

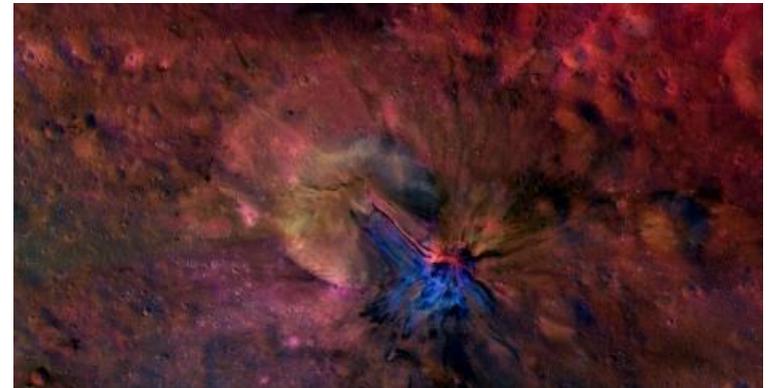


# Space Missions Cost Estimation in TruePlanning®

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- Space Missions Model Overview
- Introduction to TruePlanning<sup>®</sup>
- Framework Orientation
- Space Mission Cost Objects
- Space Missions Model in Use



- Cost estimating for Formulation through Implementation for robotic Earth and Space Science Missions
- Methodology used in 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
  - Updated regularly with data from missions such as Lunar Atmosphere and Dust Environment Explorer(LADEE), Mars Science Laboratory (MSL), Gravity Recovery and Interior Laboratory (GRAIL), etc.

# Space Missions Overview

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



Subsystem Component	Subsystem Component	Subsystem Component
<b>STRUCTURE &amp; MECHANISMS</b>	<b>GUIDANCE, NAVIGATION, &amp; CONTROL</b>	<b>ENTRY &amp; DESCENT</b>
Primary Structure	Star Tracker	Thermal Protection System *
Secondary Structure	Sun Sensor	Parachute *
Shielding	Reaction Wheel	
Solar Array Substrate/Structure	Torque Rod	<b>OPTICS</b>
HGA Structure	Gimbals	Optical Bench
Electronics Boxes	IMU-Gyro	Optics
Mechanisms	Actuators	Gratings
Motor/Actuator	Radar Altimeter *	Filter Wheel
Booms		Optics Filters/Misc
	<b>COMMUNICATIONS</b>	<b>SENSOR SYSTEMS</b>
<b>ROBOTIC ARM</b>	Transponder	Laser *
Robotic Arm - Limb	Transmitter	Sensors-Detectors
Robotic Arm - Joint/Actuator	Amplifier	CCD Detectors
	Misc RF Electronics	Magnetometer
<b>THERMAL CONTROL</b>	HGA	TOF Spectrometer
MLI, Paints, Coatings	MGA/LGA	ESA sensor
Heaters, RHUs, Thermostats	Waveguide/Comm Cabling	Photodiode
Radiators/Louvers		Bolometer
Heat Pipes	<b>COMMAND &amp; DATA HANDLING</b>	Ion Source
Cryocooler	Command/Data Processing	Gamma Sensor
	Solid State Memory	Neutron Sensor
<b>PROPULSION</b>	<b>POWER</b>	Dust Detector
Propulsion Lines/Valves/Fittings	Power Management and Distribution	Readout Electronics
Pressure Regulator	Solar Cells/Electrical	
Tanks	Pyrotechnics	
Thrusters	Batteries	
	Harness	
<b>ELECTRIC PROPULSION</b>		
Ion Thruster *		
Power Processing Unit *		

