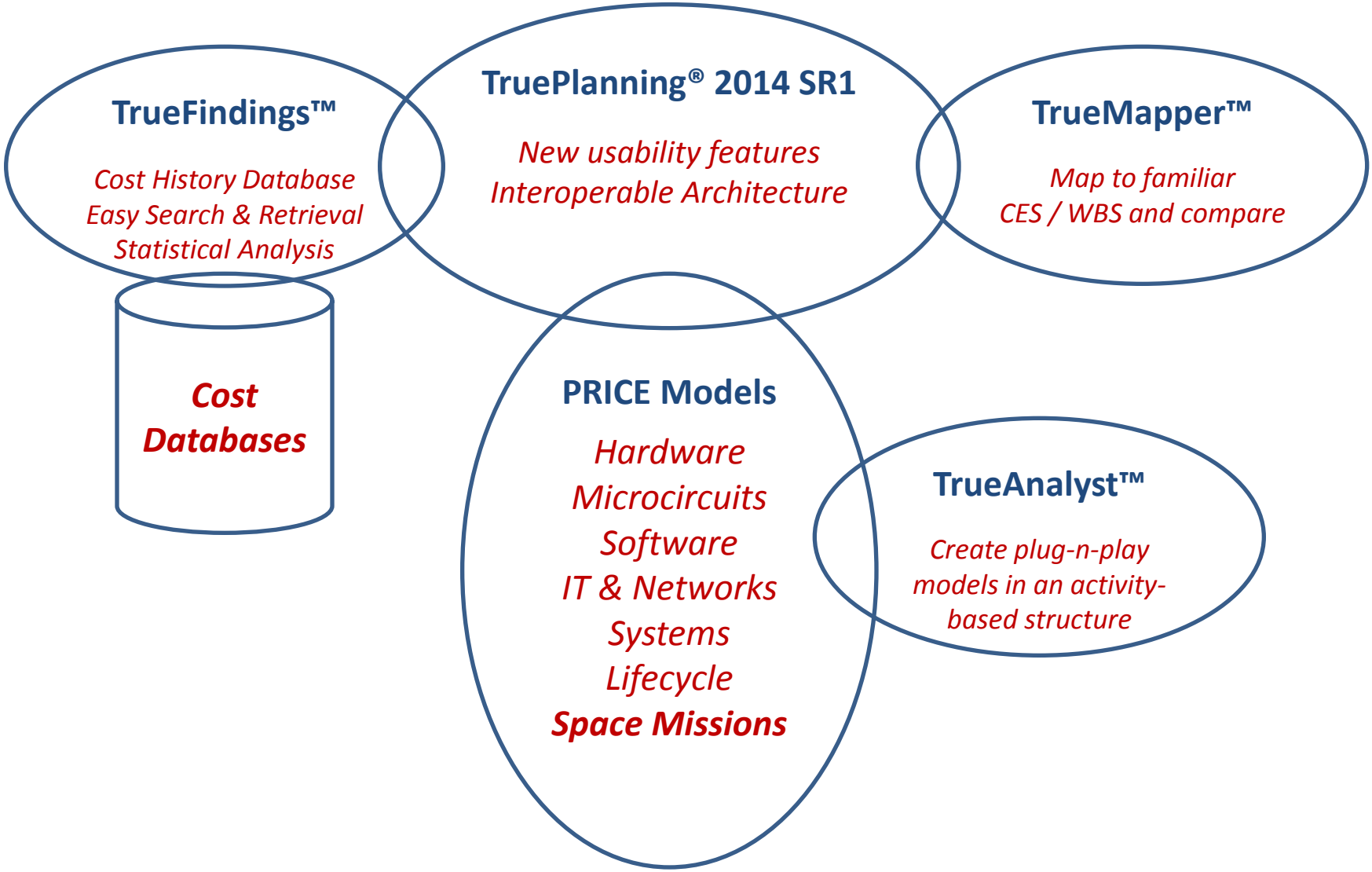
Space Missions Estimating Environment



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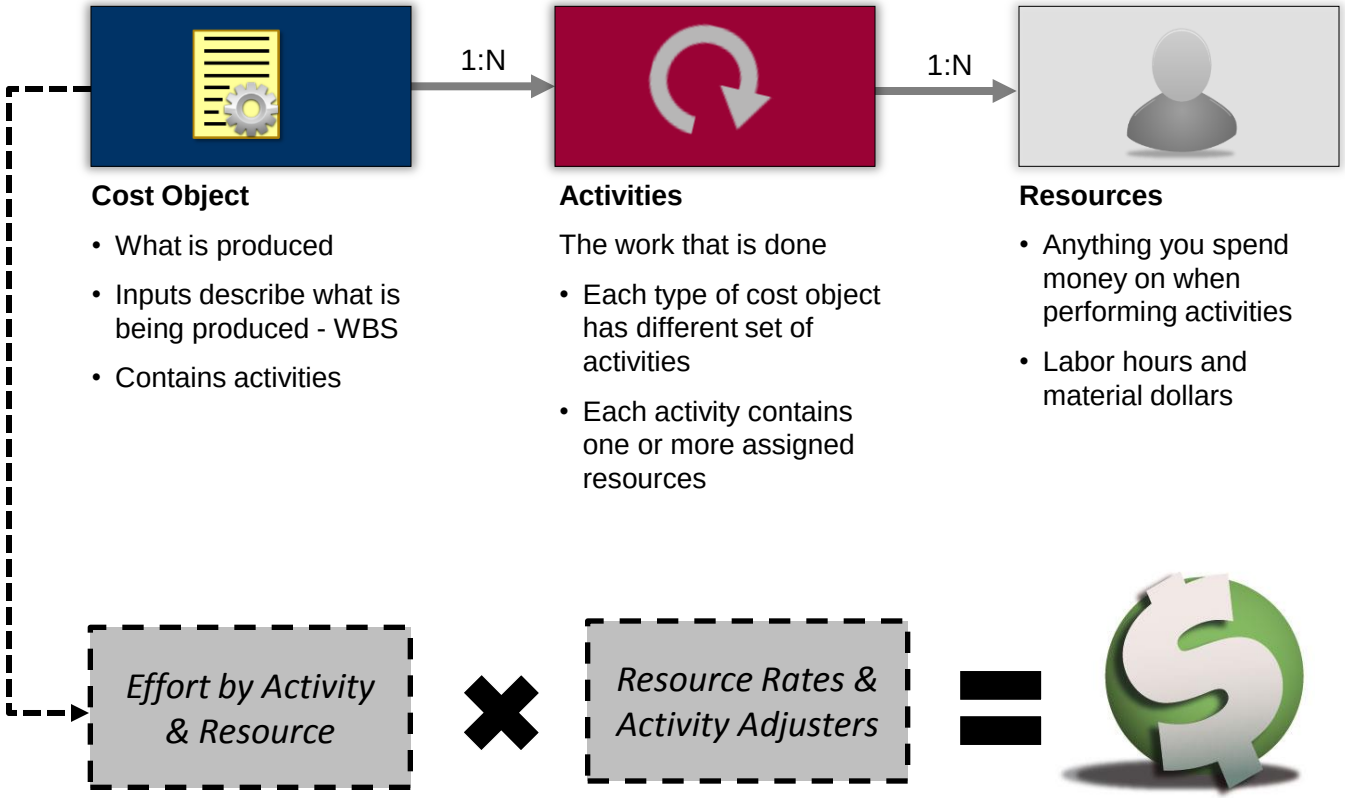
ABC's of PRICE Parametric Estimation

