

Understanding and Measuring the Impact of Design and Systems Engineering Decisions on Affordability

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Zachary Jasnoff

Solutions Architect, Director
PRICE Systems, LLC
1501 Lee Highway, Suite 206
Arlington, VA 22209
USA 703.740.0082



Introduction

In today's data driven cost estimating environment, it is critical to understand the impact of design and systems engineering decisions on cost.

- Need for Cost Estimating Relationships (CERs) that relate engineering design and performance parameters to cost.
- New methodologies are needed to understand the cost impact on Measures of Effectiveness and Measures of Performance.
- Engineers also need the ability to visualize the sensitivity of the CERs to changes in design and performance parameters.
- Using new interfaces between systems engineering and cost estimating tools, this presentation will demonstrate how sensitivity analysis for custom developed CERs can easily be generated.

The Current Landscape

- In 2009, the Weapon Systems Acquisition Reform Act (S. 454) was signed into law by President Obama. One of the key principles is getting things right from the start with sound systems engineering and defensible cost estimating practices.
- System Engineering practices must ensure consideration of trade-offs between cost, schedule and performance early in the process of developing major weapon systems.
- One of the key analytical tools available to System Engineering for including cost as a trade off consideration is parametric estimating.
- By amalgamating cost variables into a few cost drivers, parametric cost estimating require less information than other methodologies.
- The cost drivers used in parametric cost estimating often align to engineering drivers, allowing concurrent development of estimates and design alternatives; no other methods have demonstrated this ability.

Affordability is now treated as an engineering parameter and not simply a downstream result.

What is Needed in Today's Environment?

- Ability to include align CERs within the Measure of Effectiveness
- Ability to have both databases of historical data points including estimating CERs within an integrated framework.
- Integration with System Engineering tools such as ModelCenter to conduct sensitivity, Design of Experiments, optimization studies, etc.

An Integrated Framework between cost estimating tools and System Engineering is required to fully assess Affordability issues.

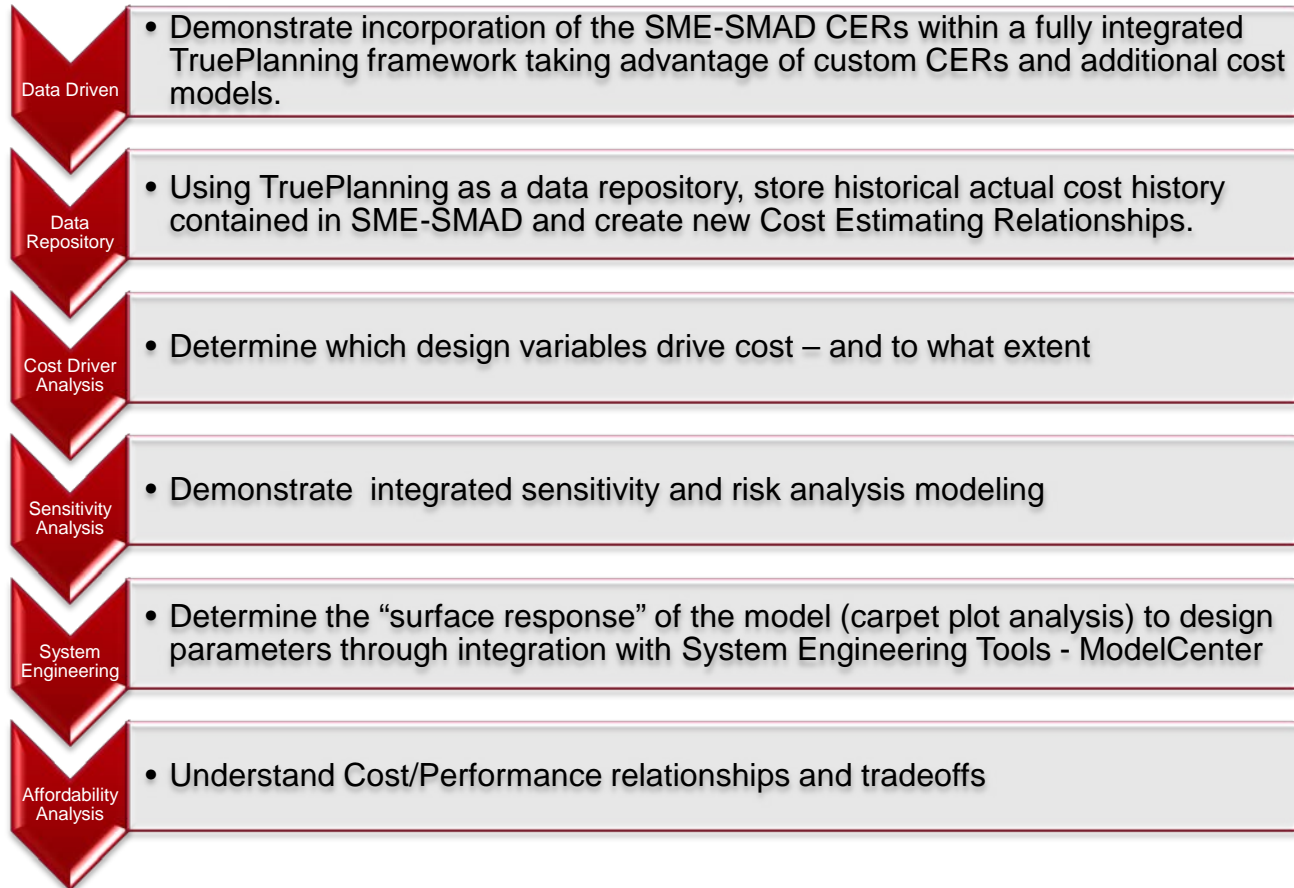
Case Study Example

An Integrated Affordability Framework

Leveraging Data-Driven CERs and System Engineering Tools in Satellite Estimating

FireSat Case Study

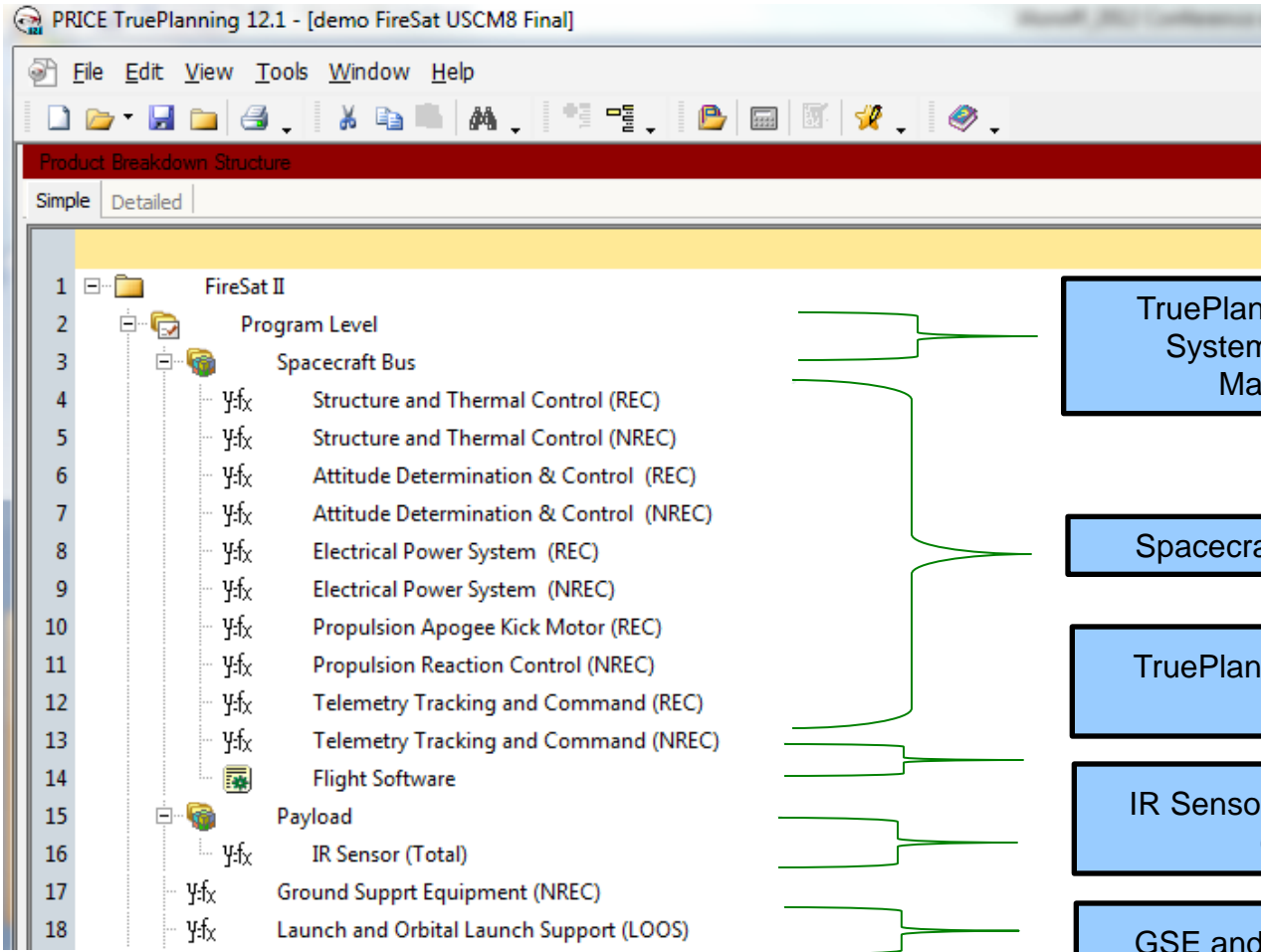
- Using equations from the Space Mission Engineering The New SMAD (SME-SMAD) Chapter 11 Cost Estimating (Henry Apgar) the objectives of this case study are to:



