

Optimizing Data Driven Cost Estimating Models for Space Mission Analysis and Design

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 TruePlanning®
by PRICE® Systems

Introduction

- In today's data driven cost estimating environment, it is critical to understand the impact of design and systems engineering decisions on cost.
 - Important to leverage actual cost data in developing data-driven Cost Estimating Relationships (CERs) that relate engineering design and performance parameters to cost.
 - Critical in today's environment to have the ability to conduct sensitivity analysis on not only the CER, but on the entire system estimated to understand the full impact on Measures of Effectiveness and Measures of Performance.
 - Using the FireSat satellite example we will discuss how to create libraries of data-driven CERs for future projects. These CERs are "white box" and auditable both in terms of the trend line equation and underlying data points.
 - The presentation will also cover the benefits of implementing a data-driven methodology in the TruePlanning framework vs. maintaining CERs in EXCEL.
 - Using a new interface developed for TruePlanning, this presentation will also demonstrate how sensitivity analysis for custom developed CERs can easily be generated.

Data Driven Estimating

- What does it mean?
 - It means the kind of estimating envisioned by S. 454, Weapon Systems Acquisition Reform Act of 2009, signed into law by President Obama on May 22, 2009.
- Among the initiatives of the act are:
 - Getting things right from the start with sound systems engineering, cost-estimating;
 - Ensure that cost estimates for major defense acquisition programs are fair, reliable, and unbiased;
 - Ensure the consideration of trade-offs between cost, schedule, and performance early in the process of developing major weapon systems;
 - An infusion of highly skilled and capable acquisition specialists to carry out the requirements of this bill and address the problems in the defense acquisition system.

Parametric Estimating

- Parametric estimating represents the most widely adopted method in the integrated engineering and costing environment. Among the reasons:
 - Parametrics are faster to respond than conventional or bottoms-up cost estimating;
 - Parametrics, by amalgamating cost variables into a few cost drivers, require less information than other methods;
 - Parametric cost drivers often align to engineering drivers, allowing concurrent development of estimates and design alternatives; no other methods have demonstrated this ability;
 - Interfaces between Systems Engineering tools and parametric estimating tools, some commercial, are in use right now;
 - When properly calibrated, parametric estimating is at least as accurate as any other estimating method; parametrics is often better.

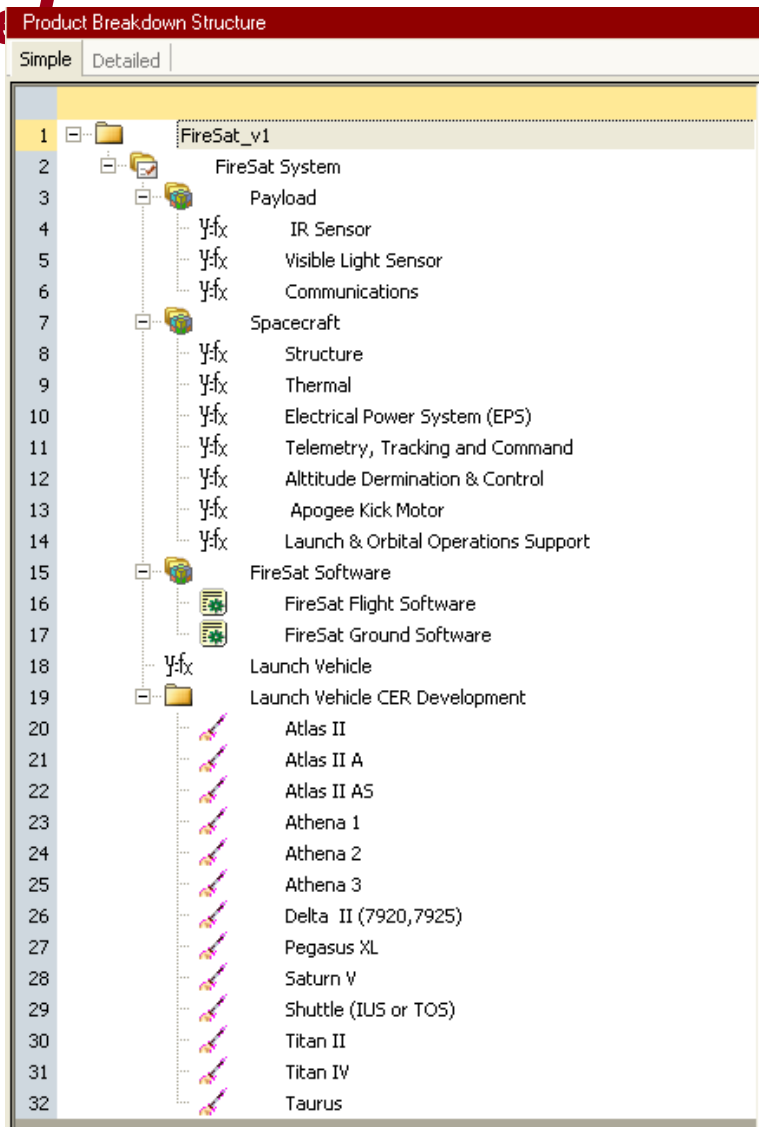
Case Study

Leveraging Data-Driven CERs and Sensitivity Analysis in Satellite Estimating

FireSat Case Study

- Using Space Mission Analysis Design FireSat equations, 3rd edition, and PRICE Systems cost research, the objectives of this case study are to:
 - Develop a data-driven estimating model.
 - Determine the “surface response” of the model (carpet plot analysis) to changes in design and design life parameters.
 - Understand which of the design variables drive cost – and to what extent (Design of Experiments).
 - Examine the trending within the cost estimating model.
 - Conduct an Independent Cost Estimate (ICE) as a cross-check against our “point” estimate.
- We begin by constructing a Work Breakdown Structure in the TruePlanning model and then integrating the results with Phoenix Integration ModelCenter 9.0.

“Data Driven” Example – FireSat TruePlanning Model



FireSat CER's from Space Mission Analysis and Design (SMAD) 3rd Edition

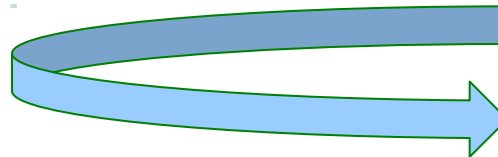
TruePlanning Software Cost Model

Launch Vehicle CER

Launch Vehicle Database / CER Development

FireSat Cost Estimating Relationships

Level	Cost Object Name	Cost Object Custom Name	Equation	X Name	X
0	System	FireSat System			
1	Assembly	Payload			
2	Single Variable Equation	IR Sensor	$142742 * (x^{0.562}) * 1000$	ApertureDiameter	1.2
2	Single Variable Equation	Visible Light Sensor	$51469 * (x^{0.562}) * 1000$	ApertureDiameter	1.2
2	Single Variable Equation	Communications	$(140 * x) * 1000$	CommWtKG	395
1	Assembly	Spacecraft			
2	Single Variable Equation	Structure	$13.1 * x * 1000$	SpacecraftDryWtKG	560
2	Single Variable Equation	Thermal	$50.6 * x^{0.707} * 1000$	Thermal_WT_KG	87
2	Single Variable Equation	Electrical Power System (EPS)	$112 * x^{0.763} * 1000$	EPS_WT_KG	573
2	Single Variable Equation	Telemetry, Tracking and Command	$635 * x^{0.568} * 1000$	TTC_WT_KG	79
2	Single Variable Equation	Altitude Dermination & Control	$293 * x^{0.777} * 1000$	ADCS_WT_KG	192
2	Single Variable Equation	Apogee Kick Motor	$4.97 * x^{0.826} * 1000$	AKM_WT_KG	966
2	Single Variable Equation	Launch & Orbital Operations Support	$4.9 * x * 1000$	LOOS_WT_KG	1537