## 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

# Space Missions Overview

## 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*

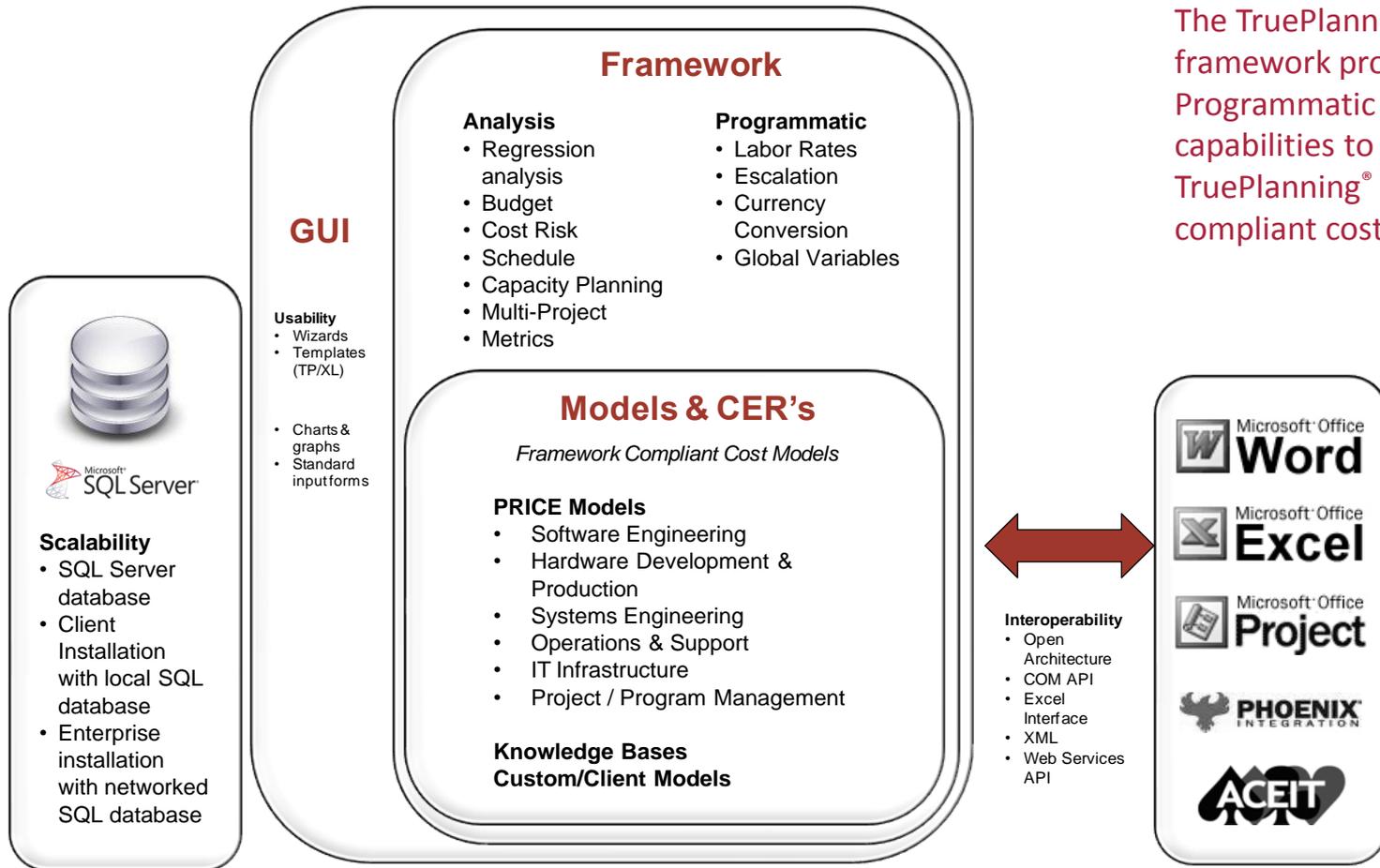
*Milestones: ATP → CDR → SIR → Ship*

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)				

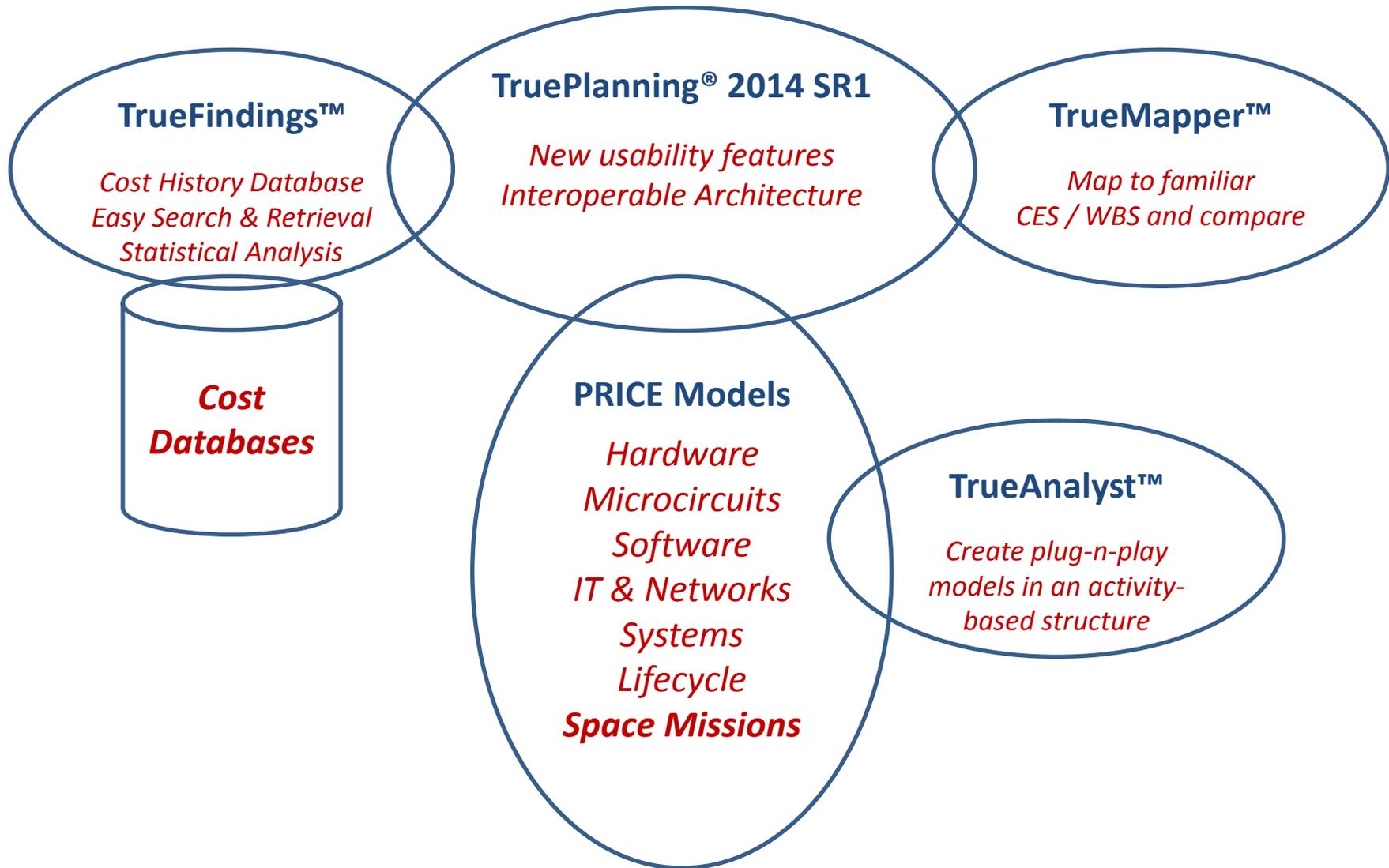
***Space Missions estimated costs align with the NASA WBS and provide phasing details***