[Space Mission Engineering The New SMAD \(SME-SMAD\) \[Wertz/Everett/Puschell, July 2011\] \(softcover\)](#)

FireSat II Integrated Parametric Cost Estimating Model – TruePlanning including UCSM8, NICM and Custom CERs

Integrated Parametric Cost Models



TruePlanning Parametric Model for System Engineering / Program Management and IA&T

Spacecraft Bus CERs from USCM8

TruePlanning for Software Parametric Model

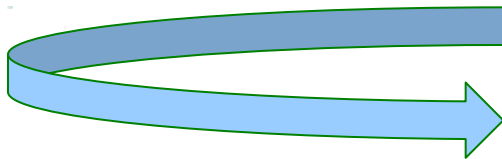
IR Sensor CER from NASA Instrument Cost Model (NICM)

GSE and Launch Support and Launch from USMC8

FireSat Cost Estimating Relationships

FIRESAT_TP_Excel Solution v6 - Microsoft Excel

Level	Cost Object Name	Cost Object Custom Name	Cost Equation	Unit Name	Unit Value	Unit Name
3	0 System Folder	FireSat II				
4	1 System	Program Level				
5	2 Assembly	Spacecraft Bus				
6	3 Equations	Structure and Thermal Control (REC)	$(22.6 * x) * 1000$	Weight(kg)	29.1	
7	3 Equations	Structure and Thermal Control (NREC)	$(646 * x^{0.684}) * 1000$	Weight(kg)	29.1	
8	3 Equations	Attitude Determination & Control (REC)	$(795 * x^{0.593}) * 1000$	ADCS Weight (kg)	11.6	
9	3 Equations	Attitude Determination & Control (NREC)	$(324 * x) * 1000$	ADCS Weight (kg)	11.6	
10	3 Equations	Electrical Power System (REC)	$(32.4 * x) * 1000$	EPS Weight (kg)	20.9	
11	3 Equations	Electrical Power System (NREC)	$(64.3 * x) * 1000$	EPS Weight (kg)	20.9	
12	3 Equations	Propulsion Apogee Kick Motor (REC)	$(29 * x + 0.024 * y) * 1000$	AKM Weight(kg)	0	Burn Time (seconds)
13	3 Equations	Propulsion Reaction Control (NREC)	$(20.0 * x^{0.485}) * 1000$	RCS Tank Vol (cc)	0	<Insert Name>
14	3 Equations	Telemetry Tracking and Command (REC)	$(883.7 * x^{0.491} * 1.13 * y) * 1000$	TT&C Weight (kg)	8.1	GTO Orbit (1 = yes 2 = no)
15	3 Equations	Telemetry Tracking and Command (NREC)	$x * 1000$	TT&C Avg. Cost	26916	<Insert Name>
16	3 Software Component	Flight Software				



SME-SMAD FireSat equations imported directly from EXCEL into TruePlanning Equation Cost Object

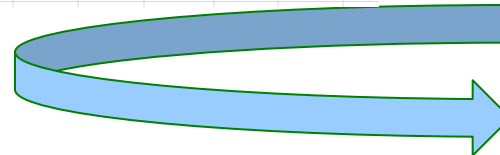
Level	Cost Object Name	Cost Object Custom Name	Cost Equation	Unit Name	Unit Value	Unit Name
1	0 System Folder	FireSat II				
2	1 System	Program Level				
3	2 Assembly	Spacecraft Bus				
4	3 Equations	Structure and Thermal Control (REC)	$Y * x$			
5	3 Equations	Structure and Thermal Control (NREC)	$Y * x$			
6	3 Equations	Attitude Determination & Control (REC)	$Y * x$			
7	3 Equations	Attitude Determination & Control (NREC)	$Y * x$			
8	3 Equations	Electrical Power System (REC)	$Y * x$			
9	3 Equations	Electrical Power System (NREC)	$Y * x$			
10	3 Equations	Propulsion Apogee Kick Motor (REC)	$Y * x$			
11	3 Equations	Propulsion Reaction Control (NREC)	$Y * x$			
12	3 Equations	Telemetry Tracking and Command (REC)	$Y * x$			
13	3 Equations	Telemetry Tracking and Command (NREC)	$Y * x$			

FireSat Launch Vehicle Historical Data in TruePlanning

FIRESAT TP_Excel Solution v6 - Microsoft Excel

Launch Vehicle Data 2012

Level	Cost Object Name	Cost Object Custom Name	Country of Origin	Capacity Payload kg to Orbit - LEO	Capacity Payload kg to Orbit - GTO	Avg Launch Cost FY10\$K	Launch Cost per kg in FY10\$K LEO	Launch Cost per kg in FY10\$K GTO
22	Equations	Launch Segment (REC)						
23	Folder	Launch Vehicle Data						
24	Launch Vehicle Data 2012	Athena 2	USA	2065	590	\$32,688.00	\$15.80	\$55.40
25	Launch Vehicle Data 2012	Cosmos	Russia	1500	0	\$18,387.00	\$12.10	\$0.00
26	Launch Vehicle Data 2012	Pegasus XL	USA	443	0	\$18,454.00	\$41.50	\$0.00
27	Launch Vehicle Data 2012	Falcon 1e	USA	1010	0	\$10,900.00	\$10.80	\$0.00
28	Launch Vehicle Data 2012	Minotaur IV	USA	1650	0	\$22,000.00	\$13.30	\$0.00
29	Launch Vehicle Data 2012	Rocket	Russia	1850	0	\$18,454.00	\$9.90	\$0.00
30	Launch Vehicle Data 2012	Shtil	Russia	430	0	\$272.00	\$0.70	\$0.00
31	Launch Vehicle Data 2012	START	Russia	632	0	\$10,215.00	\$15.90	\$0.00
32	Launch Vehicle Data 2012	Taurus	USA	1380	448	\$25,878.00	\$18.80	\$57.70
33	Launch Vehicle Data 2012	Ariane 44L	Europe	10200	4790	\$153,225.00	\$15.00	\$32.00
34	Launch Vehicle Data 2012	Atlas 2AS	USA	8618	3719	\$132,795.00	\$15.40	\$35.70
35	Launch Vehicle Data 2012	Delta 2	USA	5144	1800	\$74,910.00	\$14.60	\$41.70
36	Launch Vehicle Data 2012	Dnepr	Russia	4400	0	\$20,430.00	\$4.60	\$0.00
37	Launch Vehicle Data 2012	Falcon 9	USA	10450	4540	\$56,750.00	\$5.40	\$12.50
38	Launch Vehicle Data 2012	Long March 2C	China	3200	1000	\$30,645.00	\$9.50	\$30.60
39	Launch Vehicle Data 2012	Long March 2E	China	9200	3370	\$68,100.00	\$7.40	\$20.20
40	Launch Vehicle Data 2012	Soyuz	Russia	7000	1350	\$51,075.00	\$7.40	\$37.90
41	Launch Vehicle Data 2012	Ariane 4G	Europe 18	18000	6800	\$224,730.00	\$12.50	\$33.10
42	Launch Vehicle Data 2012	Atlas 5	USA	20050	8200	\$172,000.00	\$8.60	\$25.30
43	Launch Vehicle Data 2012	Delta 4 Heavy	USA	22560	13130	\$215,000.00	\$9.50	\$16.40
44	Launch Vehicle Data 2012	Long March 3B	China	13600	5200	\$81,720.00	\$6.00	\$15.70
45	Launch Vehicle Data 2012	Proton	Russia	19760	4630	\$115,770.00	\$5.90	\$25.10
46	Launch Vehicle Data 2012	Space Shuttle	USA	28803	5900	\$408,600.00	\$14.20	\$69.20
47	Launch Vehicle Data 2012	Zenit 2	Ukraine 13	13740	0	\$57,885.00	\$4.20	\$0.00
48	Launch Vehicle Data 2012	Zenit 3 SL	Multinational	15876	5250	\$115,770.00	\$7.20	\$22.10



