Jet Propulsion Laboratory
California Institute of Technology

Utilizing PRICE TruePlanning® at JPL

2015 NASA Cost Symposium

Presented by:
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Acknowledgements

This study is the result of work performed by the Jet Propulsion Laboratory's Cost Estimation and Pricing (CE&P) section working in close collaboration with PRICE Systems Solutions

This presentation will discuss the process and results of JPL's calibration effort of TruePlanning ® and provide recommendations on how to use the results as well as lessons learned.

This presentation will focus on five tasks of the calibration effort:

1) Data Collection
2) Data Analysis
3) Model Calibration
4) Analysis and Application of Results
5) Findings/Recommendations

PRICE-H™ History at JPL

- In 2002, NASA's Independent Program Assessment Office (IPAO) began providing PRICE site licenses and jump-start funding to NASA centers
- JPL began using PRICE H™ as a cross-check tool for our proposal and project grassroots cost estimates
- As demand for the tool increased, JPL's Cost Estimation & Pricing (CE&P) section commissioned a calibration of the tool in collaboration with PRICE Systems, the study provided:
  - Methodology for consistent application of the model to capture H/W subsystem design, fabrication and assembly & test costs
  - Validation of the above costs against the JPL/NASA WBS (validated against Spacecraft H/W subsystem costs in WBS 06 and Project System I&T WBS 10)
  - A range of calibrated values for MCPLXS and MCPLXE
- Under this paradigm:
  - JPL had subsystem MCPLX S/E complexity values established for each mission
  - MCPLX S/E values for new estimates were determined by direct analogy to a calibrated historical mission
  - Difficulty in scaling MCPLX S/E when analogy does not exists or when future mission does not fit one particular analogy

JPL has a long standing history with employing PRICE COTS models for developing validation and independent cost estimates

Transition to TruePlanning®

- With the introduction of PRICE TruePlanning® and new requirements to use PRICE TruePlanning® in the 2014 Discovery AO, JPL commissioned an update to its calibration:
  - The TruePlanning® calibration goals were as follows:
    - Calibrate each H/W subsystem using actual costs from a wide range of completed JPL missions
    - Create a consistent mapping of TP results to the JPL WBS
    - Provide guidance on the System and Assembly level inputs based on validation of the System and Assembly activity costs against applicable JPL WBS elements
    - Define MCPLX S/E based on commonly traded technical parameters
    - Allow for scaling between known technical parameters and MCPLXS/E values
    - Provide recommendations for JPL on primary and secondary inputs into TruePlanning®
- This presentation will discuss Phase 1 of the JPL TruePlanning® Calibration

The Transition to TruePlanning® required JPL to recalibrate and validate the TruePlanning® model and align the results to our WBS

Scope of the Data Collection for Calibration

- Collected Cost, Programmatic, and Technical data on 5 completed JPL projects
- Programmatic Data collected includes:
  - Mission/Orbit Type
  - Strategic / Competed/Technology Validation
  - Target Body
  - Launch date
  - Implementation mode/System Contractor
  - Mission Description
  - Design Life
  - System Dry Mass (S/C + P/L)
  - Number of Instruments
  - Type of Instruments
  - Total Payload Mass
- Data points selected for calibration:
  - Include Planetary Flyby, Orbiters, and Astrophysics/Sky surveys mission types
  - Cover a variety of system contractors (BATC, Orbital, and LM)
  - Contain both Strategic and Competed Mission Types
- Cost data collected covers Preliminary Design through Launch & Checkout (Phases B-D):
  - Costs were normalized to FY15 dollars using JPL composite inflation index
  - Costs includes realized incentive fee and JPL overhead