Space Mission Analysis Design FireSat equations imported directly from EXCEL into TruePlanning Equation Cost Object

Product Breakdown Structure

Simple Detailed

1	FireSat_v1
2	FireSat System
3	Payload
4	IR Sensor
5	Visible Light Sensor
6	Communications
7	Spacecraft
8	Structure
9	Thermal
10	Electrical Power System (EPS)
11	Telemetry, Tracking and Command
12	Altitude Dermination & Control
13	Apogee Kick Motor
14	Launch & Orbital Operations Support
15	FireSat Software
16	FireSat Flight Software
17	FireSat Ground Software
18	Launch Vehicle
19	Launch Vehicle CER Development
20	Atlas II
21	Atlas II A
22	Atlas II AS
23	Athena 1
24	Athena 2
25	Athena 3
26	Delta II (7920,7925)
27	Pegasus XL
28	Saturn V
29	Shuttle (IUS or TOS)
30	Titan II
31	Titan IV
32	Taurus

Example of FireSat CER imported into TruePlanning

Product Breakdown Structure

- 1 FireSat_v1
 - 2 FireSat System
 - 3 Payload
 - 4 IR Sensor
 - 5 Visible Light Sensor
 - 6 Communications
 - 7 Spacecraft
 - 8 Structure
 - 9 Thermal
 - 10 Electrical Power System (EPS)
 - 11 Telemetry, Tracking and Com...
 - 12 Altitude Dermination & Control
 - 13 Apogee Kick Motor
 - 14 Launch & Orbital Operations ...
 - 15 FireSat Software
 - 16 FireSat Flight Software
 - 17 FireSat Ground Software
 - 18 Launch Vehicle
 - 19 Launch Vehicle CER Development

Input Sheet: IR Sensor

Cost Objects | Input Sheet | Results | Chart

IR Sensor Detailed Estimate

Cost:	\$162,831,287	32.30%	Labor Requirement:	0.00 hours
Project Cost:	\$504,067,602		Project Labor Requirement:	1,072,226.65 hours

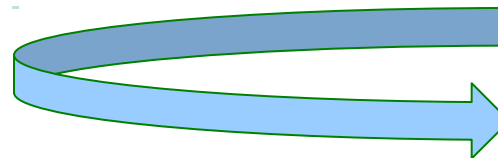
Worksheet Set: <Inherited>

	Value	Units	Spread	Notes
1 Start Date				
2 Quantity Per Next Higher Level	1.00			
3 Equation	$142742 * (x^{0.562}) * 1000$			
4 X Name	ApertureDiameter			
5 \times	1.200			
6 Activity and Resource Allocation				
7 Activity Type	Production			
8 Resource Type	Other Cost			
9 Capture Actuals				
10 Actual Cost	0	\$		
11 Actual Hours	0			

Once the CER is imported into TruePlanning it become an integral part of the framework co-existing with other CERs. The CER is not subject to breakage as in an EXCEL spreadsheet and leverages additional TruePlanning capability e.g, risk analysis.

FireSat Launch Vehicle CER Development

Level	Cost Object Name	Cost Object Custom Name	Unit Cost (\$Y00)	Cost per Kg (\$EOFY00)	New Cost
1	Folder	Launch Vehicle CER Development			
2	Launch Vehicle Data	Atlas II	\$85,000,000	\$13,700	
2	Launch Vehicle Data	Atlas II A	\$90,000,000	\$13,000	
2	Launch Vehicle Data	Atlas II AS	\$105,000,000	\$12,700	
2	Launch Vehicle Data	Athena 1	\$18,000,000	\$22,500	
2	Launch Vehicle Data	Athena 2	\$26,000,000	\$13,300	
2	Launch Vehicle Data	Athena 3	\$31,000,000	\$8,500	
2	Launch Vehicle Data	Delta II (7920,7925)	\$52,500,000	\$10,800	
2	Launch Vehicle Data	Pegasus XL	\$13,000,000	\$28,300	
2	Launch Vehicle Data	Saturn V	\$820,000,000	\$6,500	
2	Launch Vehicle Data	Shuttle (IUS or TOS)	\$400,000,000	\$16,400	
2	Launch Vehicle Data	Titan II	\$37,000,000	\$19,400	
2	Launch Vehicle Data	Titan IV	\$214,000,000	\$9,900	
2	Launch Vehicle Data	Taurus	\$21,500,000	\$15,700	