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

PRICE TruePlanning 12.1 - [demo FireSat USCM8 Final]

Product Breakdown Structure

Simple Detailed

- FireSat II
 - Program Level
 - Spacecraft Bus
 - Structure and Thermal Control (REC)
 - Structure and Thermal Control (NREC)
 - Attitude Determination & Control (REC)
 - Attitude Determination & Control (NREC)
 - Electrical Power System (REC)
 - Electrical Power System (NREC)
 - Propulsion Apogee Kick Motor (REC)
 - Propulsion Reaction Control (NREC)
 - Telemetry Tracking and Command (REC)
 - Telemetry Tracking and Command (NREC)
 - Flight Software
 - Payload
 - IR Sensor (Total)
 - Ground Support Equipment (NREC)
 - Launch and Orbital Launch Support (LOOS)
 - Launch Segment (REC)
 - Launch Vehicle Data
 - Athena 2
 - Cosmos
 - Pegasus XL
 - Falcon 1e
 - Minotaur IV
 - Rocket
 - Shtil
 - START
 - Taurus
 - Ariane 44L
 - Atlas 2AS
 - Delta 2
 - Dnepr
 - Falcon 9
 - Long March 2C
 - Long March 2E
 - Soyuz
 - Ariane 4G

Example of FireSat Multivariate CER imported into TruePlanning

Once the CER is imported into TruePlanning it becomes an integral part of the framework co-existing with other CERs.

The CER is not subject to breakage as in an EXCEL spreadsheet.

Leverages additional TruePlanning capability e.g, risk analysis

The screenshot displays the TruePlanning 12.1 interface. On the left, the 'Product Breakdown Structure' shows a hierarchical tree for 'FireSat II', including 'Spacecraft Bus', 'Payload', and 'Launch Vehicle Data'. The 'Propulsion Apogee Kick Motor (REC)' is highlighted in the tree. On the right, the 'Input Sheet: Propulsion Apogee Kick Motor (REC)' is shown, containing project cost and labor requirements, and a table with columns for Value, Units, Spread, and Notes. The table includes rows for start date, quantity, additional units, define variables (AKM Weight, Burn Time), enter equations (Cost Equation, Labor Equation, Material Cost Equation), other settings (Activity Type, Equation Type), integration drivers (Component Type, Integration Size, Complexity), and optional capture actuals.

	Value	Units	Spread	Notes
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 Define Variables				
7 x Name	AKM Weight(kg)			
8 x Value	0.000			
9 y Name	Burn Time (seconds)			
10 y Value	0.000			
11 z Name	<Insert Name>			
12 z Value	1.000			
13 a Name	<Insert Name>			
14 a Value	1.000			
15 b Name	<Insert Name>			
16 b Value	1.000			
17 Enter Equations				
18 Cost Equation	$(29*x + 0.024*y) * 1000$		\$ in 2012	
19 Labor Equation	0		hours	
20 Material Cost Equation	0		\$ in 2012	
21 Schedule Duration Equation			months	
22 Other Settings				
23 Activity Type	Development			
24 Equation Type	Total			
25 Integration Drivers				
26 Component Type	Hardware			
27 Component Integration Size	Small Component			
28 Component Complexity	Nominal			
29 External Integration Complexity	3.00			
30 Optional - Capture Actuals				
31 Actual Cost	0		\$	

Example of FireSat Multivariate CER imported into TruePlanning

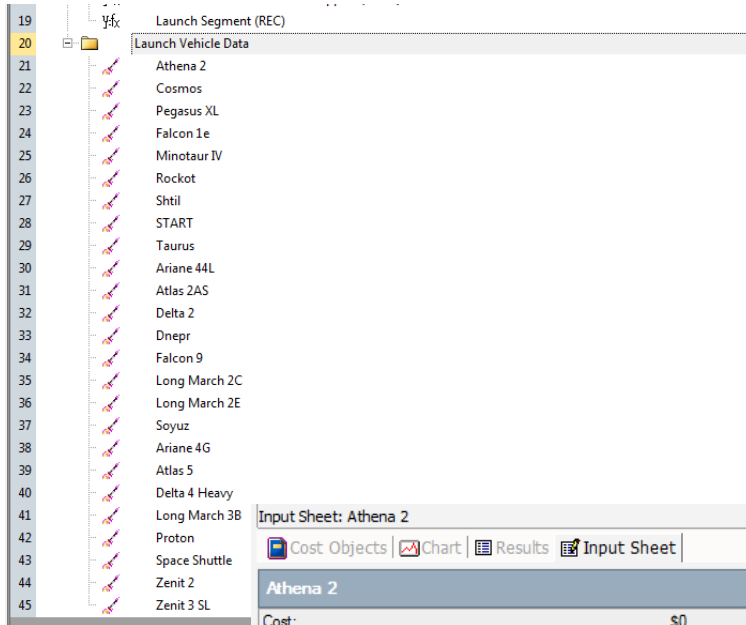
Key Benefit:

CER leverage's TruePlanning's Integration and Test algorithm to contribute to Assembly IA&T and System level costs

The screenshot displays the PRICE TruePlanning 12.1 interface. On the left, the 'Product Breakdown Structure' shows a hierarchical tree for 'FireSat II', including levels like 'Spacecraft Bus', 'Payload', and 'Launch Vehicle Data'. The 'Propulsion Apogee Kick Motor (REC)' component is highlighted. On the right, the 'Input Sheet' for this component is shown, containing the following data:

Worksheet Set:	Value	Units	Spread	Notes
Cost:	\$0	0.00%	Labor Requirement:	0.00 hours
Project Cost:	\$221,680,576		Project Labor Requirement:	583,260.06 hours
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	Define Variables			
7	x Name	AKM Weight (kg)		
8	x Value	0.000		
9	y Name	Burn Time (seconds)		
10	y Value	0.000		
11	z Name	<Insert Name>		
12	z Value	1.000		
13	a Name	<Insert Name>		
14	a Value	1.000		
15	b Name	<Insert Name>		
16	b Value	1.000		
17	Enter Equations			
18	Cost Equation	$(29x + 0.024y) * 1000$	\$ in 2012	
19	Labor Equation	0	hours	
20	Material Cost Equation	0	\$ in 2012	
21	Schedule Duration Equation		months	
22	Other Settings			
23	Activity Type	Development		
24	Equation Type	Total		
25	Integration Drivers			
26	Component Type	Hardware		
27	Component Integration Size	Small Component		
28	Component Complexity	Nominal		
29	External Integration Complexity	3.00		
30	Optional - Capture Actuals			
31	Actual Cost	0	\$	