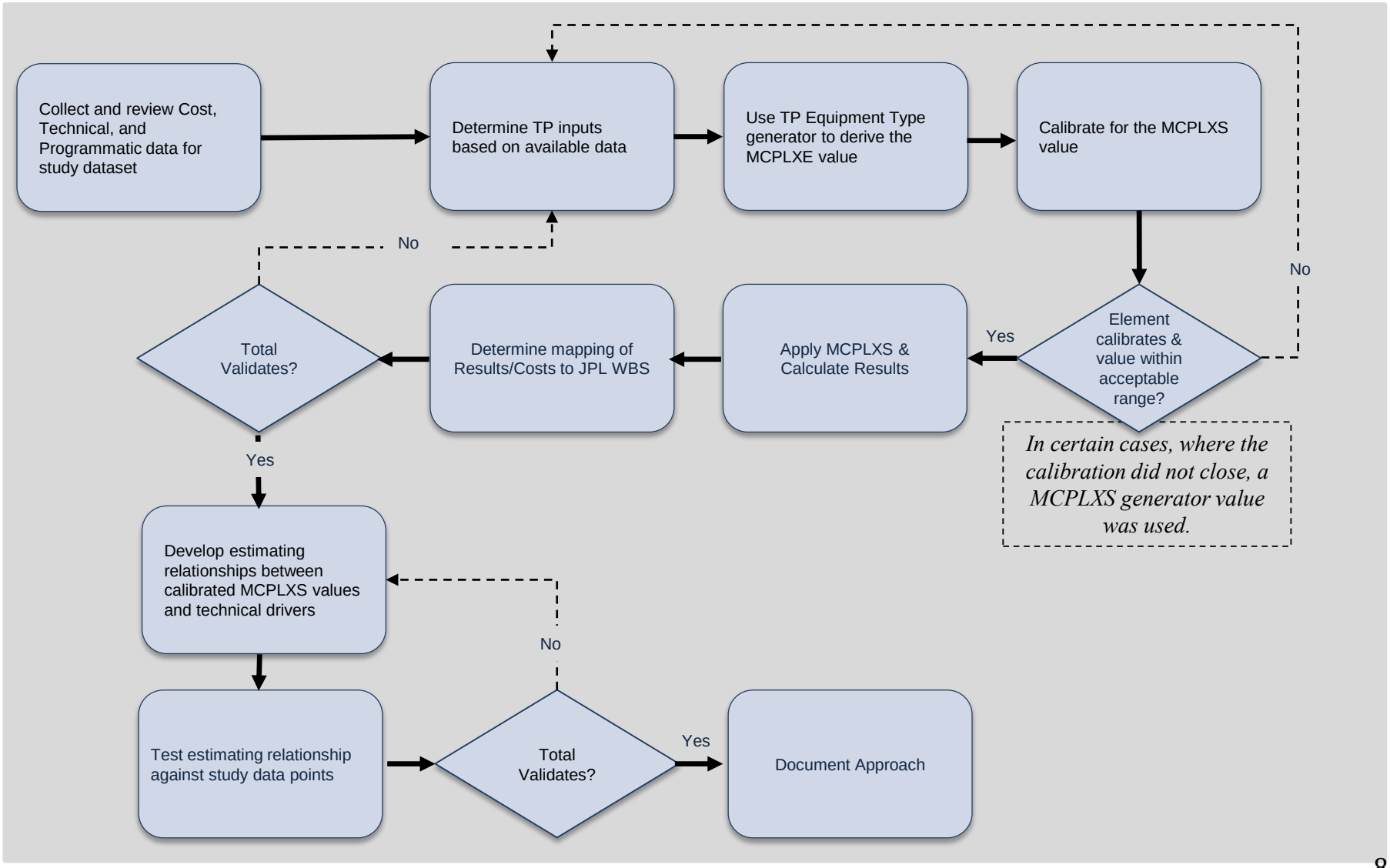
The data collected covers a variety of mission types and implementation modes

Technical data collected by Subsystem

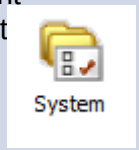
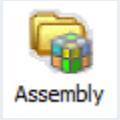
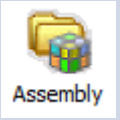
WBS 06.04 Power Subsystem											
Total Mass	WS	WE	% Active Electronic Mass	Solar Array Area	Beginning of Life (BoL) Power	Power Storage / Battery Capacity (Amp Hours)	Number of Unique Boards	Number of Total Boards			
WBS 06.05 Command & Data Handling Subsystem											
Total Mass	WS	WE	% Active Electronic Mass	Interface Type	Number of Unique Boards	Number of Total Boards					
WBS 06.06 Telecom Subsystem											
Total Mass	WS	WE	% Active Electronic Mass	Maximum Range	Power Amp. Output	Maximum Downlink	HGA Diameter	HGA Articulation	Frequency Band (s)	Number of Unique Boards	Number of Total Boards
WBS 06.07 Mechanical Subsystem + 06.11 Harness											
Total Mass	WS	WE	% Active Electronic Mass	Number of Mechanisms	Number of Deployments						
WBS 06.08 Thermal Subsystem											
Total Mass	WS	WE	% Active Electronic Mass	Active/Passive	RHUs						
WBS 06.10 Guidance, Navigation & Control Subsystem											
Total Mass	WS	WE	% Active Electronic Mass	Attitude Control Type	Pointing Control	Pointing Accuracy	Pointing Knowledge	Pointing Stability	Number of Unique Boards	Number of Total Boards	Reaction Wheels
WBS 06.09 Propulsion Subsystem											
Total Mass	WS	WE	% Active Electronic Mass	Propulsion Type	Propellant Budget (Total Delta V)	Propellant Budget (ACS)	Specific Impulse	Main Engine Rating	ACS Thrusters		