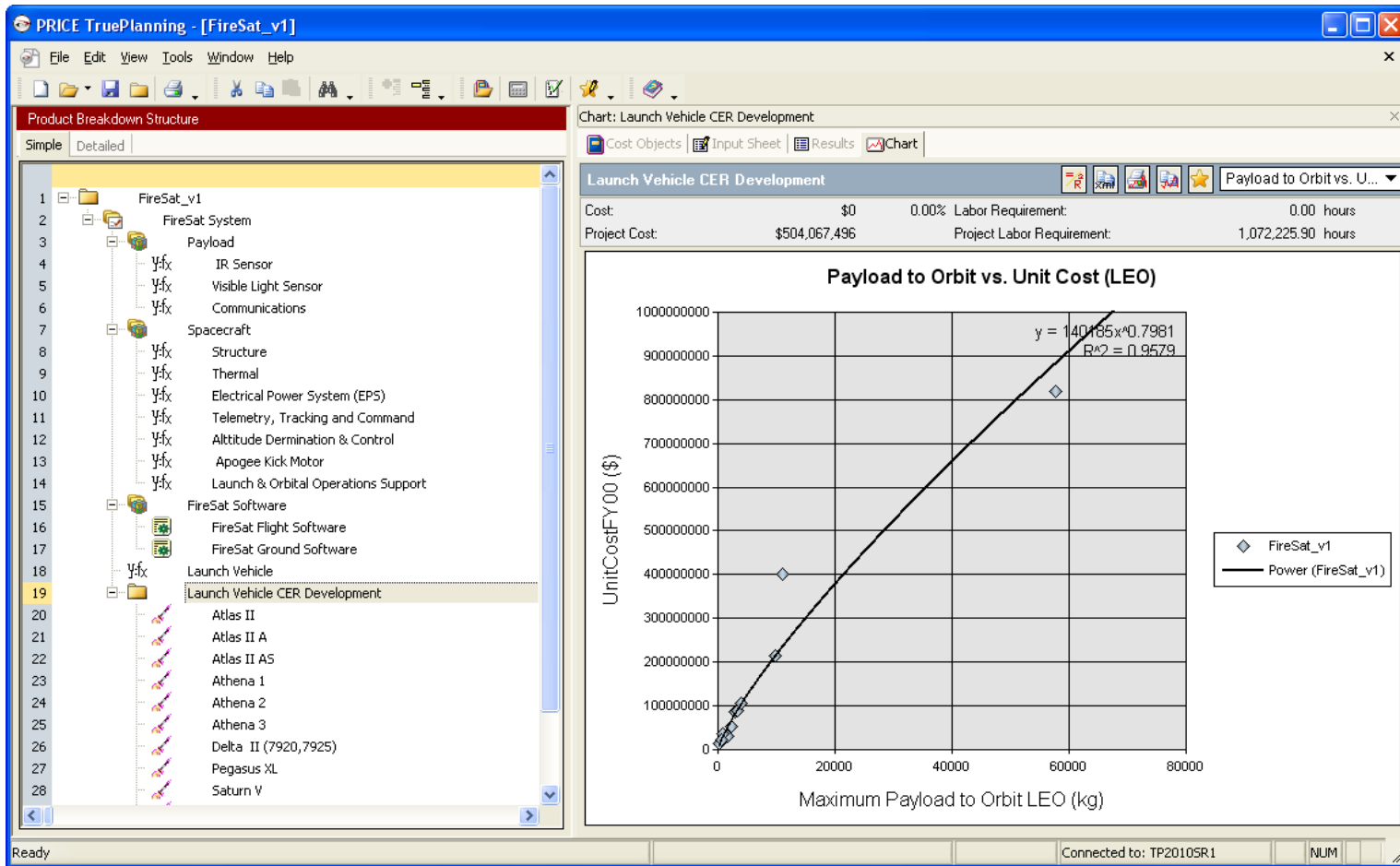
Product Breakdown Structure

Simple Detailed

- 1 FireSat_v1
 - 2 FireSat System
 - 3 Payload
 - 4 IR Sensor
 - 5 Visible Light Sensor
 - 6 Communications
 - 7 Spacecraft
 - 8 Structure
 - 9 Thermal
 - 10 Electrical Power System (EPS)
 - 11 Telemetry, Tracking and Command
 - 12 Altitude Determination & Control
 - 13 Apogee Kick Motor
 - 14 Launch & Orbital Operations Support
 - 15 FireSat Software
 - 16 FireSat Flight Software
 - 17 FireSat Ground Software
 - 18 Launch Vehicle
 - 19 Launch Vehicle CER Development
 - 20 Atlas II
 - 21 Atlas II A
 - 22 Atlas II AS
 - 23 Athena 1
 - 24 Athena 2
 - 25 Athena 3
 - 26 Delta II (7920,7925)
 - 27 Pegasus XL
 - 28 Saturn V
 - 29 Shuttle (IUS or TOS)
 - 30 Titan II
 - 31 Titan IV
 - 32 Taurus

Space Mission Analysis Design Launch Vehicle Data imported from EXCEL to TruePlanning for CER development

FireSat Launch Vehicle CER Development



Space Mission Analysis Design Launch Vehicle Data regression analysis and CER development in TruePlanning

FireSat - Launch Vehicle CER

The screenshot displays the PRICE TruePlanning interface. On the left, the 'Product Breakdown Structure' shows a hierarchical tree for 'FireSat_v1', including categories like 'Payload', 'Spacecraft', 'FireSat Software', and 'Launch Vehicle'. The 'Launch Vehicle' item is selected. On the right, the 'Input Sheet: Launch Vehicle' is open, showing a 'Detailed Estimate' table with columns for Value, Units, Spread, and Notes. The table contains the following data:

	Value	Units	Spread	Notes
1 Start Date				
2 Quantity Per Next Higher Level	1.00			
3 Equation	140185.241119311*[x*...			
4 X Name	Payload_WT_LEO_KG			
5 X	395.000			
6 Activity and Resource Allocation				
7 Activity Type	Production			
8 Resource Type	Other Cost			
9 Capture Actuals				
10 Actual Cost	0	\$		
11 Actual Hours	0			

Resultant CER based on regression analysis of Launch Vehicle data is encapsulated into a Launch Vehicle CER cost object.

This can become part of a library of CER's including the source data

FireSat - TruePlanning Software Estimating Model

The screenshot displays the TruePlanning software interface for a project named 'FireSat Flight Software'. On the left, a 'Product Breakdown Structure' tree shows the hierarchy from 'FireSat_v1' down to 'Launch Vehicle CER Development' with various sub-items like 'IR Sensor', 'Spacecraft', and 'FireSat Software'. The main window shows a 'Detailed Estimate' for 'FireSat Flight Software' with a cost of \$34,026,658 and 253,353.91 hours of labor requirement. Below this, a table lists various software development metrics:

	Value	Units	Spread
1 Start Date			
2 -			
3 Application Type	None		
4 Functional Complexity	7.00		
5 Operating Specification	2.00		
6 Organizational Productivity	1.000		
7 Development Team Complexity	3.00		
8 -			
9 Size Units	Source Lines of Code (SLOC)		
10 New Code Size	200,000		
11 New Size Non-executable	20.00%	%	
12 Adapted Code Size	0		
13 Adapted Size Non-executable	0.00%	%	
14 Percent of Design Adapted	0.00%	%	
15 Percent of Code Adapted	0.00%	%	
16 Percent of Test Adapted	0.00%	%	
17 Reused Code Size	0		
18 Reused Size Non-executable	0.00%	%	
19 Deleted Code Size	0		
20 Code Removal Complexity	Remove code that is integrated through a single point		
21 Auto Generated Code Size	0		
22 Auto Gen Size Non-executable	0.00%	%	
23 Auto Translated Code Size	0		
24 Auto Trans Size Non-executable	0.00%	%	

For software, we have augmented the SMAD CERs with TruePlanning for Software. This allows a much more robust modeling of the software estimate taking into account additional parameters software sizing, effective lines of code and team experience.

"FireSat Model Cost Estimate Model

The screenshot displays the PRICE TruePlanning software interface for a project named 'FireSat_v1'. On the left, a 'Product Break-down Structure' tree shows the hierarchy of the system, including Payload, Spacecraft, and various sensors and software components. On the right, the 'Results' window shows a cost estimate table for the 'FireSat System'.

Costs : FireSat System - [S Currency in USD (\$) (as ...)				
	Total	Development	Production	Operation & Support
1 FireSat System	59,781,947	59,781,947		
2 Payload	1,085,878	1,085,878	0	0
3 IR Sensor	162,831,287	0	162,831,287	
4 Visible Light Sensor	58,712,667	0	58,712,667	
5 Communications	56,939,199	0	56,939,199	
6 Spacecraft	364,112	364,112	0	0
7 Structure	7,553,453	0	7,553,453	
8 Thermal	1,224,833	0	1,224,833	
9 Electrical Power System...	14,668,180	0	14,668,180	
10 Telemetry, Tracking and...	7,821,898	0	7,821,898	
11 Altitude Determination & ...	17,934,071	0	17,934,071	
12 Apogee Kick Motor	1,494,974	0	1,494,974	
13 Launch & Orbital Operati...	7,754,542	0	7,754,542	
14 FireSat Software	17,860,945	17,860,945	0	0
15 FireSat Flight Software	34,026,658	34,026,658	0	0
16 FireSat Ground Software	36,966,328	36,966,328	0	0
17 Launch Vehicle	17,046,629	0	17,046,629	
18 Total	504,067,602	150,085,869	353,981,733	0

Total System Estimate @ \$504M

Based on:

- SMAD CERs
- Launch Vehicle CER Development
- TruePlanning System of Systems Estimates
- True Planning Software Estimates