FireSat/TruePlanning Launch Segment Database and Custom CER Development



Launch Segment CER

TruePlanning Database Repository for Launch Vehicle Data

Input Sheet: Athena 2

Cost Objects | Chart | Results | Input Sheet

Athena 2

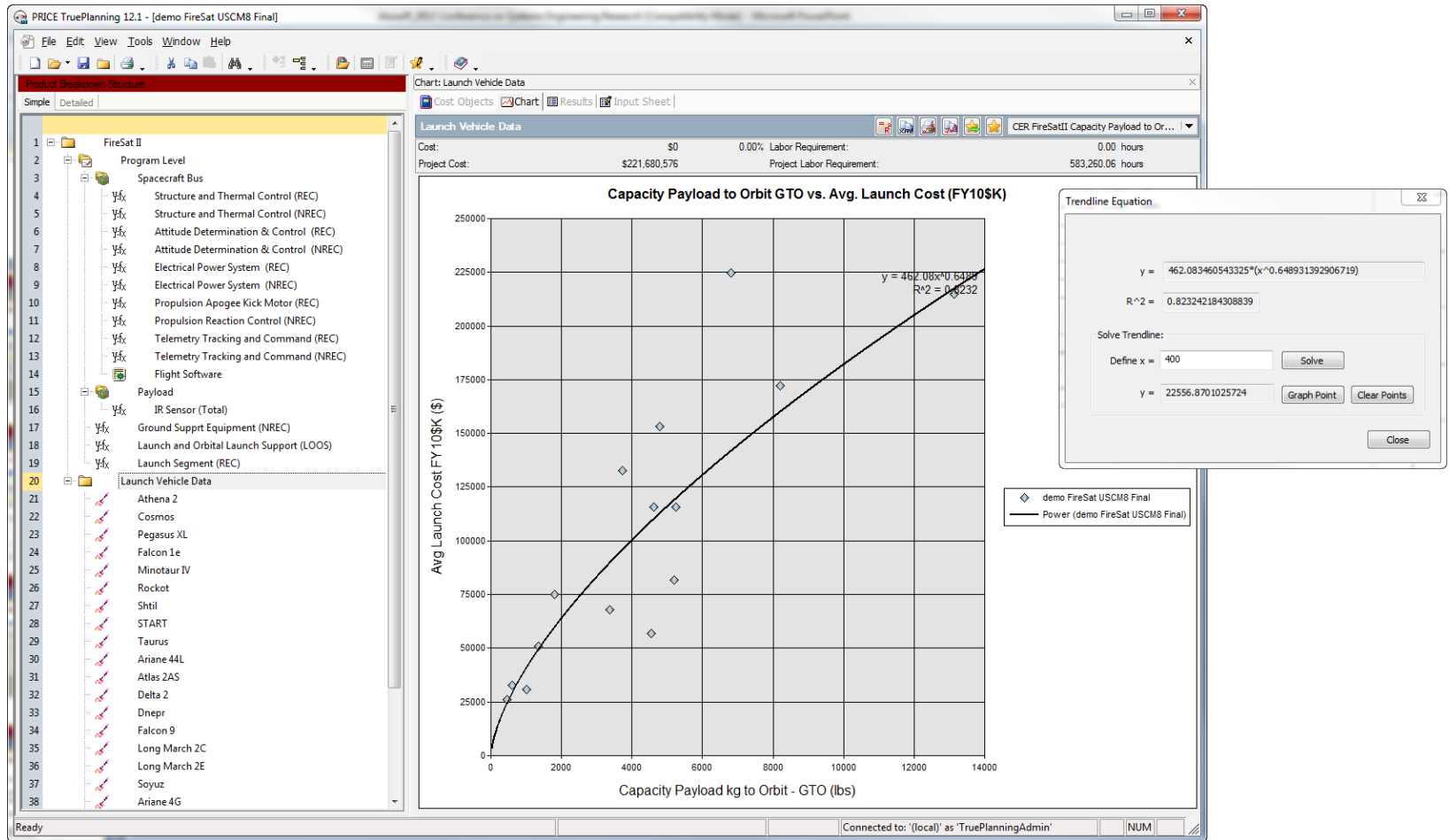
Cost: \$0 0.00% Labor Requirement:
Project Cost: \$221,680,576 Project Labor Requirement:

Worksheet Set: <Inherited>

	Value	Units
1 Start Date		
2 Country of Origin		USA
3 Capacity Payload kg to Orbit - LEO	2,065.00	lbs
4 Capacity Payload kg to Orbit - GTO	590.00	lbs
5 Avg Launch Cost FY10\$K	32,688	\$
6 Launch Cost per kg in FY10\$K LEO	15.8	\$/lbs
7 Launch Cost per kg in FY10\$K GTO	55.4	\$/lbs

TruePlanning Custom Cost Object – Database repository

FireSat Launch Vehicle CER Development



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

FireSat - Launch Vehicle CER

PRICE TruePlanning 12.1 - [demo FireSat USCM8 Final]

Product Breakdown Structure: FireSat II

- Program Level
 - Spacecraft Bus
 - Structure and Thermal Control...
 - Attitude Determination & Con...
 - Electrical Power System (REC)
 - Propulsion Apogee Kick Moto...
 - Telemetry Tracking and Com...
 - Payload
 - IR Sensor (Total)
 - Ground Support Equipment (NREC)
 - Launch and Orbital Launch Support...
 - Launch Vehicle Data
 - Athena 2
 - Cosmos
 - Pegasus XL
 - Falcon 1e
 - Minotaur IV
 - Rocket
 - Shtil
 - START
 - Taurus
 - Ariane 44L
 - Atlas 2AS
 - Delta 2
 - Dnepr
 - Falcon 9
 - Long March 2C
 - Long March 2E
 - Soyuz
 - Ariane 4G

Input Sheet: Launch Segment (REC)

Launch Segment (REC) Summary:

Cost:	\$24,904,987	11.24%	Labor Requirement:	0.00 hours
Project Cost:	\$221,669,964		Project Labor Requirement:	583,198.39 hours

Worksheet Set: <Inherited>

	Value	Units	Spread	No
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 Define Variables				
7 x Name	Spacecraft Weight (kg)			
8 x Value	400.000			
9 y Name	<Insert Name>			
10 y Value	1.000			
11 z Name	<Insert Name>			
12 z Value	1.000			
13 a Name	<Insert Name>			
14 a Value	1.000			
15 b Name	<Insert Name>			
16 b Value	1.000			
17 Enter Equations				
18 Cost Equation	$(462.083460543325 \cdot x^{0.649}) \cdot 1000$		\$ in 2012	
19 Labor Equation		0	hours	
20 Material Cost Equation		0	\$ in 2012	
21 Schedule Duration Equation			months	
22 Other Settings				
23 Activity Type	Production			
24 Equation Type	Total			
25 Integration Drivers				
26 Component Type	Hardware			
27 Component Integration Size	Large Assemblies			
28 Component Complexity	Very High			
29 External Integration Complexity	3.00			
30 Optional - Capture Actuals				

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.

Descriptors for component integration size and complexity.

Influences IA&T cost at assembly and system level.

FireSat - TruePlanning Software Estimating Model

The screenshot displays the TruePlanning 12.1 interface for a project named 'PRICE TruePlanning 12.1 - [demo FireSat USCM8 Final]'. The left pane shows a 'Product Breakdown Structure' tree with 'FireSat II' selected. The right pane shows the 'Input Sheet: Flight Software' with a 'Detailed Estimate' view. The table below is a summary of the parameters shown in the screenshot:

	Value	Units	Spread	Notes
1 Start Date				
2 -				
3 Application Type	None			
4 Functional Complexity	6.00			
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	38,100			
11 New Size Non-executable	10.00%	%		
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 Design Repeat	0.00%	%		
18 Reused Code Size	0			
19 Reused Size Non-executable	0.00%	%		
20 Deleted Code Size	0			
21 Code Removal Complexity	Remove code that is integrated thro...			
22 Auto Generated Code Size	0			
23 Auto Gen Size Non-executable	0.00%	%		
24 Auto Translated Code Size	0			
25 Auto Trans Size Non-executable	0.00%	%		
26 Auto Translation Tool Efficiency	Nominal - 80%			
27 -				
28 Language	C			
29 Language Object Oriented	Yes			
30 Project Constraints	0.95			
31 Estimate to Complete	100.00%	%		

The software cost estimate leverages the TruePlanning for Software model.

This allows a much more robust modeling of the software estimate.

This model takes into account additional parameters software sizing, effective lines of code and team experience.

FireSat Results using TruePlanning

The screenshot displays the PRICE TruePlanning 12.1.1 interface. On the left, a hierarchical tree shows the structure of the FireSat II program, including Spacecraft Bus, Payload, and Launch Vehicle Data. On the right, a 'Results' window shows a cost table for the 'Program Level'.