- 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*

# What is the TruePlanning® Framework?

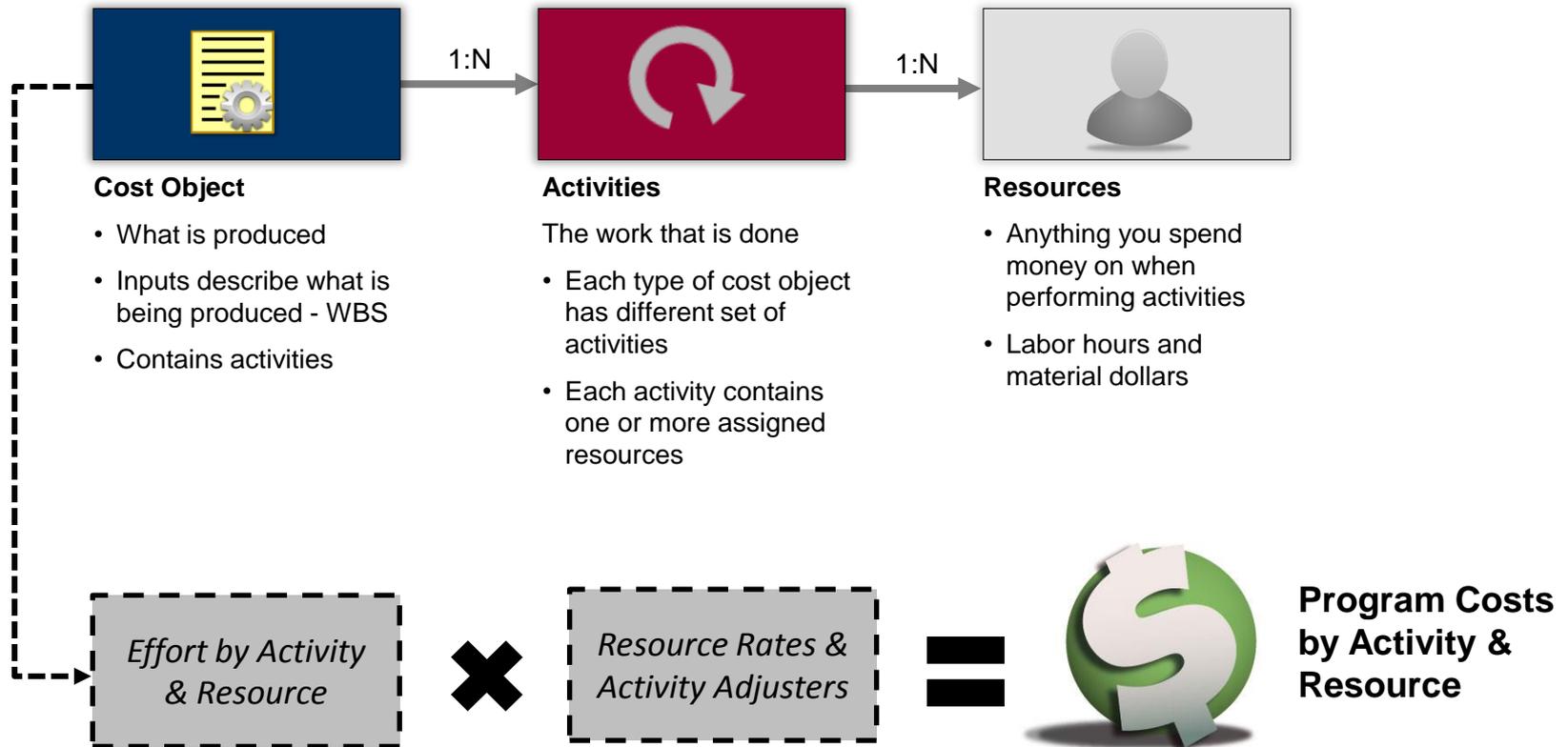


The TruePlanning® framework provides Programmatic & Analysis capabilities to any TruePlanning® framework, compliant cost model.