TruePlanning® Is a parametric cost engineering solution which estimates costs in support of activity-based costing



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Activity-Based Costing Definition

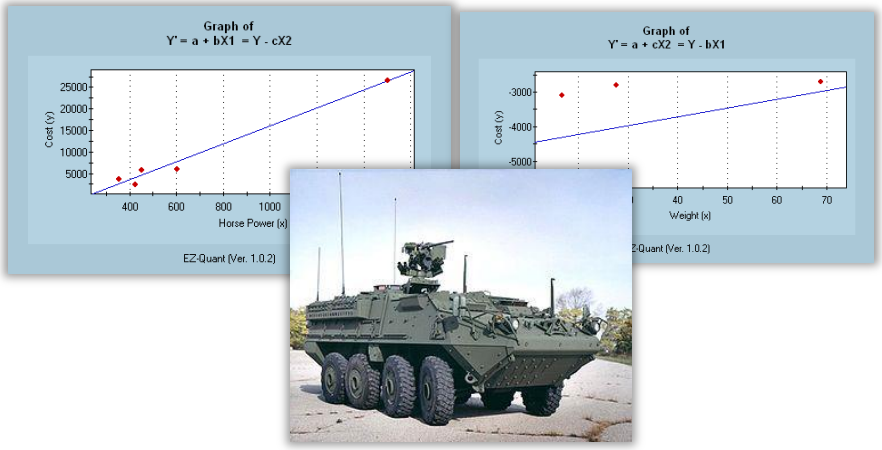
- A special costing model that identifies activities in an organization and assigns the cost of each activity with resources to all products and services according to the actual consumption by each
- A method that measures the cost and performance of process-related activities and cost objects
- Assigns cost activities based on their use of resources, and assigns cost-to-cost objects, such as products or customers, based on their use of activities
- Recognizes the causal relationship of cost drivers to activities
- Measures the cost and performance of process-related activities and cost objects

Source: The CAM-I Glossary of Activity-Based Management, 1990

Estimating Approach Comparison

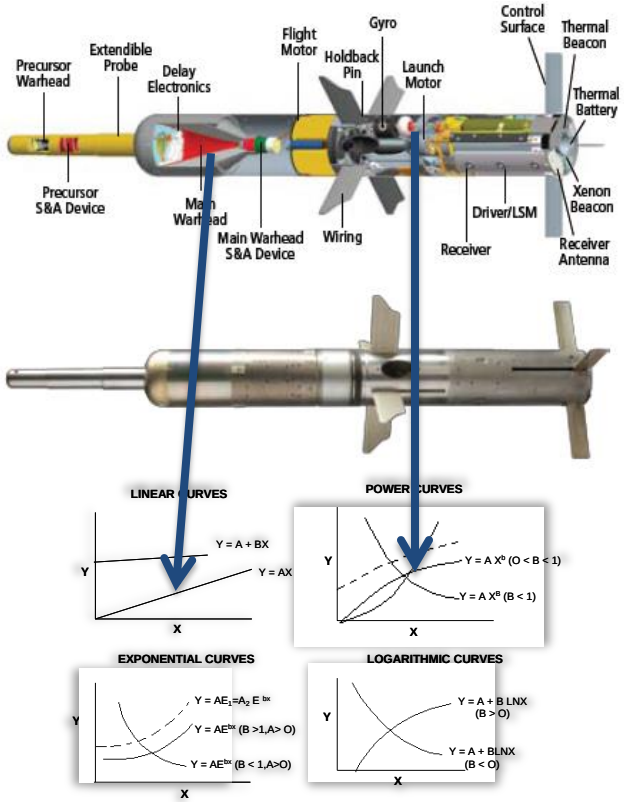
Traditional Approach

MDSNAME	Avg Annaul Class IX Cost	Horse Power	Weight
STRYKER	$4,191.54	350	16.47
PALADIN	$6,559.67	450	27.5
ABRAMS	$28,417.17	1500	68.7
BRADLEY	$6,955.52	600	27.6
FAASV	$3,342.55	420	26.1