FireSat Sensitivity Modeling

- Our TruePlanning model provide a single “point estimate”. However, we want to understand:
 - Sensitivity of the model to changes in CER parameters.
 - The response surface or “Carpet Plot” of the model to parameter changes
 - Which of the design variables drive cost – and to what extent (Design of Experiments)
- Using ModelCenter 9.0 from Phoenix Integration, we can conduct these (and many other) system engineering studies.
- This allows us to determine the sensitivities of FireSat CERs within the TruePlanning model

FireSat Sensitivity Modeling

TruePlanning - [FireSat_v1]

Project: FireSat_v1

Costs: FireSat System (B Category) (USD) (B) (a...	Total	Development	Production	Operation & Support
1 FireSat System	53,781,542	53,781,542	0	0
2 Payload	1,005,879	1,005,879	0	0
3 IT Sensor	162,831,297	0	162,831,297	0
4 Visible Light Sensor	50,712,867	0	50,712,867	0
5 Communications	56,939,199	0	56,939,199	0
6 Spacecraft	384,112	384,112	0	0
7 Structure	7,953,493	0	7,953,493	0
8 Thermal	1,224,833	0	1,224,833	0
9 Electrical/Power System	14,680,100	0	14,680,100	0
10 Telemetry, Tracking and...	7,821,898	0	7,821,898	0
11 Attitude Determination...	17,934,871	0	17,934,871	0
12 Apogee Kick Motor	1,434,914	0	1,434,914	0
13 Launch & Orbital Oper...	7,754,542	0	7,754,542	0
14 FireSat Software	17,880,945	17,880,945	0	0
15 FireSat Flight Software	34,626,608	34,626,608	0	0
16 FireSat Ground Software	36,966,328	36,966,328	0	0
17 Launch Vehicle	17,046,829	0	17,046,829	0
18 Total	504,067,602	150,005,863	353,981,733	0

ModelCenter 9.0 contains a “plug in” for TruePlanning allowing exposure of all TruePlanning inputs and outputs.

This allows the ability to take full advantage of ModelCenter System Engineering tools

ModelCenter 9.0

Phoenix Integration ModelCenter 9.0 - [C:\Documents and Settings\jasnoff\Desktop\NASA CAD\FireSatv3.pxc] - [Model (Analysis View)]

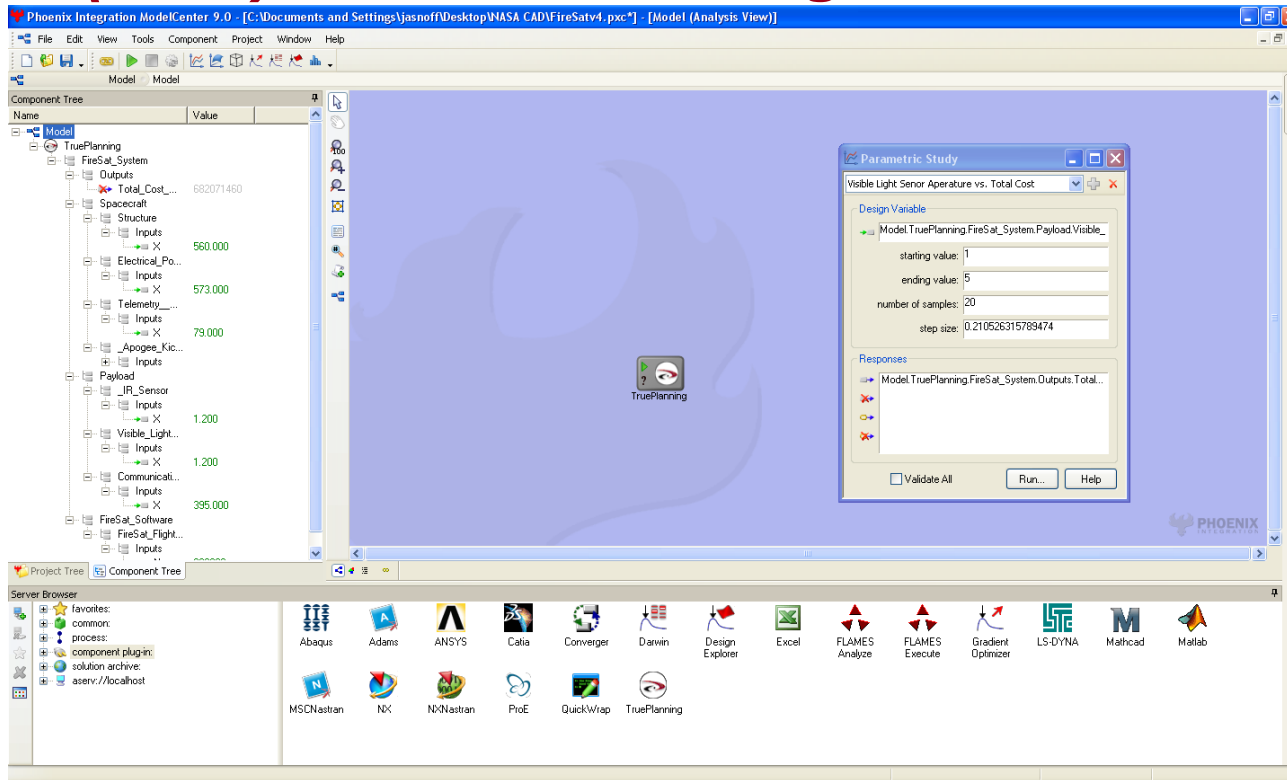
Component Tree

Name	Value
Model	
TruePlanning	
FireSat_System	
Outputs	
Total_Cost...	504067602
Spacecraft	
Structure	
Inputs	
Electrical_Po...	560,000
Inputs	
Telemetry...	573,000
Inputs	
Apogee_Kic...	79,000
Inputs	
Payload	966,000
Inputs	
J_R_Sensor	1,200
Inputs	
Viable_Light...	1,200
Inputs	

Server Browser

- Abaqus
- Adams
- ANSYS
- Catia
- Converger
- Darwin
- Design Explorer
- Excel
- FLAMES Analyze
- FLAMES Execute
- Gradient Optimizer
- LS-DYNA
- Mahcad
- Mallab
- MSCNastran
- NX
- NXNastran
- ProE
- QuickWap
- TruePlanning