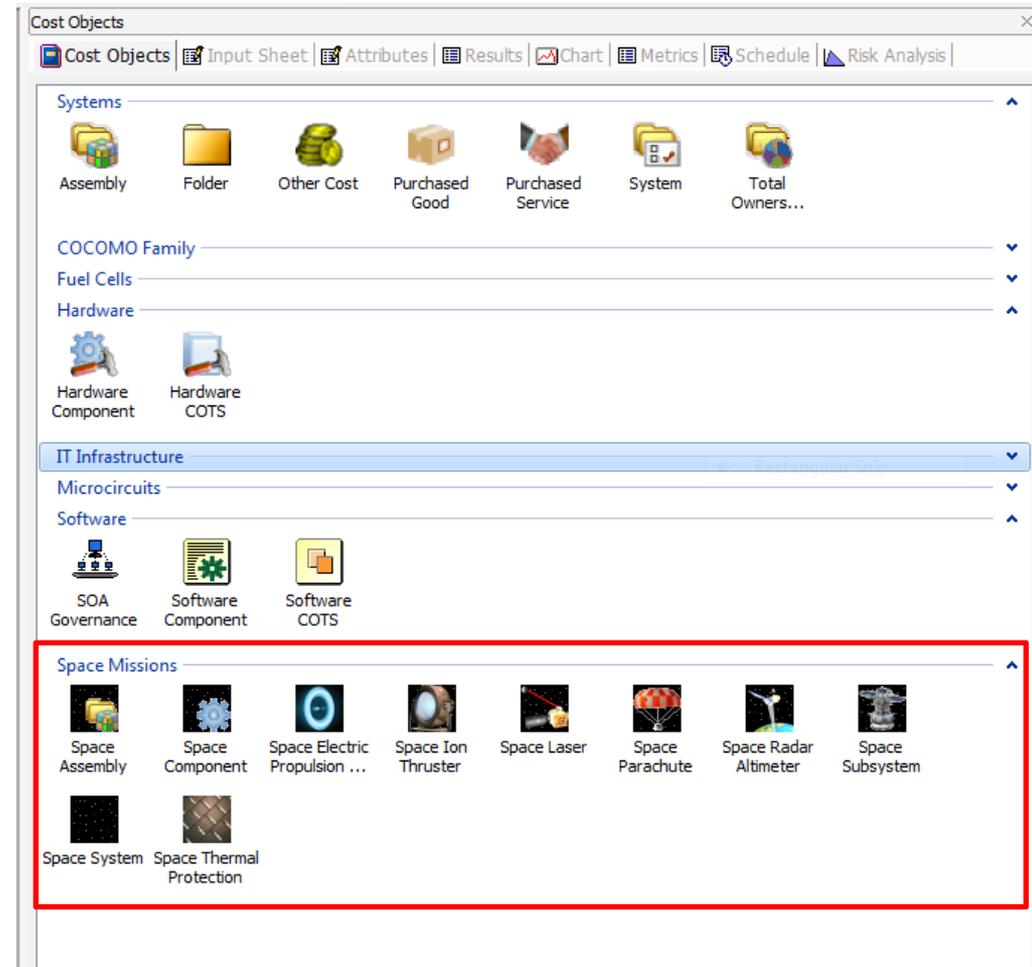
# ABC's of PRICE Parametric Estimation

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



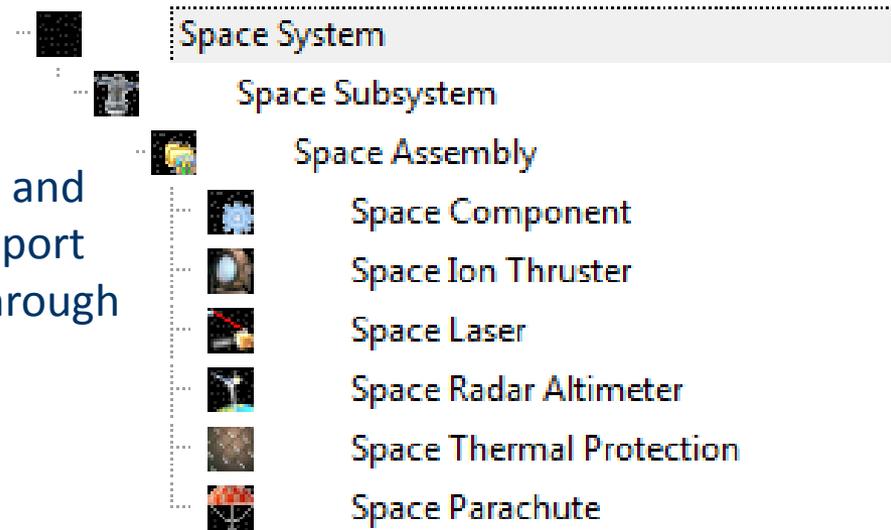
# Cost Objects – PBS Building Blocks

- 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) and Spacecraft or Instrument subsystem support to System I&T and Launch Operations through 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