CER: System to Class IX Parts Total Cost

TruePlanning® Approach



CER: Component Parts to Hours To Build

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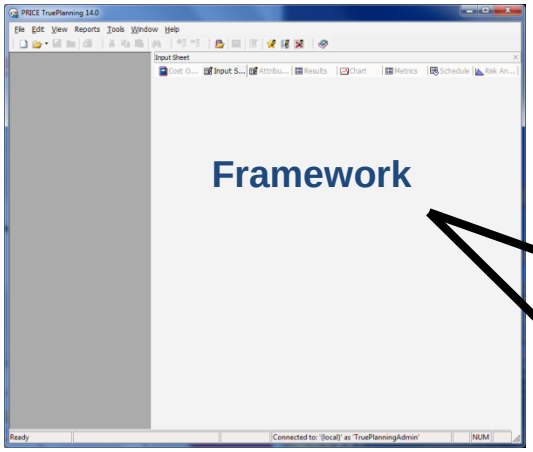
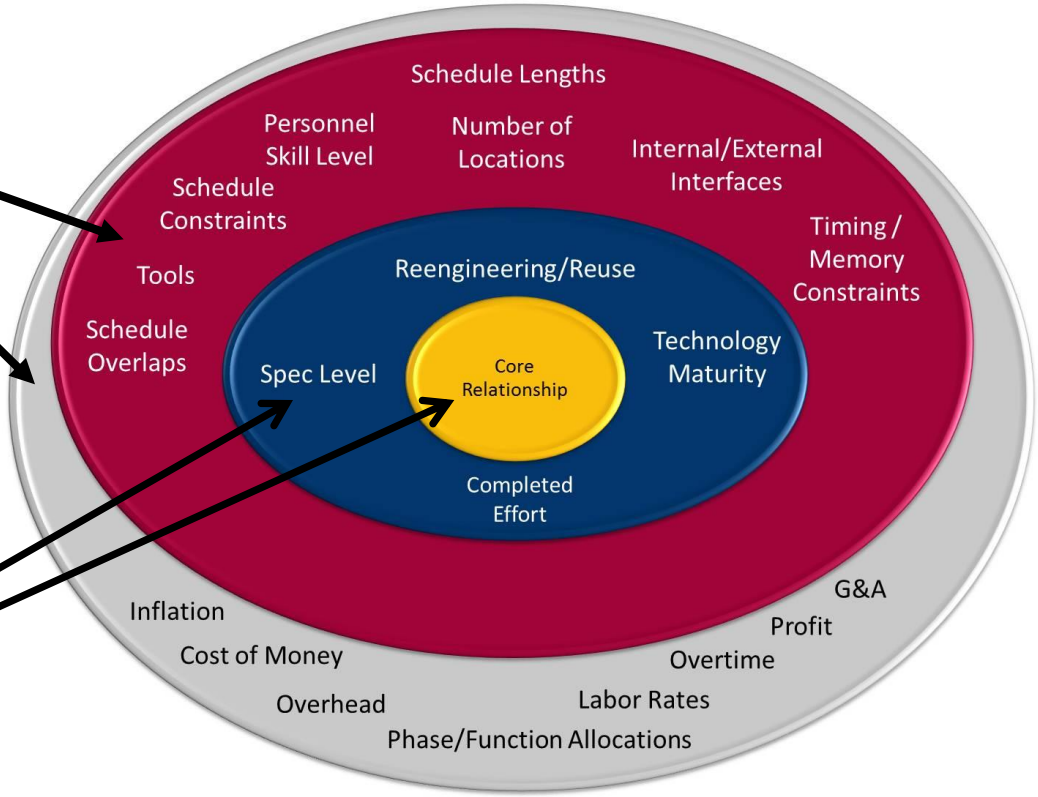
Framework Orientation

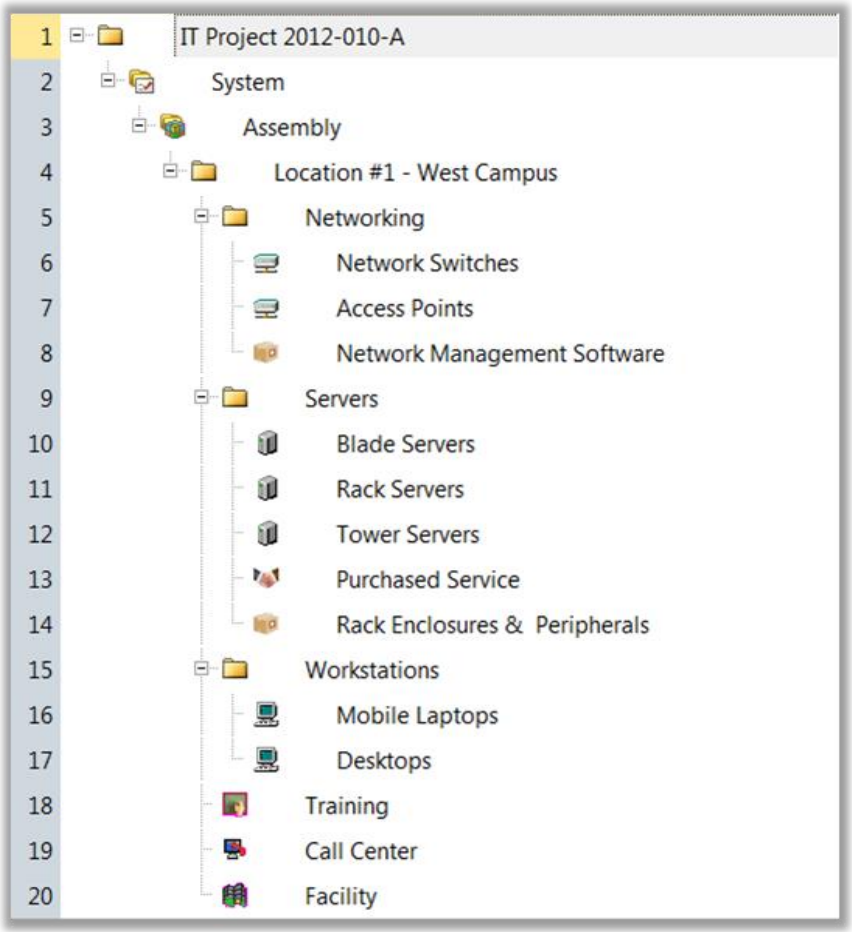
Cost Research Content Hosted In An Analysis Framework