Possible technical drivers were collected for each of the spacecraft subsystems

JPL TP Calibration Overview

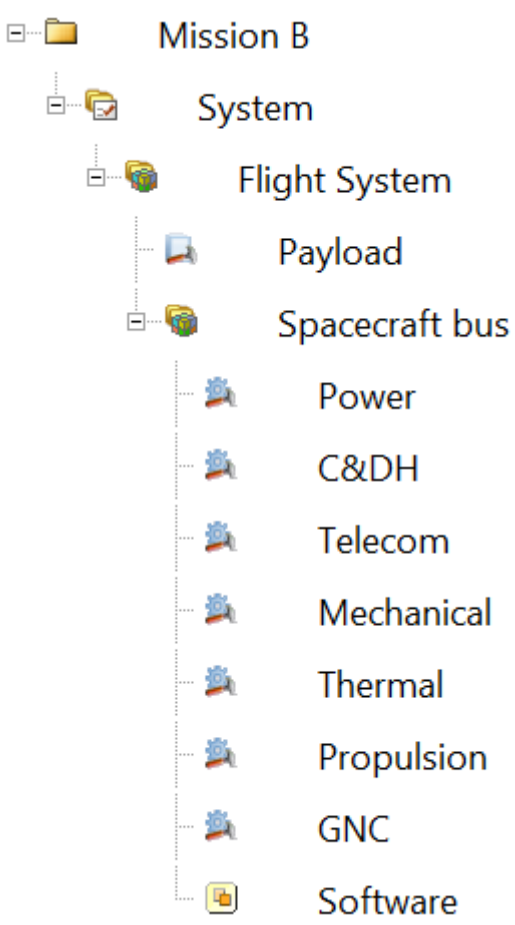


Mapping TP Activities to JPL's WBS

TP Output		JPL WBS
• Project Initiation and Planning for Development • Project Management and Control for Development • Quality Assurance Management for Development • Configuration Management for Development • Vendor Management for Development • Documentation for Development		• WBS 01 Project Management • WBS 02 Project System Engineering • WBS 03 Safety & Mission Assurance
• Requirements Definition and Analysis • System Design • Development Engineering • Development Manufacturing • Development Tooling and Test		• WBS 06.01 Spacecraft System Management • WBS 06.02 Spacecraft System Engineering • WBS 06.03 Spacecraft System Product Assurance • WBS 06.16.01 SC System Contract Management • WBS 06.16.02 SC System Contract System Engineering • WBS 06.16.03 SC System Contract Product Assurance
• Software Integration and Test • Hardware Software Integration and Test • Operational Test and Evaluation		• WBS 06.13 Materials and Processes: • WBS 06.14 Spacecraft System Testbeds: • WBS 06.15 Spacecraft Integration and Test: • WBS 10 Project Systems Integration and Test (ATLO)
• HW Component Development Engineering • HW Component Development Manufacturing • HW Component Development Tooling and Test		• WBS 06.04 through 06.11 • WBS 06.16.04 through 06.16.11

Mapping

TP Product Breakdown Structure



JPL WBS Mapping

- SEIT Activities at top Assy Object (Flight System) map to Spacecraft SE and Project System I&T WBS elements
- SEIT Activities at Spacecraft Bus map to Spacecraft System Contract SE and Spacecraft I&T WBS Elements
- All H/W Level Activities map into respective Spacecraft SS