Costs: Program Level - [System] Currency in USD (\$) (as spent)	Total	2011	2012	2013	2014	2015	2016	2017
1 Program Level	57,288,639	203,801	2,947,847	3,755,113	6,049,261	7,391,897	7,032,443	7,118,717
2 Spacecraft Bus	16,448,811	156,935	944,752	1,211,871	1,313,942	1,439,257	1,550,017	1,550,017
3 Structure and Thermal Control (REC)	725,342		725,342					
4 Structure and Thermal Control (NREC)	7,146,229		7,146,229					
5 Attitude Determination & Control (REC)	3,750,873		3,750,873					
6 Attitude Determination & Control (NREC)	4,145,192		4,145,192					
7 Electrical Power System (REC)	746,849		746,849					
8 Electrical Power System (NREC)	1,482,173		1,482,173					
9 Telemetry Tracking and Command (REC)	3,076,034		3,076,034					
10 Telemetry Tracking and Command (NREC)	29,705,679		29,705,679					
11 Flight Software	24,223,534		1,346,097	1,682,978	3,229,834	4,070,537	3,541,182	3,541,182
12 Payload	2,019		2,019					
13 IR Sensor (Total)	26,593,390		26,593,390					
14 Ground Support Equipment (NREC)	15,039,690		15,039,690					
15 Launch and Orbital Launch Support (LOOS)	6,401,135		6,401,135					
16 Launch Segment (REC)	24,904,987		24,904,987					
17 Total	221,680,576	360,736	128,958,289	6,649,962	10,593,037	12,901,691	12,123,642	12,318,906

Total System Estimate @ \$221M

Based on:

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

FireSat TruePlanning Model Integration with System Engineering Tools

Integrated
Systems
Engineering
Models

- While the TruePlanning model provide a single “point estimate”, we want to understand:
 - Sensitivity of the model to changes in CER parameters.
 - The response surface or “Carpet Plot” of the model to selected parameter changes
 - Which of the design variables drive cost – and to what extent (Design of Experiments)
- Using ModelCenter10 from Phoenix Integration, we can conduct these (and many other) system engineering studies.
- Allows us to determine the response of FireSat CERs within the TruePlanning model

Complete Integration between TruePlanning and Engineering Tools via ModelCenter

ModelCenter - Integrated CAIV Example

CAIV Example

"Cost as independent variable" analysis is the technique of developing a comparison of cost vs. performance for a potential system. In general, we want to see what level of system performance can be achieved for different price points. In this example we illustrate how to accomplish this goal using the Darwin optimizer. We feed the two key outputs, cost and performance, in as objectives to the Darwin optimizer, seeking to minimize the first and maximize the later. We then enter the various discrete design variables into Darwin's design variables section. At this point, you may run the Darwin component to solve your system, then open the Darwin tool and press the "Details" button to view your cost vs. performance chart.

NOTE: This example requires a licensed copy of Darwin to run. In order to obtain a license, please contact Phoenix Integration at support@phoenix-int.com

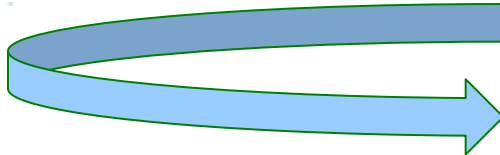
Name	Value
Model	
Specification	
PlatformType	Track Vehi...
SensorType	High Apert...
ThreatType	Cruise
PlatformSpec	
SensorSpec	
ThreatSpec	
DefenseSystem	
NumberOfPlatforms	4
DetectionRange	75
PlatformSpeed	72
SensorCapacity	7
SensorDensity	8
SensorEffectiveness	0.4
DetectionEnvelopeRate	5400
NumberOfSensors	224
SystemEffectiveness	89.6
Scenario	
PicketRange	1000
Effectiveness	89.6
PlatformSpeed	72
SensorRange	75
ThreatLethality	0.35
ThreatSpeed	503.25
DetectionRange	215.808
DetectionScore	45.8155
DetectionTime	1.95567
ClosureRate	575.25
KillsScore	176.138
TotalScore	0.26011
CostModel	
NumberOfSensors	224
CostPerSensor	15000
NumberOfPlatforms	4
CostPerPlatform	100000
TotalSensorCost	3.36e+006
TotalPlatformCost	400000
TotalSystemCost	3.76e+006
OptimizationTool	

Affordability Analysis linking Cost Modeling and System Engineering Tools

FireSat Affordability Example

	A	B	C
1			
2		Parameter	New Parameter
3	Structure and Thermal Control Wt (kg)	29.1	32.01
4	Attitude Determination & Control Wt (kg)	11.6	12.76
5	Electrical Power System Wt (kg)	20.9	22.99
6	IR Sensor Mass	30.2	33.22
7	IR Sensor Power	35	38.5
8	IR Sensor Data	100	110
9	TT&C Wt (kg)	8.1	8.91
10	SLOC	38100	41910
11			
12			
13			
14	Simple Sizing Parameter	1.1	
15			
16			

Performance Model Driving TruePlanning Through ModelCenter 10



Cost	6221 685.576	100.00%	Labor Requirement	583 260.06	Hours						
Project Cost	6221 685.576		Project Labor Requirement	583 260.06	Hours						
Cost	Program Level (System)										
Cost	Currency in USD (\$)	(at start)									
			Total	2011	2012	2013	2014	2015	2016	2018	2019
1	Program Level		57 288.628	203.801	2 347.847	3 755.113	6 043.261	7 391.897	7 032.443	7	
2	Spacecraft Bus		16 448.811	156.935	544.752	1 211.871	1 313.342	1 439.257	1 550.017	1	
3	Structure and Thermal Control (NREC)		725.342		725.342						
4	Structure and Thermal Control (NREC)		7 146.229		7 146.229						
5	Attitude Determination & Control (NREC)		3 756.873		3 756.873						
6	Attitude Determination & Control (NREC)		4 145.192		4 145.192						
7	Electrical Power System (NREC)		746.849		746.849						
8	Electrical Power System (NREC)		1 482.173		1 482.173						
9	Telemetry Tracking and Command (NREC)		3 076.034		3 076.034						
10	Telemetry Tracking and Command (NREC)		29 705.679		29 705.679						
11	Flight Software		24 223.534		1 346.097	1 682.978	3 229.834	4 076.537	3 541.182	3	
12	Payload		2 019		2 019						
13	IR Sensor (Total)		26 595.398		26 595.398						
14	Ground Support Equipment (NREC)		15 039.690		15 039.690						
15	Launch and Orbital Launch Support (LOOS)		6 401.136		6 401.136						
16	Launch Segment (NREC)		24 904.987		24 904.987						
17	Total		221 686.576	360.776	128 958.289	6 649.962	10 593.837	12 961.691	12 123.642	12.3	