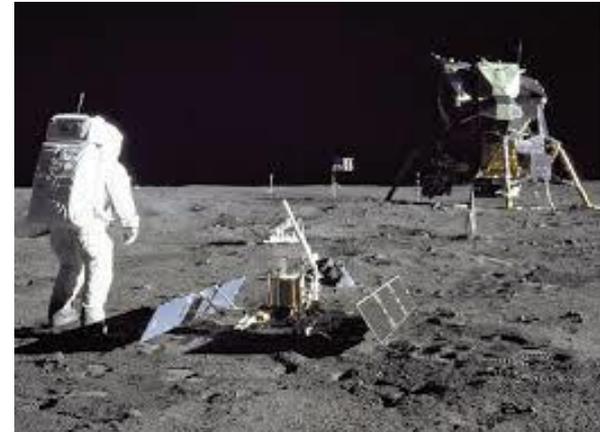
The screenshot shows a software window titled 'Tables and Calculators' with a 'Component Type' configuration form. The form includes a 'Show Descriptions' checkbox and a table with two columns: 'Section Name' and 'Input Field'. Below the table is a summary section with various parameters and their values.

Section Name	Input Field
Subsystem Type	Communications
Component Type	Miscellaneous RF Electronics
Platform	Planetary
Parts Class	S1
<b>Component Inputs</b>	
Unit Mass	2.205
Flight	1.00
Spares	1.00
Protos	1.00
Heritage Structure	Minimal Modifications
Heritage Electronics	Minimal Modifications
Advanced Technology Development	No
Software Heritage	0.00%
Frequency Band	Ultra High Frequency

Quantity Per Next Higher Level	1.00
Number of Additional Production Units	1.00
Number of Additional Prototypes	1.00
Operating Specification	2.25
Weight of Structure	0.712 lbs

- 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 <b>Additional Units</b>		
6 Number of Additional Production Units	0.00	
7 Number of Additional Prototypes	0.00	
8 <b>Cost Sharing Units</b>		
9 Total Number of Production Units Produced	0	
10 Total Number of Prototypes Produced	0.00	
11 <b>Technical Description</b>		
12 Equipment Type	None	
13 Operating Specification	2.25	
14 Weight of Structure	12.130	kg
15 Weight of Electronics	0.000	kg
16 <b>Volume</b>	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	0.665	
21 Percent of New Electronics	0.000	
22 Percent of Design Repeat for Electronics	0%	
23 Engineering Complexity	0.000	
24 Labor Learning Curve	0%	
25 Material Learning Curve	0.000	
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	

Tables and Calculators

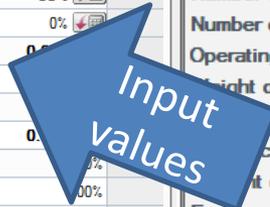
Component Type

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
Weight of Structure	12.130 kg
Volume	77.263
Manufacturing Complexity for Structure	8.630
Percent of New Structure	95.00 %
Engineering Complexity	0.665
External Integration for Structure	2.00

OK Cancel



- 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

Product Breakdown Structure

Simple Detailed

Item	Sub-component
1	Dawn at Launch v13
2	Spacecraft
3	WBS 6 Spacecraft Subsystem Subtotal
4	Structures
9	Thermal
20	Reaction Control System
25	Electric Propulsion
26	IPS Assembly
27	IPS Structure/Misc
28	Electric Propulsion Power Processing Unit
29	Ion Thruster
30	Ion Prop - Lines/Valves/Fittings
31	Xe Tank
32	DCIU
33	Harness/Cabling
34	Guidance, Navigation, & Control
40	Communications
48	Command & Data Handling
67	Power
78	Payload (NASA WBS 5)
79	WBS 6 Individual Payload Element Subtotal
80	Framing Camera
94	VIR
107	GRaND
108	GRaND Assembly
109	BGO detector
110	BGO R/O electronics
111	CZT detector
112	CZT R/O electronics
113	PMTs
114	Scintillators
115	Control Electronics
116	Memory
117	HVPS
118	Misc PMAD
119	Structure

# Space Missions in Use

PRICE TruePlanning 14.1 - [Dawn at Launch v13\*]