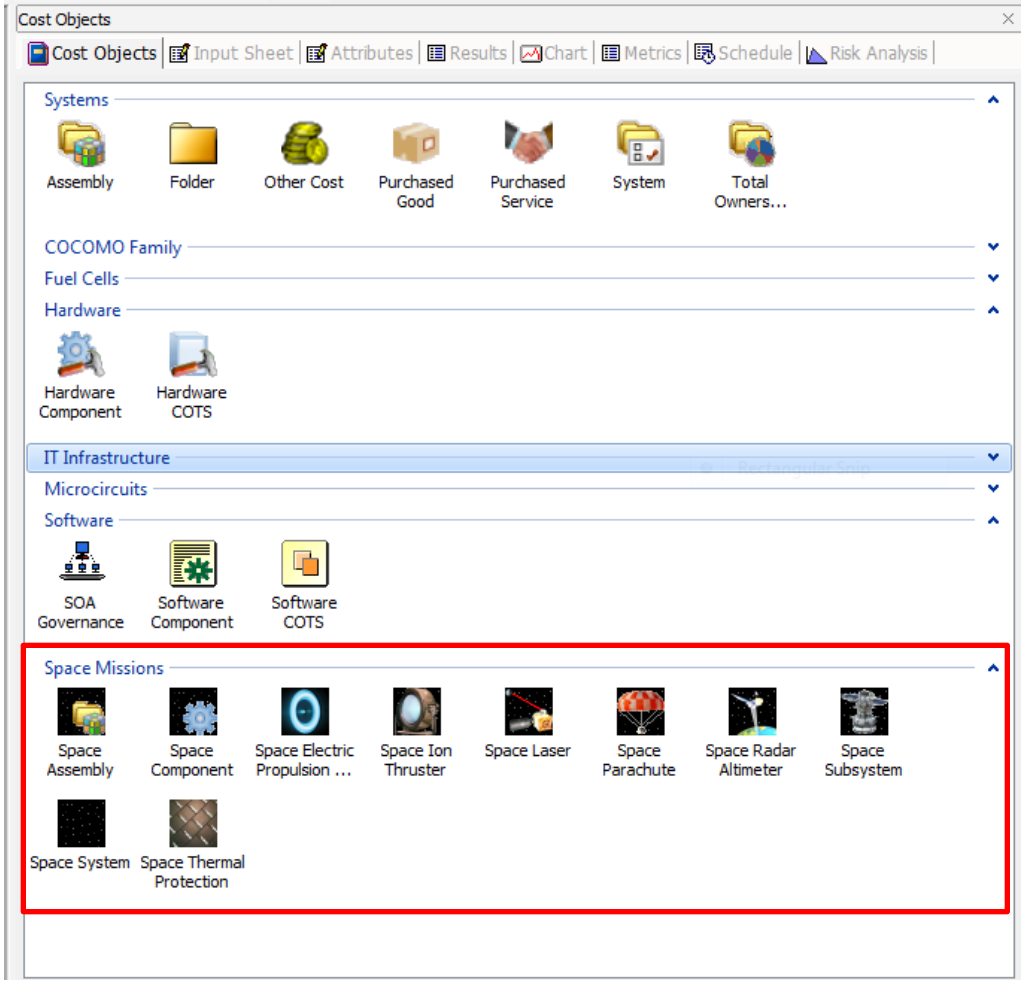
Hierarchical PBS and Integrated Models

- The PBS/WBS is a **hierarchical** method of representing a program with component models
- How the PBS Structure is modeled determines how cost, effort, schedule and risk are reported
- Models can be dragged into the PBS and **renamed** to be more useful or appropriate
- Objects have a Parent/Child relationship



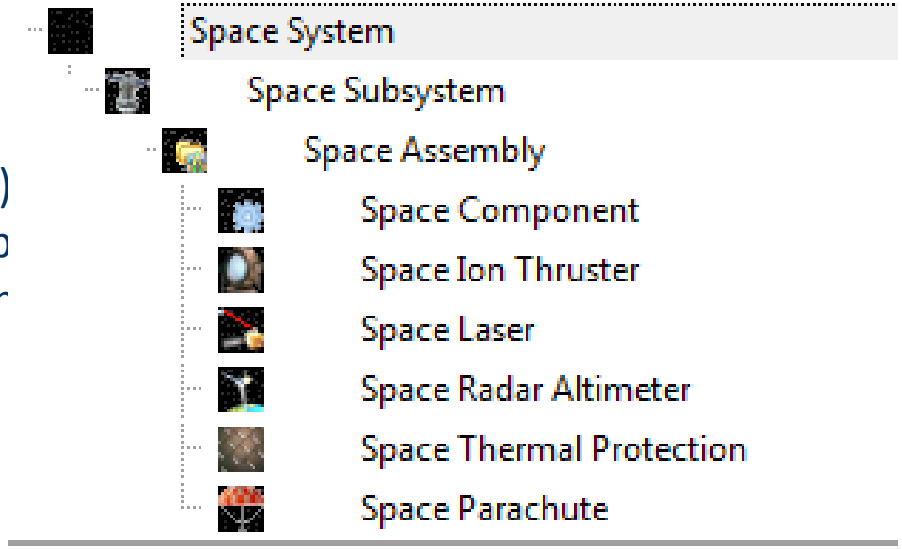
Cost Objects – PBS Building Blocks

- Cost Models are stored in “Catalogs”
- Each Cost Model contains a series of interrelated cost estimating relationships, an input sheet, activities and resources.