Integrated Cost/Effectiveness Modeling

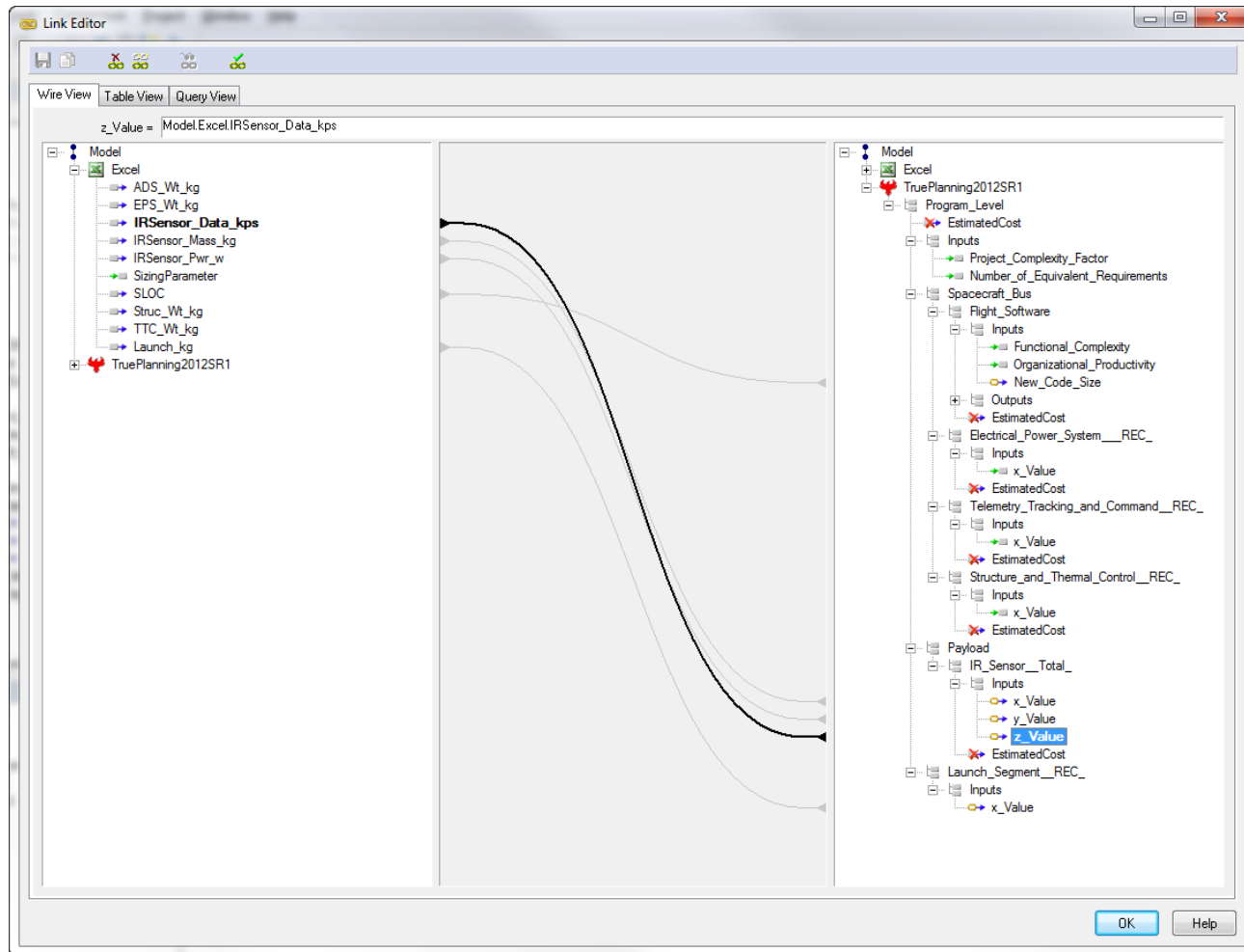
Cost/Effectiveness
Modeling

The screenshot displays the Phoenix Integration ModelCenter 10.0 interface. The main window shows a model tree on the left and a workflow diagram on the right. The model tree lists various components and their values, including ADS_Wt_kg (11.6), EPS_Wt_kg (20.9), IRSensor_Data_kps (100), IRSensor_Mass_kg (30.2), IRSensor_Pwr_w (35), SizingParameter (1), SLOC (38100), Struc_Wt_kg (23.1), TTC_Wt_kg (8.1), and Launch_kg (400). The workflow diagram shows a sequence of steps: a green play button icon, an Excel icon, and a TruePlanning2012SR1 icon, connected by arrows.

Name	Value
Model	
Excel	
ADS_Wt_kg	11.6
EPS_Wt_kg	20.9
IRSensor_Data_kps	100
IRSensor_Mass_kg	30.2
IRSensor_Pwr_w	35
SizingParameter	1
SLOC	38100
Struc_Wt_kg	23.1
TTC_Wt_kg	8.1
Launch_kg	400
TruePlanning2012SR1	
Program_Level	
EstimatedCost	\$216,399.3...
Inputs	
Project_Complexity_Factor	75
Number_of_Equivalent_Require...	1000
Spacecraft_Bus	
Payload	
IR_Sensor_Total	
Inputs	
x_Value	30.2
y_Value	35
z_Value	100
EstimatedCost	\$21,320.428
Launch_Segment_REC_	

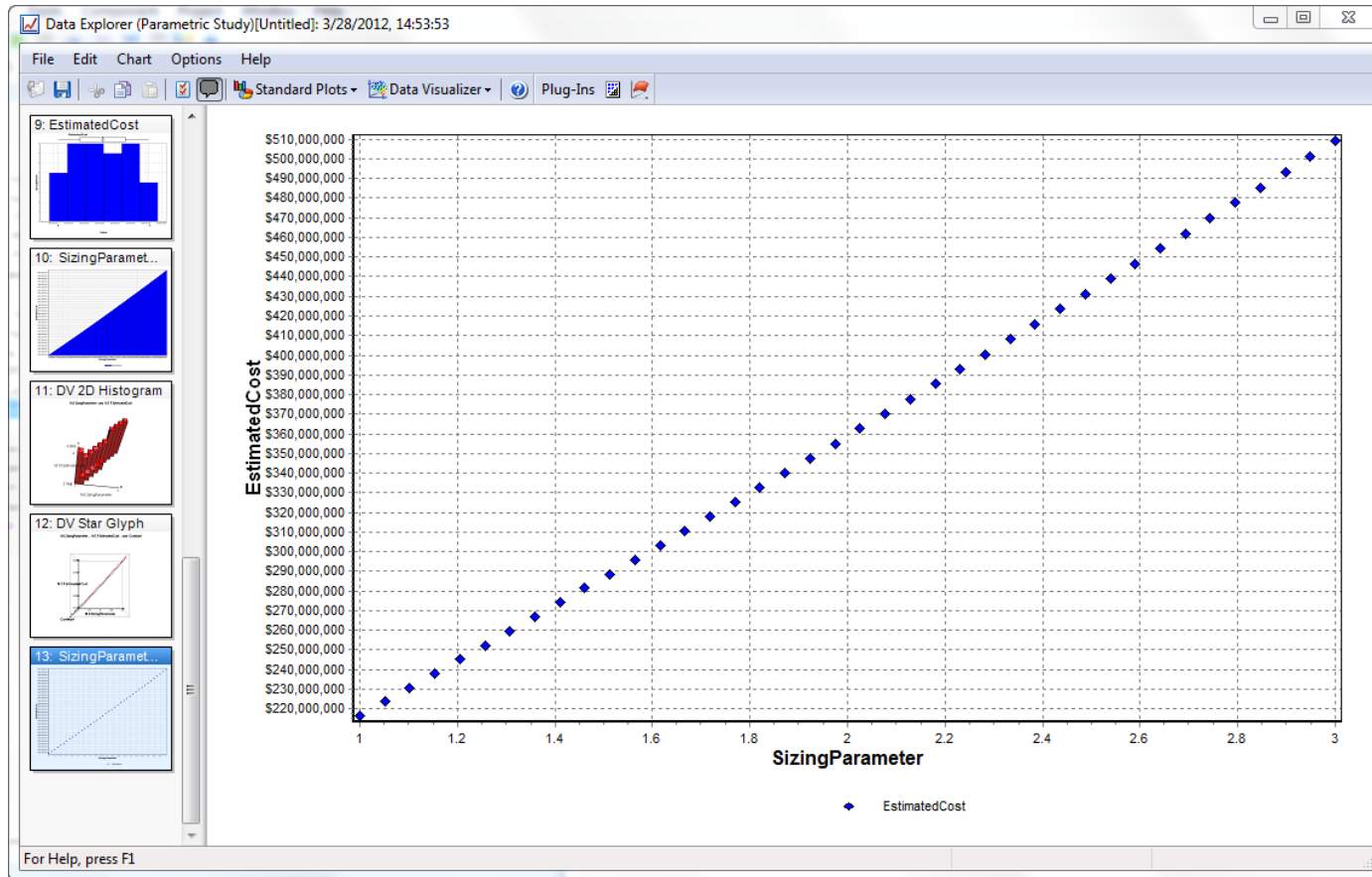
Simple EXCEL Performance Model Integrated with TruePlanning via ModelCenter