File Edit View Reports Tools Window Help

Product Breakdown Structure

Simple Detailed

1 Dawn at Launch v13

2 Spacecraft

3 WBS 6 Spacecraft Subsystem Subtot

4 Structures

9 Thermal

20 Reaction Control System

25 Electric Propulsion

26 IPS Assembly

27 IPS Structure/Misc

28 Electric Propulsion Powe

29 Ion Thruster

30 Ion Prop - Lines/Valves/...

31 Xe Tank

32 DCIU

33 Harness/Cabling

34 Guidance, Navigation, & Contr

40 Communications

48 Command & Data Handling

67 Power

78 Payload (NASA WBS 5)

79 WBS 6 Individual Payload Element S

80 Framing Camera

94 VIR

107 GRaND

108 GRaND Assembly

109 BGO detector

110 BGO R/O electronics

111 CZT detector

112 CZT R/O electronics

113 PMTs

114 Scintillators

115 Control Electronics

116 Memory

117 HVPS

118 Misc PMAD

119 Structure

Tables and Calculators

Component Type

Show Descriptions

Section Name	Input Field
Subsystem Type	Propulsion
Component Type	Propulsion - Lines/Valves/Fi...
Platform	Planetary
Parts Class	S1
<b>Component Inputs</b>	
Unit Mass	31.304
Flight	1.00
Spares	0.00
Protos	0.00
Heritage Structure	New
Advanced Technology Development	No
Material	Titanium

Quantity Per Next Higher Level	1.00
Number of Additional Production Units	0.00
Number of Additional Prototypes	0.00
Operating Specification	2.25
Weight of Structure	69.014 lbs

OK Cancel

33 Prototype Support Adjustment Factor	1.00		
34 Material Index for Development Manufacturing	0.00%	%	
35 Material Index for Production Manufacturing	0.00%	%	

Ready

Calculate Connected to: '(local)' as 'TruePlanningAdmin'

# Space Missions in Use: Custom CERs

PRICE TruePlanning 14.1 - [Dawn at Launch v13\*]  
 File Edit View Reports Tools Window Help  
 Product Breakdown Structure  
 Simple | Detailed |  
 1 Dawn at Launch v13  
 2 Spacecraft  
 3 WBS 6 Spacecraft Subsystem Subtotal  
 4 Structures  
 9 Thermal  
 20 Reaction Control System  
 25 Electric Propulsion  
 26 IPS Assembly  
 27 IPS Structure/Misc  
 28 Electric Propulsion Power Processing Unit  
 29 Ion Thruster  
 30 Ion Prop - Lines/Valves/Fittings  
 31 Xe Tank  
 32 DCIU  
 33 Harness/Cabling  
 34 Guidance, Navigation, & Control  
 40 Communications  
 48 Command & Data Handling  
 67 Power  
 78 Payload (NASA WBS 5)  
 79 WBS 5 Individual Payload Element Subtotal  
 80 Framing Camera  
 81 Framing Camera Assembly  
 82 FC Struct/misc  
 83 Ebox Housing  
 84 Ebox Processing Boards  
 85 Ebox Memory  
 86 Ebox MLI  
 87 Camera Structure  
 88 Camera Optics  
 89 CCD  
 90 Filter Wheel  
 91 Radiator  
 92 Camera MLI  
 93 Harness/Cabling  
 94 VIR  
 107 GRaND

	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 <b>Integration information</b>		
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	

# 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	5,223,358	10,222,504	1,318,870	
5 04. Science/Technology	6,079,443	606,507	1,937,752	2,950,772	584,412
6 07. Mission Operation System	14,479,097	1,830,120	2,040,194	1,178,964	174,677
7 10a. Assembly and Integration Sup...	5,223,358	1,313,551	5,020,577	6,904,756	1,240,213
8 10b. System Test	26,323,956	1,830,120	2,040,194	1,178,964	174,677
9 10c. Ground Support	9,020,553	4,507,513	6,137,144	14,801,032	878,238
10 Assembler	15,595,185	And the rest of the Space System Resources similarly mapped			
11 Assembly Integration and Test	44,224,506				
12 Design Engineering	53,228,453				
13 Fabricator	8,884,251				
14 Launch Operation	7,161,229				
15 Manufacturing Engineering	20,595,168				
16 Material	24,836,224				
17 Non-Recuring Cost	3,876,541				
18 Recuring Cost	2,478,552				
19 Support Engineering	43,698,639				
20 System Engineering	4,349,083				
21 Test Engineering	17,656,271				