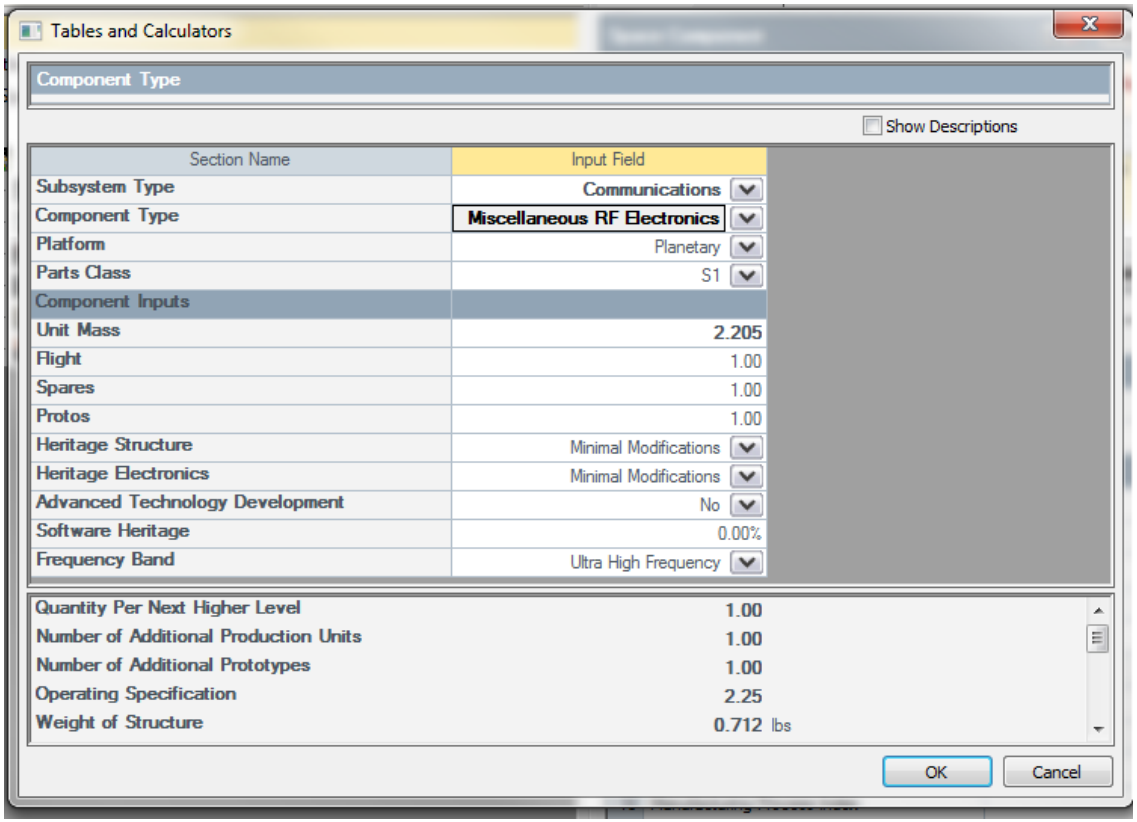
Space Mission Cost Objects

- Space System
  - Project Support Function Costs for Spacecraft and/or Payload
- Space Subsystem
  - Subsystem-level Integration & Test (I&T) Spacecraft or Instrument subsystem sup to System I&T and Launch Operations th On-Orbit Check-Out
- Space Assembly
  - Roll-up of Subsystem-level Design and Fabrication
- Space Component
  - Design and Fabrication via True Hardware Calculation
- Custom Components
  - Custom CER implementations



Space Component Cost Object

- Subsystems
  - Command and Control
  - Communications
  - Guidance, Navigation and Control
  - Optics
  - Power
  - Propulsion
  - Robotic Arm
  - Sensor System
  - Structure and Mechanisms
  - Thermal Control



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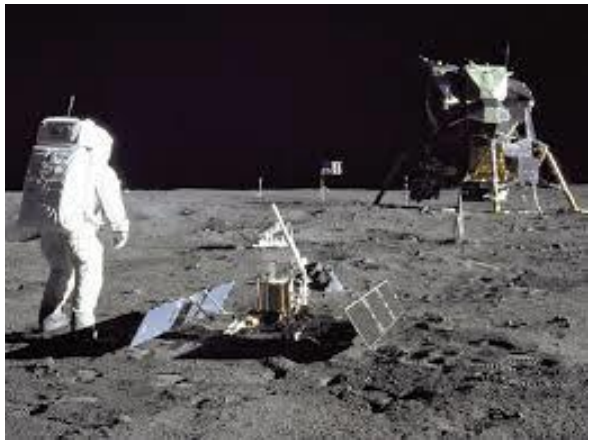
Space Component Cost Object

- Space Component Calculator inputs generate True H inputs for:
  - Quantity
  - Prototypes
  - Spares
  - Operating Specification (Platform)
  - Weight of Structure
  - Weight of Electronics
  - Manufacturing Complexity of Structure
  - Manufacturing Complexity for Electronics
  - Percent New Structure
  - Percent New Electronics
  - Engineering Complexity



Space Component Cost Object

		Value	Unit
1	Start Date		
2	Subsystem Type	**Propulsion**	
3	Component Type	**Primary Structure**	
4	Quantity Per Next Higher Level	1.00	
5	**Additional Units**		
6	Number of Additional Production Units	0.00	
7	Number of Additional Prototypes	0.00	
8	**Cost Sharing Units**		
9	Total Number of Production Units Produced	0	
10	Total Number of Prototypes Produced	0.00	
11	**Technical Description**		
12	Equipment Type	None	
13	Operating Specification	**2.25**	
14	Weight of Structure	**12.130**	kg
15	Weight of Electronics	0.000	kg
16	Volume	**77.263**	
17	Manufacturing Complexity for Structure	**8.630**	
18	Percent of New Structure	**95%**	
19	Percent of Design Repeat for Structure	0%	
20	Manufacturing Complexity for Electronics		
21	Percent of New Electronics		
22	Percent of Design Repeat for Electronics		
23	Engineering Complexity		
24	Labor Learning Curve		
25	Material Learning Curve		
26	Manufacturing Process Index	0.000	
27	Technology Improvement Control	1.0	
28	Technology Obsolescence Control	0.0	
29	Year of Technology		
30	External Integration Complexity for Structure	**2.00**	
31	External Integration Complexity for Electronics	**2.00**	
32	Hardware Software Integration Factor	**0.50**	