Linkage Between Cost and Performance Model



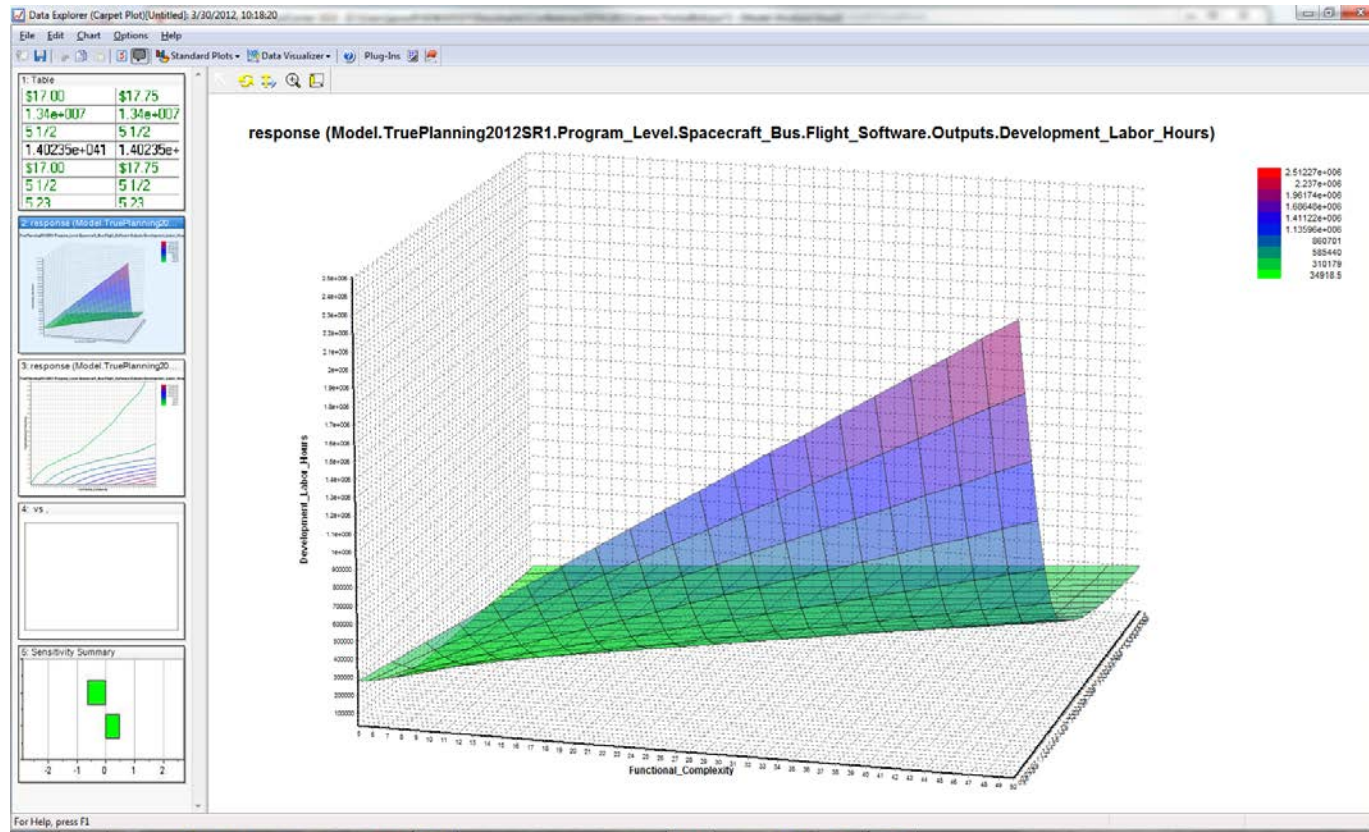
Linkage Between Performance Model and TruePlanning via ModelCenter

FireSat Sensitivity Modeling – Performance Sizing Parameter vs. Estimated Cost



Iteration of Sizing Parameter drives TruePlanning FireSat CERs and Estimated Cost

FireSat Affordability Modeling – Flight Software



ModelCenter Carpet plot tools used to example relationship between Organizational Productivity and Functional Complexity vs. Development Labor Hours

Sensitivity Analysis - TruePlanning EXCEL Companion Application- WBS Tornado Chart

Analyze Project Input

Select Input to Vary

Select Project: demo FireSat USCM8 Final

Select Cost Object: FireSat II

View Summary

Find Cost Drivers: 10

Select Input

Lowest Value: Min Value =

Highest Value: Max Value =

Iterations: 25

Select Outputs to Graph

Output Cost Object: FireSat II

Outputs - System Folder

Output 1: Estimated Cost

Output 2:

Output 3:

Summary

RPS Item	Cost in Thousands \$	% of Total
Project	221,669.96	100%
FireSat II	221,669.96	100%
FireSat II	221,669.96	100%

Input Sheet - System Folder

Number of Prototypes: 0

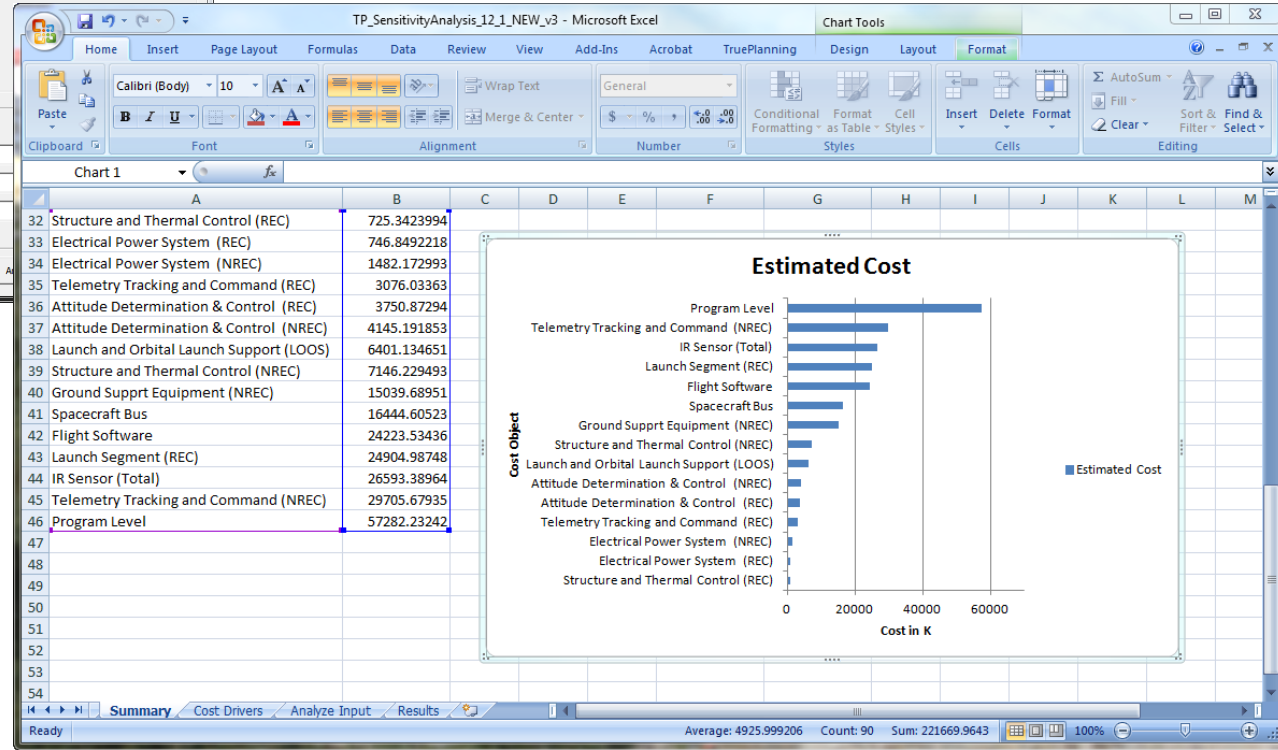
Number of Production Units: 1

Number of System Deployments: 0

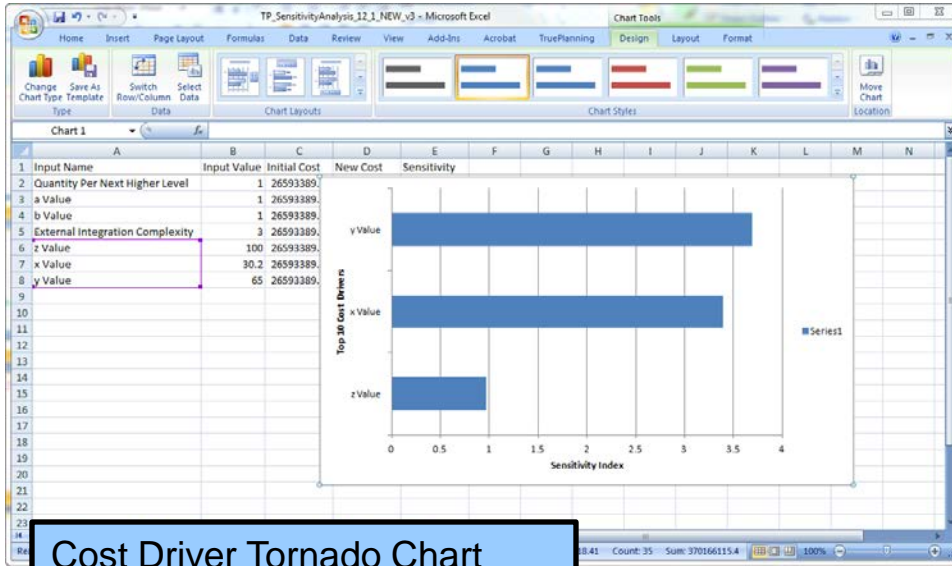
Learning Curve Type: Unit Learning Curve