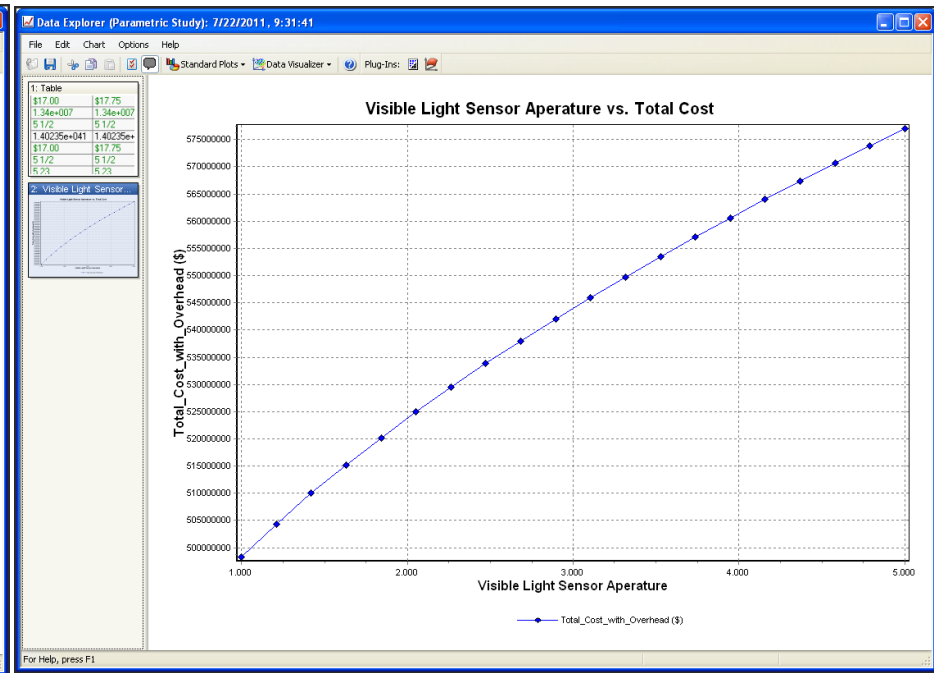
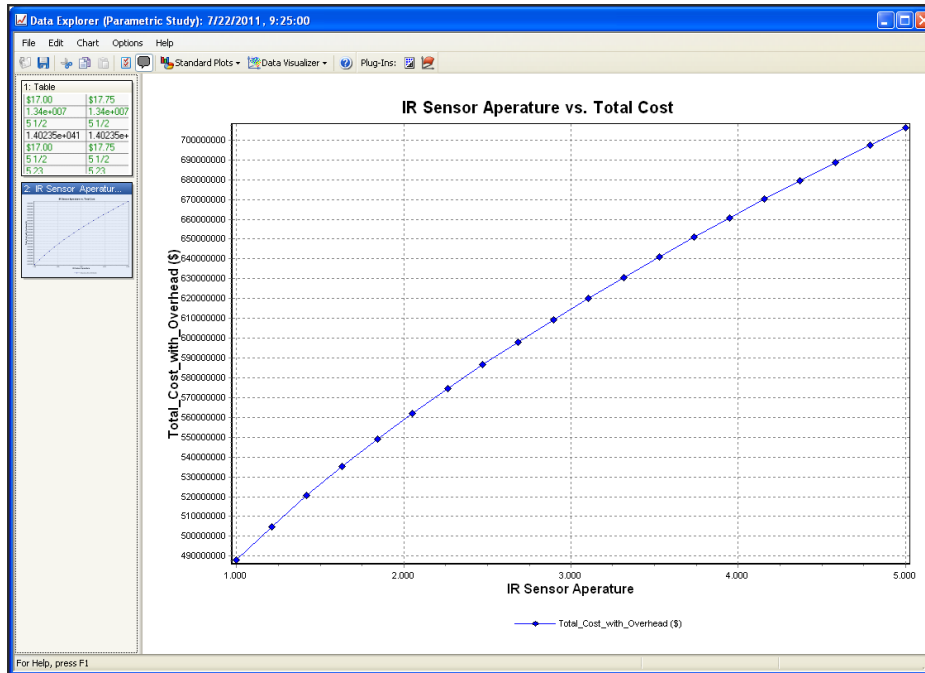
FireSat Sensitivity Modeling – Parametric Study - Sensors Cost Estimating Relationship (CER) in TruePlanning



Using ModelCenter 9.0, we want to do a “Parametric Study” of the Aperture Diameter to understand how variations of Aperture size influence cost.

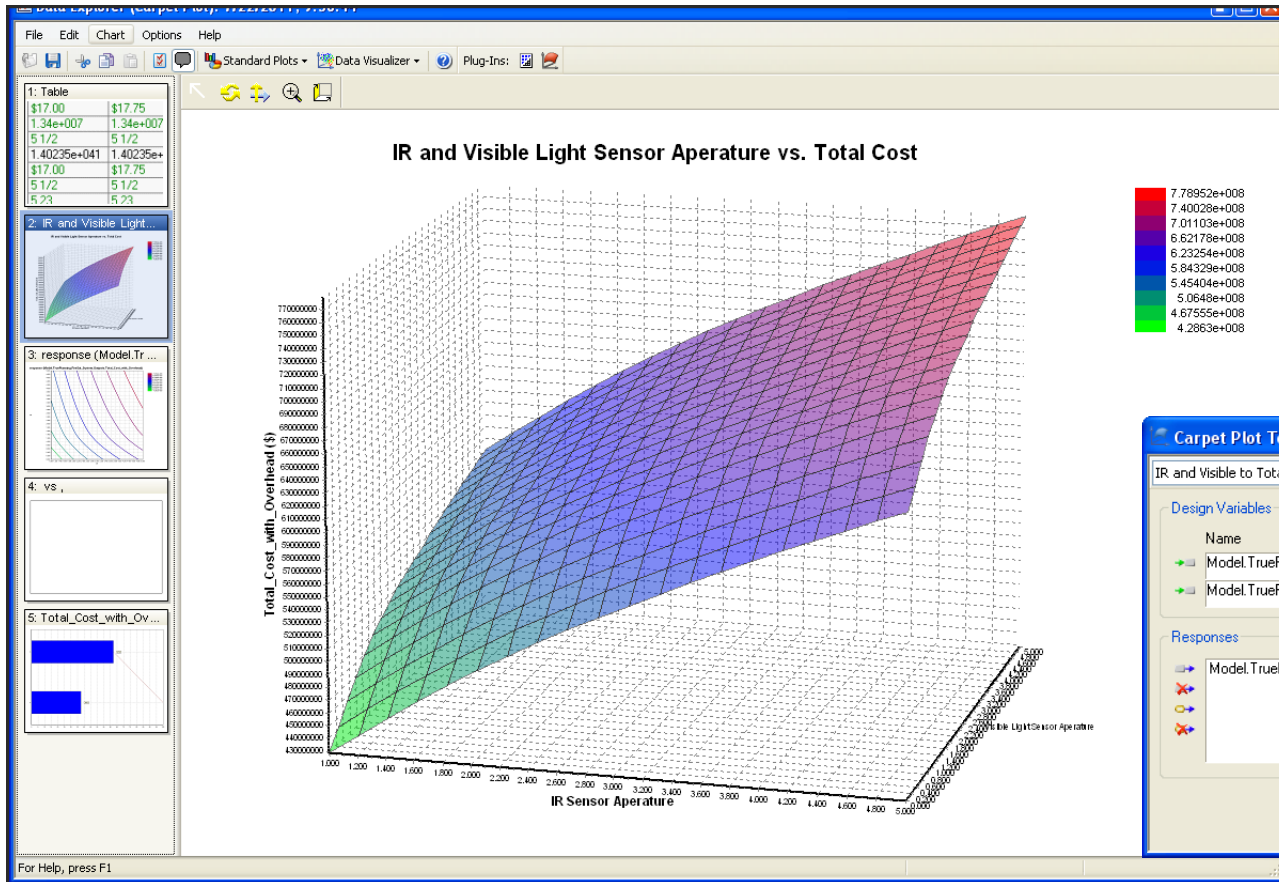
TruePlanning model opened in ModelCenter 9.0 showing selected inputs.