Validation of Mapped Cost Results

JPL WBS #	Description	Mission A	Mission B	Mission C	Mission D	Mission E	Average Estimate Delta	Absolute Estimate Delta
WBS 01-03	PM Management, Sys Eng'g, and SMA.	-29%	-36%	37%	60%	0%	**6%**	**33%**
WBS 06.01- 06.03 & WBS 06.161-06.16.03	Spacecraft and Spacecraft Contractor Mgmt., Sys Eng'g, and Prod Assur	46%	71%	-28%	-33%	-14%	**8%**	**38%**
WBS 06.04	Power Subsystem	0%	-3%	66%	9%	-1%	**14%**	**16%**
WBS 06.05	C&DH Subsystem	20%	-1%	30%	-11%	-1%	**8%**	**13%**
WBS 06.06	Telecomm Subsystem	-10%	-8%	1%	-3%	0%	**-4%**	**5%**
WBS 06.07	Mechanical Subsystem (incl Harness)	0%	0%	0%	0%	1%	**0%**	**0%**
WBS 06.08	Thermal	0%	0%	0%	0%	0%	**0%**	**0%**
WBS 06.09	Propulsion	N/A	0%	0%	0%	0%	**0%**	**0%**
WBS 06.10	GN&C	58%	0%	52%	27%	-1%	**27%**	**28%**
WBS 06.11	Harness	incl in 06.07	incl in 06.07	incl in 06.07	incl in 06.07	incl in 06.07	**incl in 06.07**	**incl in 06.07**
WBS 06.12	Flight Software	0%	0%	0%	0%	0%	**0%**	**0%**
WBS 06.13 -06.15 & WBS 10	Spacecraft and Project System I&T	-47%	-1%	-1%	-4%	8%	**-9%**	**12%**
	Total:	**4%**	**0%**	**8%**	**0%**	**-2%**	**2%**	**3%**

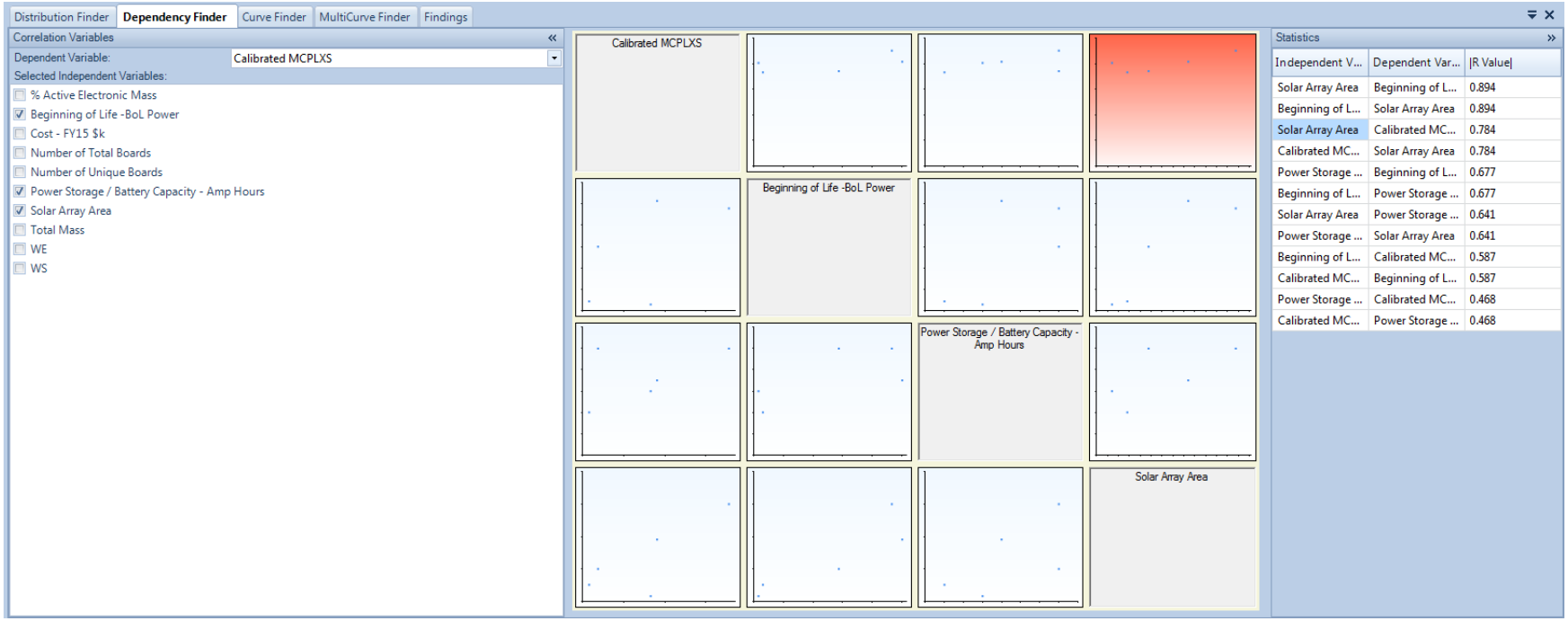
*Values above in red font indicate those subsystem where calibration did not close and generator values were used to reflect appropriate complexity.
** Flight software was handled as a pass-through using the software COTS object in TP

All missions validate to within 10% of the total actual costs. However large deltas exists in certain WBS elements.