Production Gap Learning Loss Factor: 1

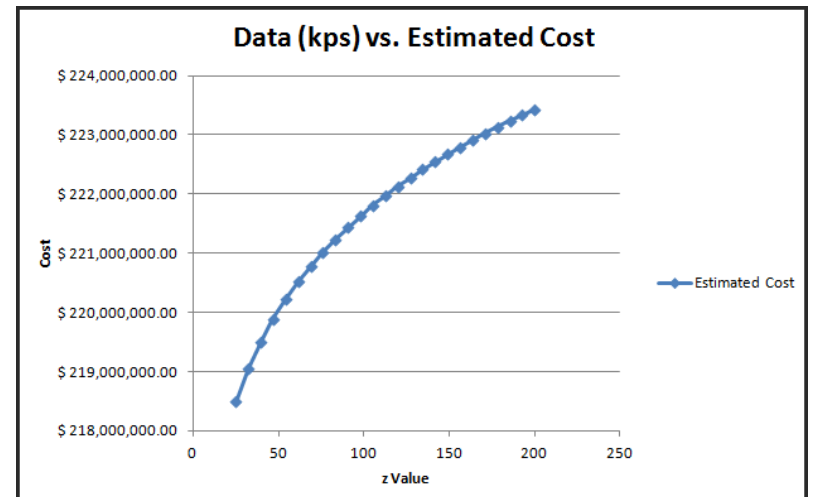
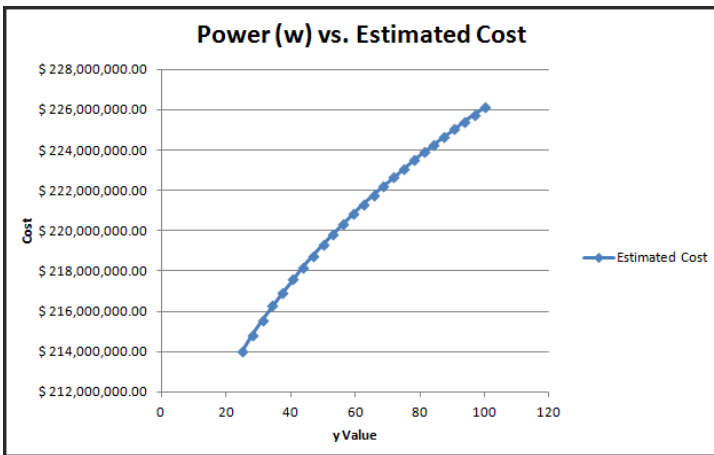
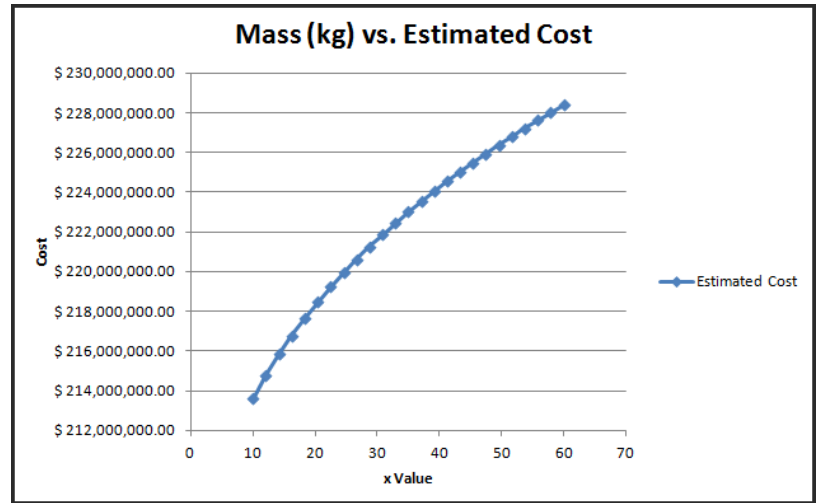
Results Iterated Through TruePlanning Interface



Sensitivity Analysis - IR Sensor CER Cost Drivers



Cost Driver Tornado Chart

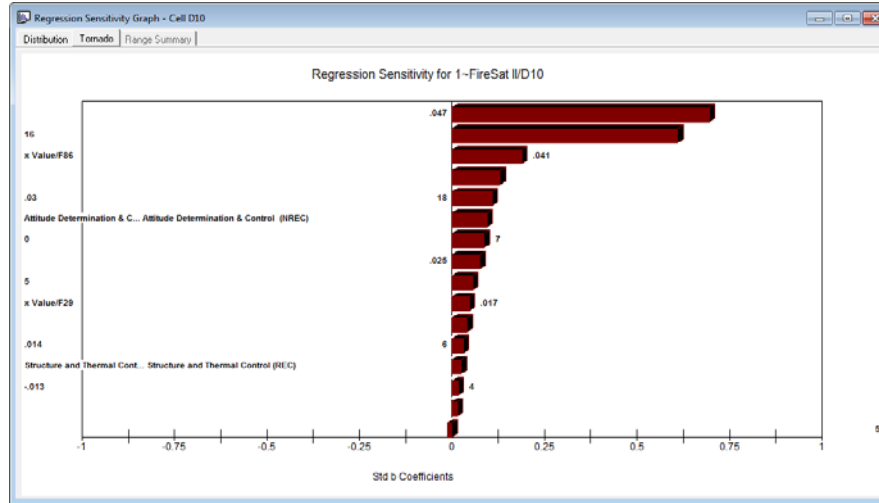


@Risk/TruePlanning Risk Analysis - FireSat

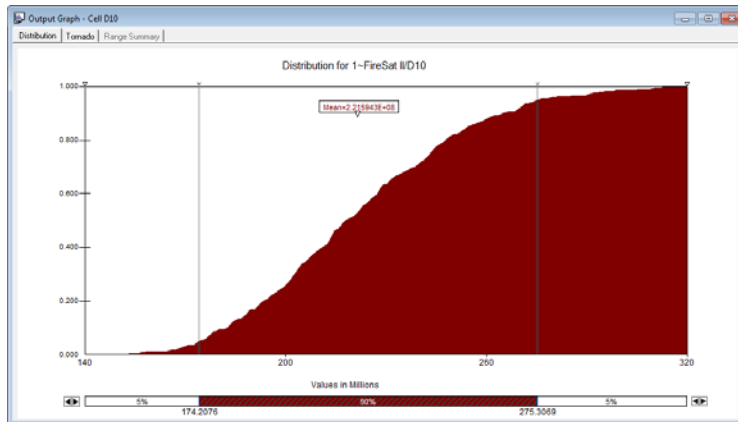
Risk Analysis

- To complete the analysis, @Risk is run to understand the risk profile
- Through a EXCEL Companion Application @Risk and TruePlanning are completely integrated
- All parameters within TruePlanning including FireSat multivariate equations are selectable and accessible through @Risk (and Crystal Ball)
- Parameters examined
 - All multivariate variables (USCM8, NICM)
 - Number of Equivalent Requirements (TruePlanning)
 - Source Lines of Code and Functional Complexity (TruePlanning)

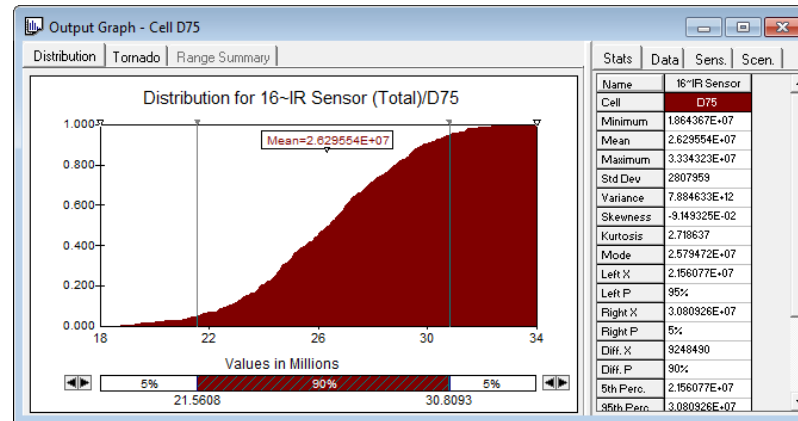
@Risk/TruePlanning Risk Integrated Analysis



Regression Sensitivity



Total FireSat Confidence Level ~50%



IR Sensor Confidence Level ~40%

Conclusion

- The methodology presented today demonstrates how System Engineering can integrate engineering tools with data-driven parametric cost estimating models such as the TruePlanning to conduct complete affordability analysis including sensitivity and risk analysis.
- Affordability is integrated as an engineering design parameter allowing engineers to rapidly conduct sensitivity and optimization studies. Prior to this integration cost models and engineering tools were for the most part stand alone or difficult to integrate.
- Measures of Effectiveness and Measures of Performance are linked with Affordability in determining the most cost/effective solutions.

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**