FireSat Sensitivity Modeling – Parametric Study - Sensors



For this study we use ModelCenter 9.0 to iterate a range of aperture parameters for IR Sensor and Visible Light Sensor to examine the impact on Total Cost

FireSat Sensitivity Modeling – Carpet Plot, ModelCenter 9.0



Carpet Plot Tool

IR and Visible to Total Cost

Design Variables

Name	From	To	Num Steps	Step Size
Model.TruePlanning.FireSat_System.Payload_IR_1	1	5	4	1.333333333
Model.TruePlanning.FireSat_System.Payload.Visible	0	5	4	1.666666666

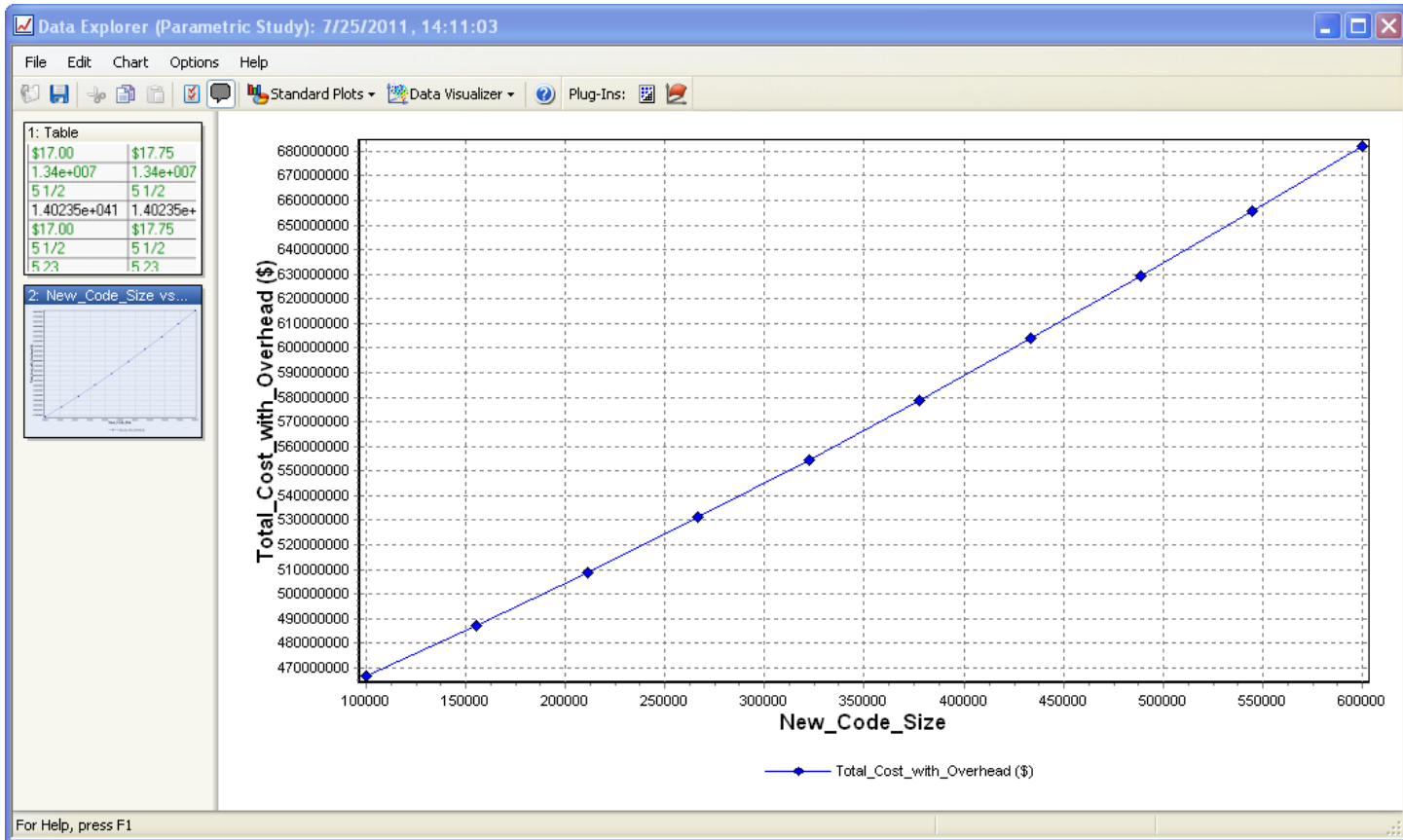
Responses

- Model.TruePlanning.FireSat_System.Outputs.Total_Cost_with_Overhead

Validate All

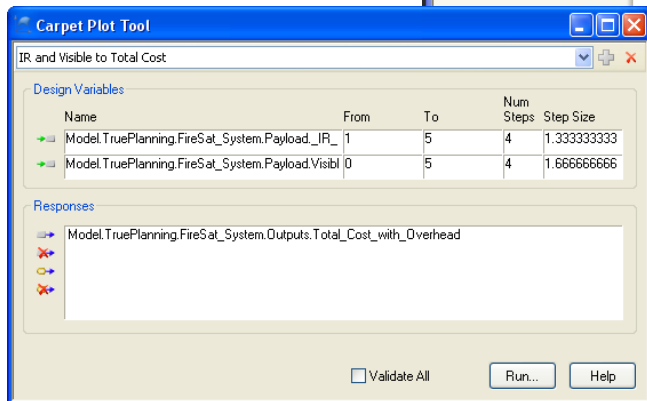
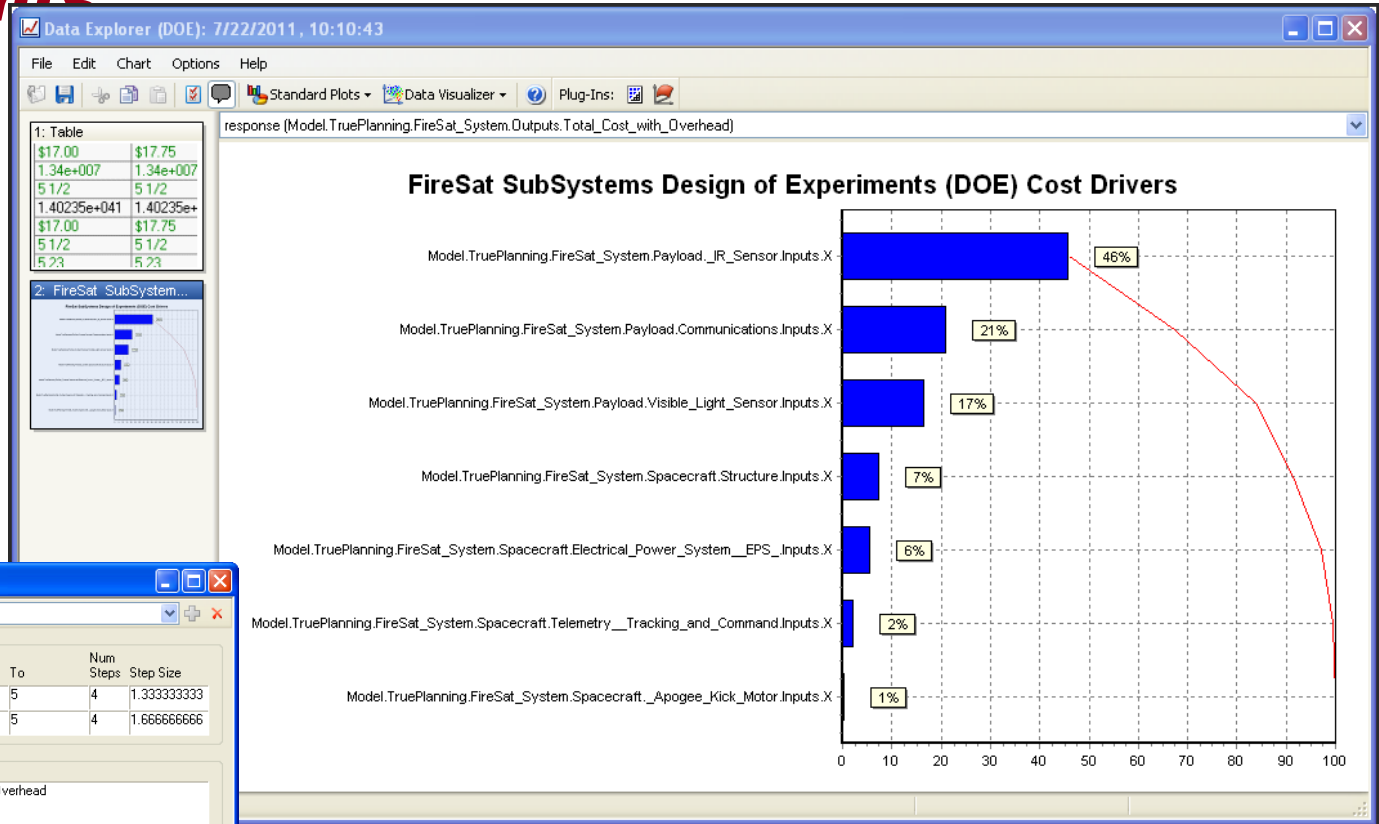
Using the Carpet Plot tool, we can examine the impact of changes to the IR and Visible Light apertures over a simultaneous range of values and visualize the impact on cost.