Input values

Tables and Calculators

Component Type

Section Name	Input Field
Subsystem Type	Propulsion
Component Type	More Options
All Component Types	Primary Structure
Platform	Planetary
Parts Class	S1
Component Inputs	
Unit Mass	12.130
Flight	1.00
Spares	0.00
Protos	0.00
Heritage Structure	Major Modifications
Advanced Technology Development	No
Material	Composite

Quantity Per Next Higher Level	1.00
Number of Additional Production Units	0.00
Number of Additional Prototypes	0.00
Operating Specification	2.25
ight of Structure	12.130 k
	77.263 I
cturing Complexity for Structure	8.630
t of New Structure	95.00 %
Engineering Complexity	0.665
External Integration for Structure	2.00

OK Cancel

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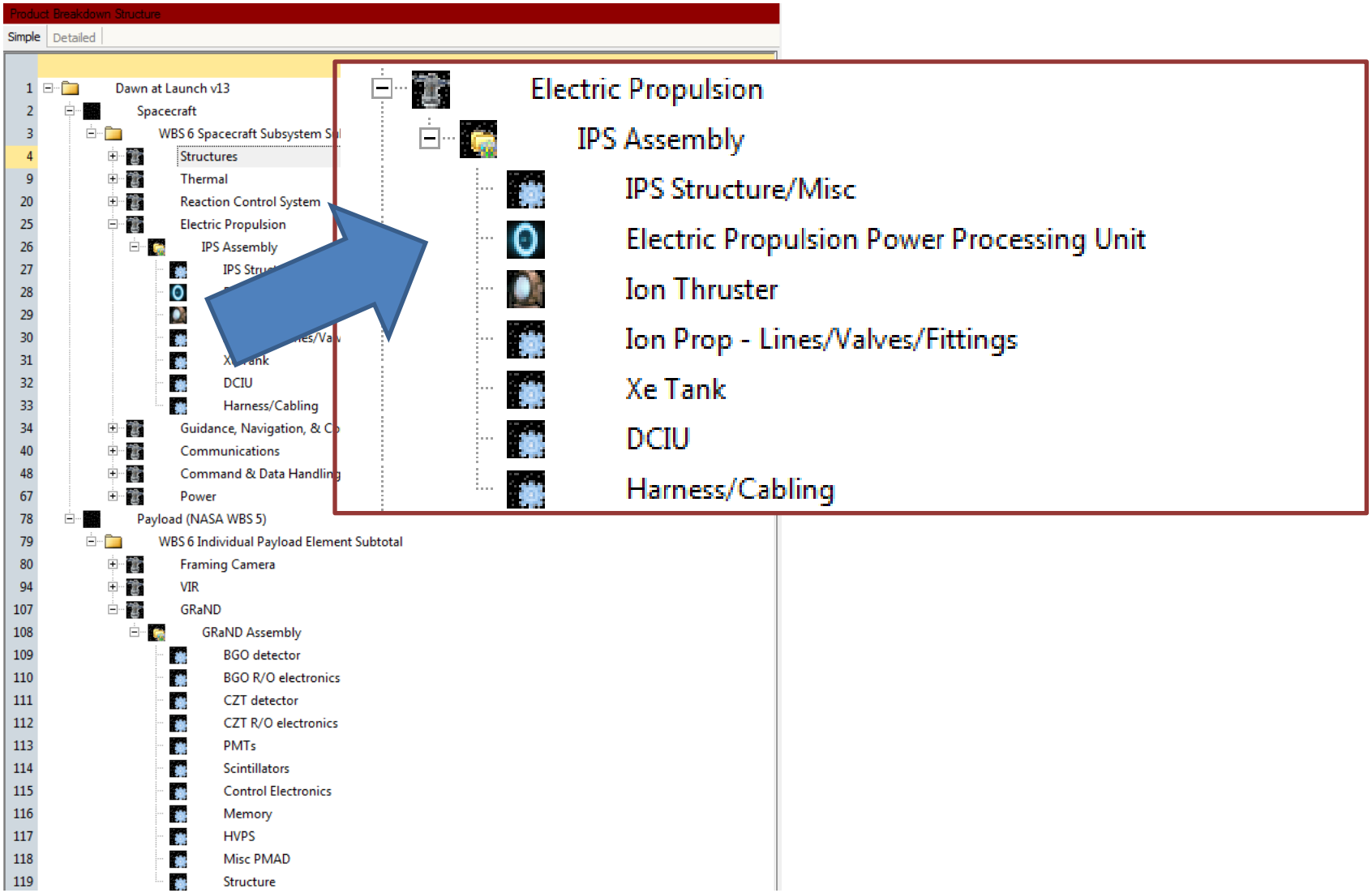
Space Missions in Use

- Estimate for Dawn Mission at Launch
- The Dawn Mission's goal is to investigate in detail two large protoplanets – Ceres and Vesta to learn their condition and history
- Estimate is based on technical and cost data collected from the CADRE and through interviews with Subject Matter Experts