	Mass (kg)	COST				Total
		Design	Fabrication	AIT	Launch Operations	
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 Safety and Mission Assurance		\$5,223,358	\$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	\$26,323,956
05 Payload (Space System CO)	75.78	\$22,391,180	\$35,864,479	\$20,067,930	\$3,222,012	\$81,545,600.6
Framing Camera	22.68	\$26,869,416.20	\$43,037,374.46	\$24,081,515.91	\$3,866,414.14	\$97,854,720.7
FC Struct/Misc	1.33	\$12,283,579.92	\$13,247,447.62	\$5,596,313.68	\$980,273.28	\$32,107,614.5
Ebox Housing	1.16	\$2,919,207.37	\$3,165,517.16			\$6,084,724.53
Ebox Processing Boards	0.2					
...	...					
VIR	25.8	\$10,236,317	\$11,039,540	\$4,663,595	\$816,894	\$26,756,345.4
Optics Module Struc	12.08	\$2,432,673	\$2,637,931			\$5,070,603.78
Cryocooler	0.5	\$184,994	\$31,735			\$216,728.216
IR Detector	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	\$77,468,320.6
Structure	132.7	\$9,724,500.77	\$10,487,562.70	\$4,430,415.00	\$776,049.68	\$25,418,528.1
Primary Structure	72.85	\$2,311,039.17	\$2,506,034.42			\$4,817,073.59
Secondary Structure	45.75	\$175,743.94	\$30,147.87			\$205,891.806
Balance Weight	14.1					
....	...					
....	...					

- PRICE consultants are currently using these models to perform estimates validating several space missions against actuals
  - Validating Space Mission Models vs actuals for 16 different programs
  - Modeled to Level III Breakdown, matching At-Launch Spacecraft and Payload configurations and weights
  - Calculator input values derived from Cost Analysis Data Requirement (CADRE) Part-B data
  - Outputs mapped to NASA WBS categories in alignment with CADRE Part C data
  - Error-bands determined for total, spacecraft, payload and payload instrument costs
  - Burdening and escalation normalized across programs

- 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



**To submit a question,** please use the “**Questions**” feature located in your control panel, which you can access by clicking on the orange arrow on the right hand side of your screen.

# Upcoming Events



12 Aug 2014, Herdon, VA | Industry Event

**NASA Cost Symposium**

17 Sep 2014 | Industry Event

**ICEAA SoCal and San Diego Chapters - Workshop**

More details at [pricesystems.com/events](http://pricesystems.com/events)

View on-demand webinars at [pricesystems.com/webinars](http://pricesystems.com/webinars)

# Wrap-up: More Information



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**Learn more about TruePlanning® 2014**

[pricesystems.com/en-us/offerings/trueplanningframework.aspx](http://pricesystems.com/en-us/offerings/trueplanningframework.aspx)

Call 1-800-43-PRICE or email: [robert.becker@pricesystems.com](mailto:robert.becker@pricesystems.com)

**Request more information**

[pricesystems.com/en-us/requestinfo.aspx](http://pricesystems.com/en-us/requestinfo.aspx)

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# Thank You!



- 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.

# 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

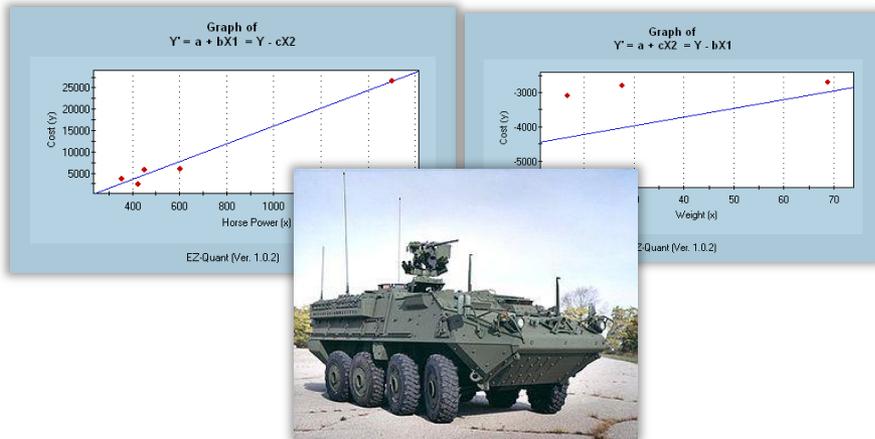


Source: The CAM-I Glossary of Activity-Based Management, 1990

# Estimating Approach Comparison

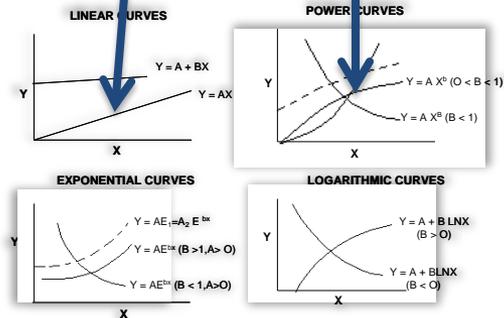
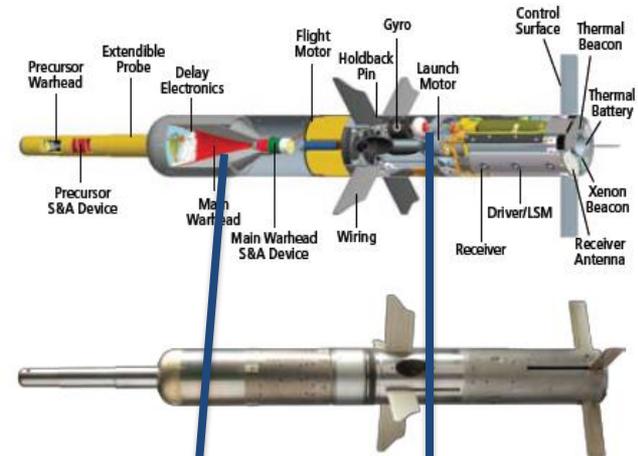
## Traditional Approach