FireSat Sensitivity Modeling – Parametric Study - Software



In addition to examining subsystems, we can also use ModelCenter to look at sensitivity of code growth to total cost.

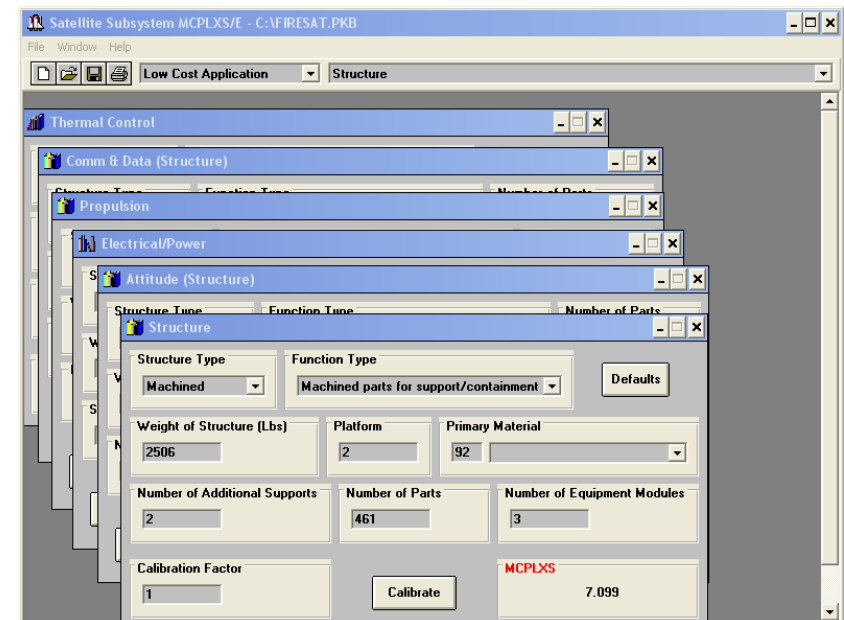
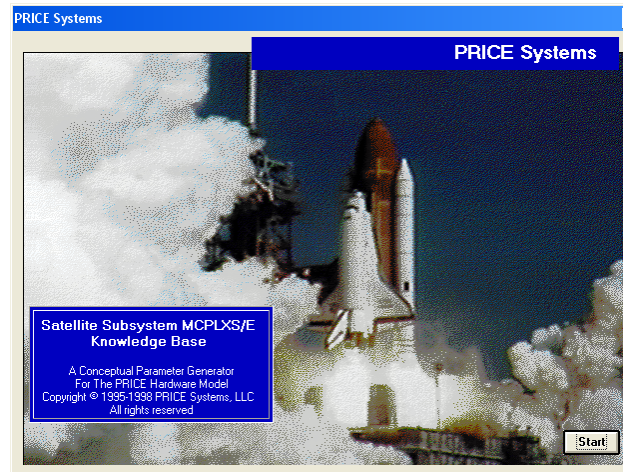
FireSat Sensitivity Modeling – Design of Experiments



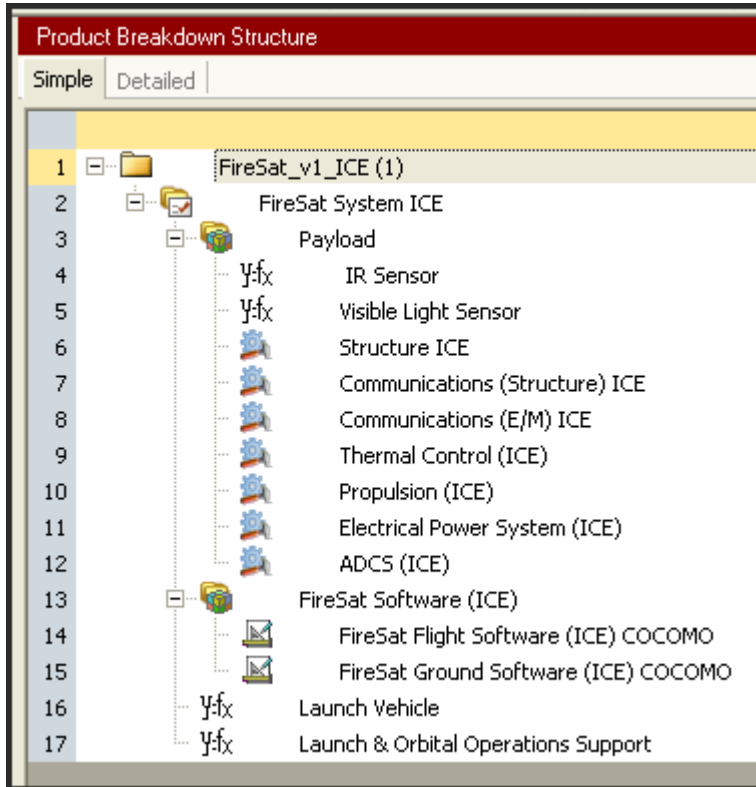
In Using the DOE tool, we can examine which of the subsystems are the largest cost drivers over a range of variation.