Space Missions in Use



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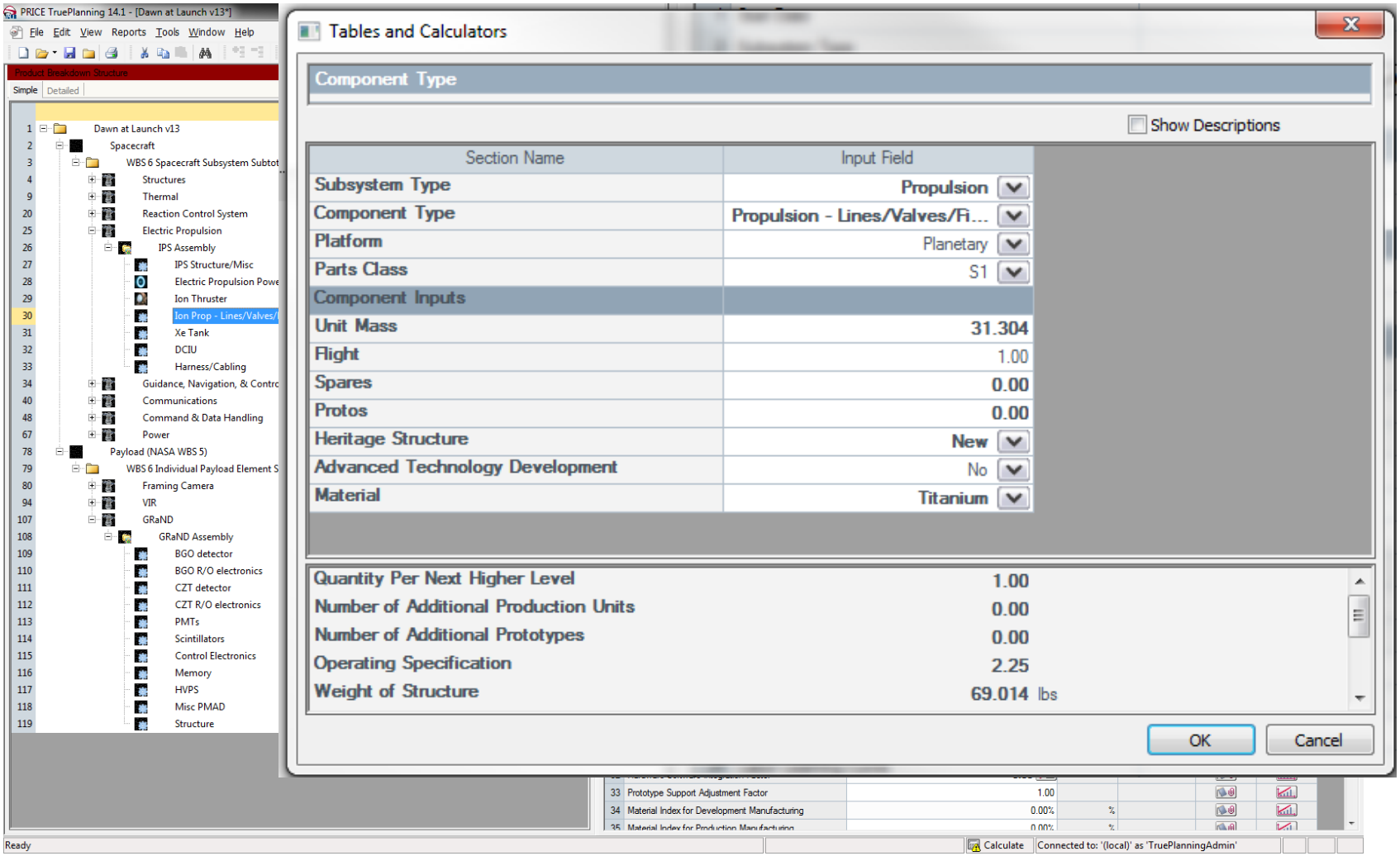
Space Missions in Use



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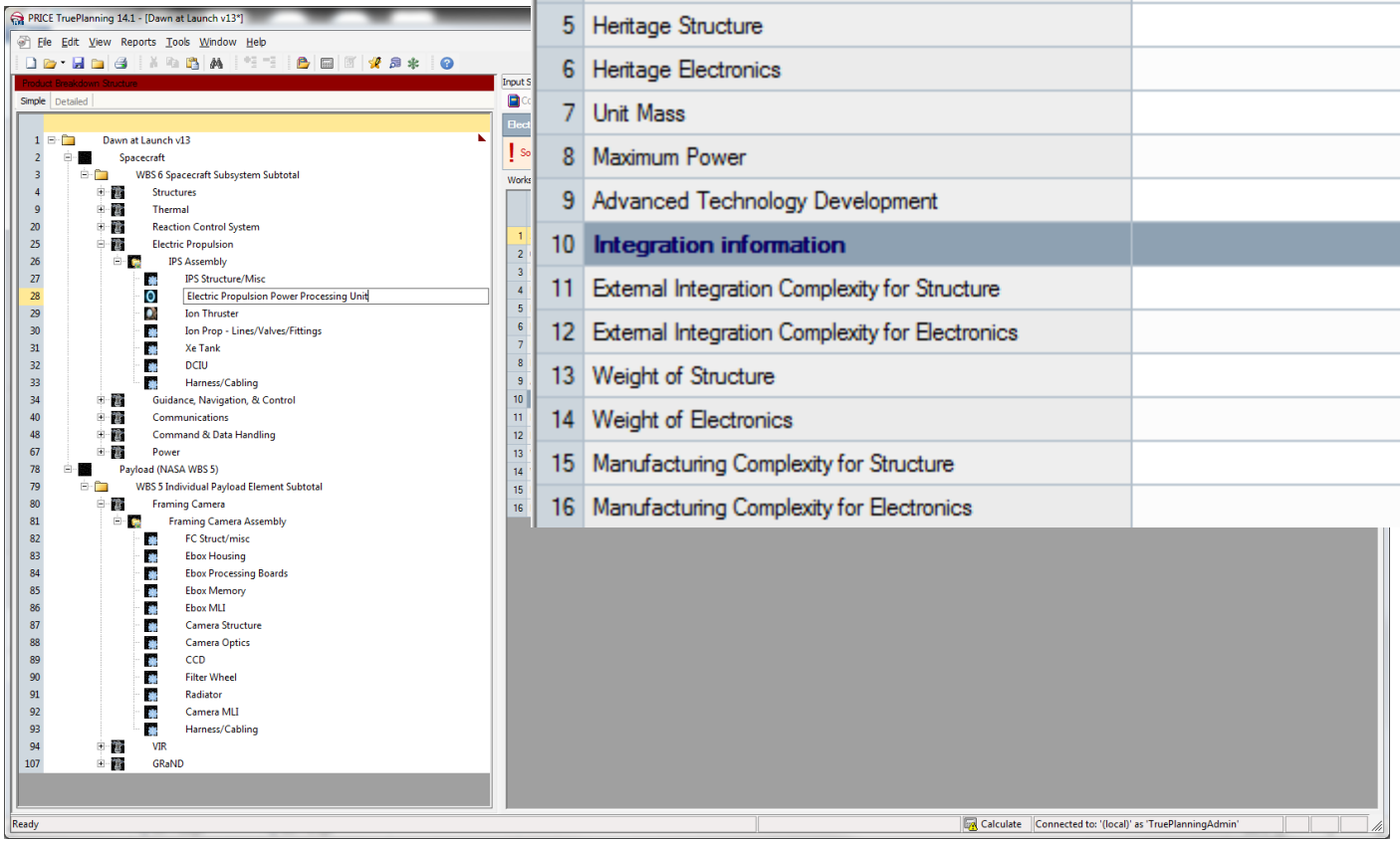
Space Missions in Use: Custom CERs