MDSNAME	Avg Annual 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



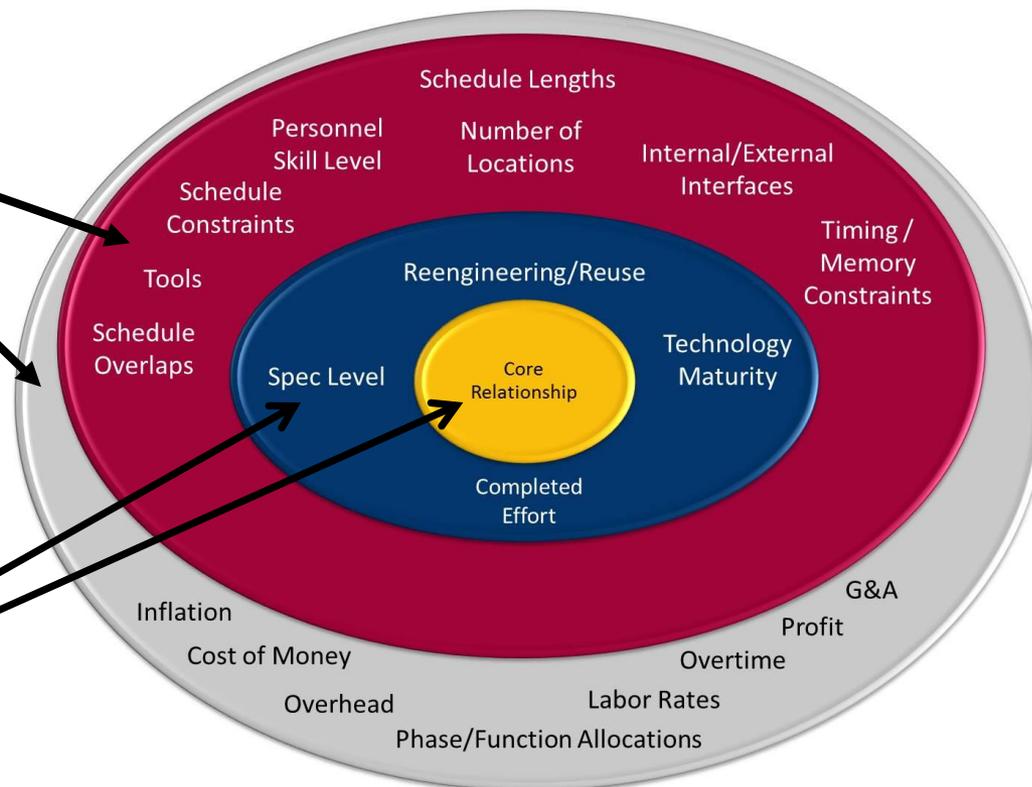
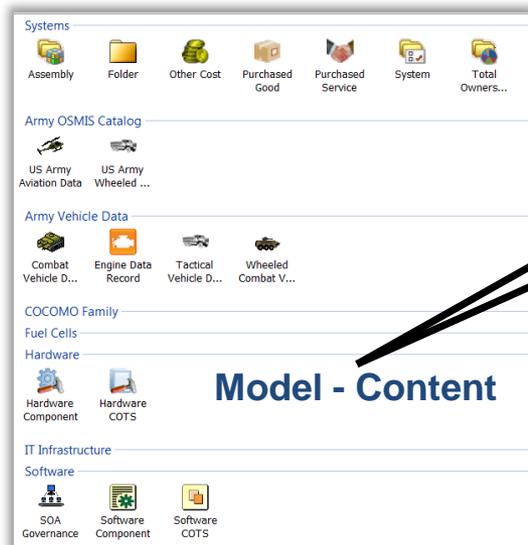
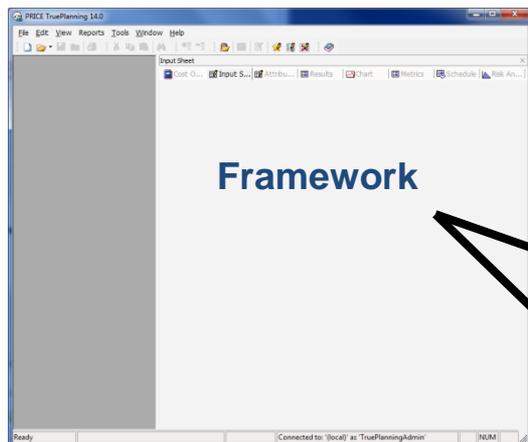
**CER: System to Class IX  
Parts Total Cost**

## TruePlanning® Approach



**CER: Component Parts to  
Hours To Build**

## 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