FireSat Sensitivity Modeling – Independent Cost Estimate

- In addition to understanding the sensitivities of the data-driven FireSat model, we also want to develop an Independent Cost Estimate (ICE) using PRICE Systems cost research.
- For the Hardware ICE, we construct a model using calibrated NASA historical data contained in the Satellite Subsystem Knowledge Base (SSKB)
- For the Software ICE, we use the COCOMO model contained in TruePlanning



FireSat Independent Cost Estimate (ICE)



FireSat IR and Visible Sensor CER from SMAD

Independent Cost Estimate (Hardware) for Subsystems from calibrated TruePlanning Hardware model

Launch Vehicle from CER library (SMAD)

The Independent Cost Estimate substitutes the SMAD CERs with calibrated TruePlanning Hardware models

FireSat - TruePlanning Hardware Estimating Model – Independent Cost Estimate (ICE)

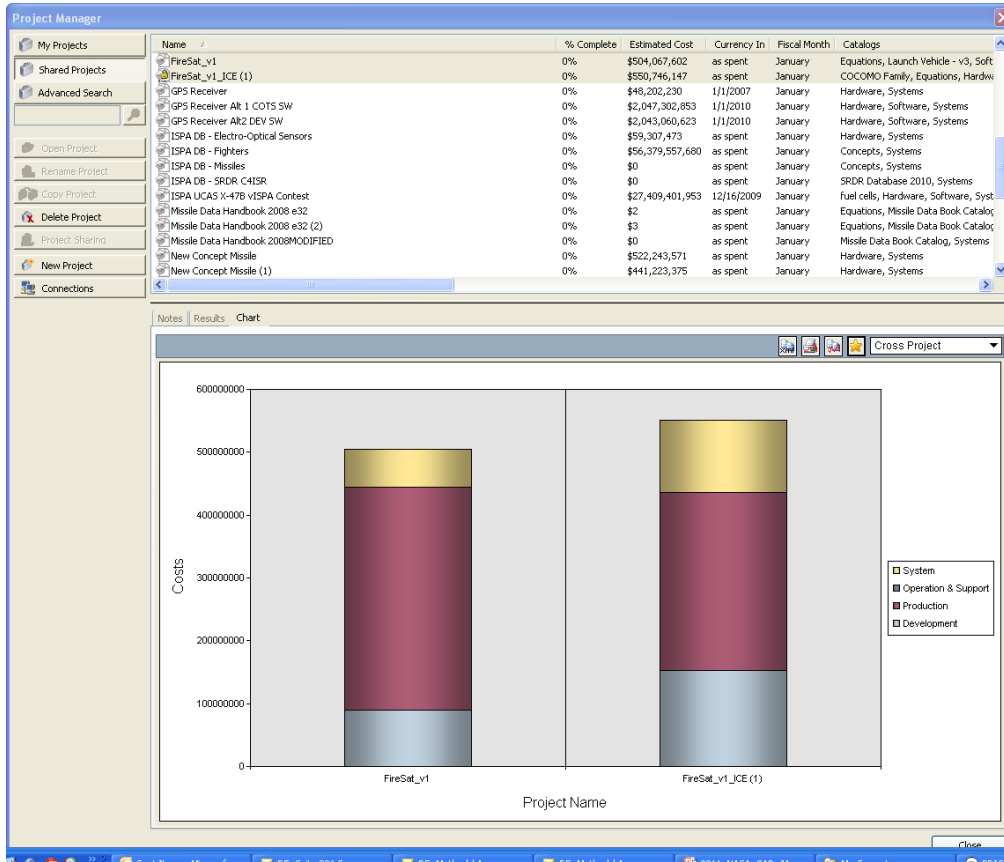
The screenshot displays the PRICE TruePlanning software interface. On the left, the 'Product Breakdown Structure' pane shows a hierarchical tree for 'FireSat_v1_ICE (1)'. The main window is titled 'Input Sheet: Structure ICE' and shows a 'Detailed Estimate' for the 'Structure ICE' component. The summary section indicates a cost of \$6,298,239 (1.14% labor requirement) and 53,136.32 hours. The 'Worksheet Set' is '<Inherited>'. The main data table lists various parameters and their values:

	Value	Units	Spread
1 Start Date			
2 Quantity Per Next Higher Level	1.00		
3 Additional Units			
4 Number of Additional Production Units	0.00		
5 Number of Additional Prototypes	0.00		
6 Cost Sharing Units			
7 Total Number of Production Units Produced	0		
8 Total Number of Prototypes Produced	0.00		
9 Technical Description			
10 Equipment Type	None		
11 Operating Specification	1.40		
12 Weight of Structure	560.000	lbs	
13 Weight of Electronics	0.000	lbs	
14 Volume	1.000	ft ³	
15 Manufacturing Complexity for Structure	7.099		
16 Percent of New Structure	100%	%	
17 Percent of Design Repeat for Structure	0%	%	
18 Manufacturing Complexity for Electronics	7.000		
19 Percent of New Electronics	100%	%	
20 Percent of Design Repeat for Electronics	0%	%	
21 Engineering Complexity	1.000		
22 Labor Learning Curve	0.000%	%	
23 Material Learning Curve	0.000%	%	
24 Manufacturing Process Index	0.000		
25 Technology Improvement Control	1.0		
26 Technology Obsolescence Control	0.0		
27 Year of Technology			
28 External Integration Complexity for Structure	3.00		
29 External Integration Complexity for Electronics	3.00		

For the ICE, we have replaced the SMAD subsystem CERs with TruePlanning for Hardware model.

This allows independent modeling of the subsystems estimate taking into account historical NASA calibrations in the Satellite Subsystem Knowledge Base (SSKB)

FireSat ICE vs. FireSat SMAD CERs



TruePlanning Project Manager display all projects within the SQL database

Cross Project chart selection control

FireSat estimate \$504M vs. FireSat ICE @ \$550M displayed in column chart format

Benefits of Data Driven Results in TruePlanning Framework

- Ability to include CERs as part of the TruePlanning Framework.
 - Leverages additional capability such as risk analysis, escalation, activity based costing and consolidated reporting.
- Ability to have both databases of historical data points including estimating CERs within the same framework.
 - PRICE Cost Research/Calibrated can be intermingled with your own CERs thus increasing estimate fidelity.
- Integration with System Engineering tools such as ModelCenter to conduct sensitivity, Design of Experiments, optimization studies, etc.

Benefits of Data Driven Results in TruePlanning Framework

- Repository for all data used to generate the databases and CERs
 - Ability to embed the entire database including EXCEL files and trend line analysis within the TruePlanning estimate for complete auditability.
- In conjunction with the TruePlanning framework, you can integrate data-driven CERs, TruePlanning cost objects (models) and your own custom models to achieve higher fidelity estimates tied to both actual data points, calibrated data and PRICE cost research.

Zachary Jasnoff

- Solutions Architect, PRICE Systems, Rosslyn VA

- **Over 25 years parametric and detailed estimating experience**
- **Past estimating experience includes:**
 - Lockheed-Martin
 - Boeing
 - US GAO
 - JPMorgan (Risk and Resiliency)
- **Graduate of Wharton/Penn Engineering**
- **Conducted extensive consulting assignments with DARPA, DHS and DoD**
- **Presented courses in**
 - hardware estimating,
 - software estimating,
 - life cycle cost,
 - Cost Estimating Relationships,
 - Information Technology,
 - risk analysis and
 - supplier assessment
- **Developed TCO/Risk model for the banking industry**
- **Presented papers at DoDCAS, ISPA/SCEA, ISACA, DJR and PRICE Systems Symposiums**