		Value	Units
1	Start Date	1/2/2003	
2	Quantity Per Next Higher Level	2.00	
3	Number of Additional Production Units	0.00	
4	Number of Additional Prototypes	0.00	
5	Heritage Structure	Copy	
6	Heritage Electronics	Copy	
7	Unit Mass	13.90	kg
8	Maximum Power	2.60	kW
9	Advanced Technology Development	No	
10	**Integration information**		
11	External Integration Complexity for Structure	2.00	
12	External Integration Complexity for Electronics	2.00	
13	Weight of Structure	4.200	kg
14	Weight of Electronics	9.700	kg
15	Manufacturing Complexity for Structure	9.210	
16	Manufacturing Complexity for Electronics	10.812	

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Space Missions in Use

Dawn at Launch v13

Cost:	$390,536,548	100.00%	Labor Requirement:	
Project Cost:	$390,536,548		Project Labor Requirement:	

	Costs : Dawn at Launch v13 - [System Folder] Currency in USD ($) (as spent)	Total	Design	Fabrication	Assembly Integration and Test	Launch Operations
1	01. Project Management	28,299,765	6,176,729	18,889,125	2,712,190	521,720
2	02a. Mission Analysis	4,912,504	2,879,336	1,022,582	643,059	367,526
3	02b. System Engineering	11,189,357	4,793,117	4,537,971	1,594,837	263,432
4	03. Safety & Mission Assurance	16,764,732	5,25			
5	04. Science/Technology	6,079,443	6			
6	07. Mission Operation System	14,47	1,3			
7	10a. Assembly and Integration Sup...	5,2				
8	10b. System Test	26,323,5				
9	10c. Ground Support	9,020,553	3,2			
10	Assembler	15,595,185	1,8			
11	Assembly Integration and Test	44,224,506				
12	Design Engineering	53,228,453	51,4			
13	Fabricator	8,884,251				
14	Launch Operation	7,161,229				
15	Manufacturing Engineering	20,595,168				
16	Material	24,836,224	5,2			
17	Non-Recurring Cost	3,876,541	3,8			
18	Recurring Cost	2,478,552				
19	Support Engineering	43,698,639	29,7			
20	System Engineering	4,349,083	4,3			
21	Test Engineering	17,656,271	2,4			

			Mass (kg)	COST				
				Design	Fabrication	AIT	Launch Operations	Total
01 Project Management				$6,176,729	$18,889,125	$2,712,190	$521,720	**$28,299,765**
02a Mission Analysis				$2,879,336	$1,022,582	$643,059	$367,526	**$4,912,504**
02b System Engineering				$4,793,117	$4,537,971	$1,594,837	$263,432	**$11,189,357**
03 Saftey and Mission Assurance				$5,256,690	$5,968,015	$4,670,624	$869,403	**$16,764,732**
07 Science/Technology				$606,507	$1,937,752	$2,950,772	$584,412	**$6,079,443**
10a Assembly and Integration Support				$1,313,551	$5,020,577	$6,904,756	$1,240,213	**$14,479,097**
10b System Test				$1,830,120	$2,040,194	$1,178,964	$174,677	**$5,223,956**
10c Ground Support				$4,507,513	$6,137,144	$14,801,032	$878,238	**$26,323,927**
And the rest of the Space System Resources similarly mapped				**$3,224,334**	**$3,714,245**	**$1,810,683**	**$271,291**	**$9,020,553**
05 Payload (Space System CO)			75.78	$22,391,180	$35,864,479	$20,067,930	$3,222,012	81545600.6
	Framing Camera		22.68	$26,869,416.20	$43,037,374.46	$24,081,515.91	$3,866,414.14	97854720.7
		FC Struct/Misc	1.33	$12,283,579.92	$13,247,447.62	$5,596,313.68	$980,273.28	32107614.5
		Ebox Housing	1.16	$2,919,207.37	$3,165,517.16			6084724.53
		Ebox Processing Boards	0.2					
		...	...					
	VIR		25.8	$10,236,317	$11,039,540	$4,663,595	$816,894	26756345.4
		Optics Module Struc	12.08	$2,432,673	$2,637,931			5070603.78
		Cryocooler	0.5	$184,994	$31,735			216728.216
		IR Detecter	0.75					
		...	...					
	...							
06 Spacecraft (Space System CO)			645.984	$21,271,621.16	$34,071,254.78	$19,064,533.43	$3,060,911.19	77468320.6
	Structure		132.7	$9,724,500.77	$10,487,562.70	$4,430,415.00	$776,049.68	25418528.1
		Primary Structure	72.85	$2,311,039.17	$2,506,034.42			4817073.59
		Secondary Structure	45.75	$175,743.94	$30,147.87			205891.806
		Balance Weight	14.1					
		....	...					
		....						

Conclusions

- The Spacecraft Missions models combine the power of the TruePlanning® framework with a time-tested space specific application of the PRICE Hardware estimating methodology
- One-stop shopping for estimating entire missions including spacecraft and payload
- Models validated by their original creators and long-time users as well as by the PRICE team

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