Steps for linking MCPLXS to Technical Drivers

Format Data for Analysis	• Export calibrated MCPLXS/E values from TP • Normalize technical data for consistency in units, values, etc., • Formatted data to TrueFindings® Input Format
Analyze Data	• Analyzed data in TF to look for technical drivers that correlate to Manufacturing Complexity by subsystem
Evaluate Reasonableness of Equation	• Look at descriptive statistics for regression analysis • Do the technical drivers and resulting equation make sense?
Validate Equation Results	• Apply equation to calculate MCPLXS for subsystem • Use calculated MCPLXS value as input into TP • Validate TP Results against actual

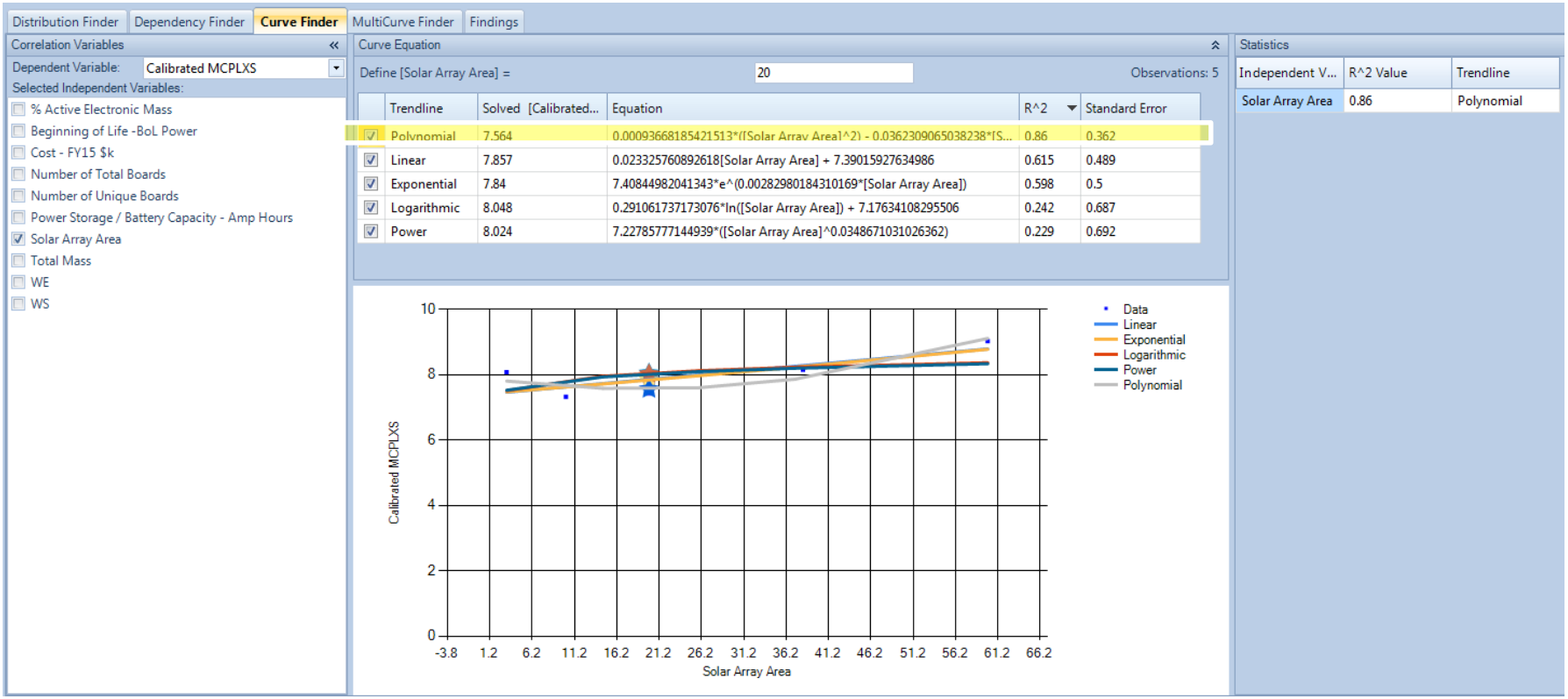
Power Subsystem – Correlation w/ Tech Driver



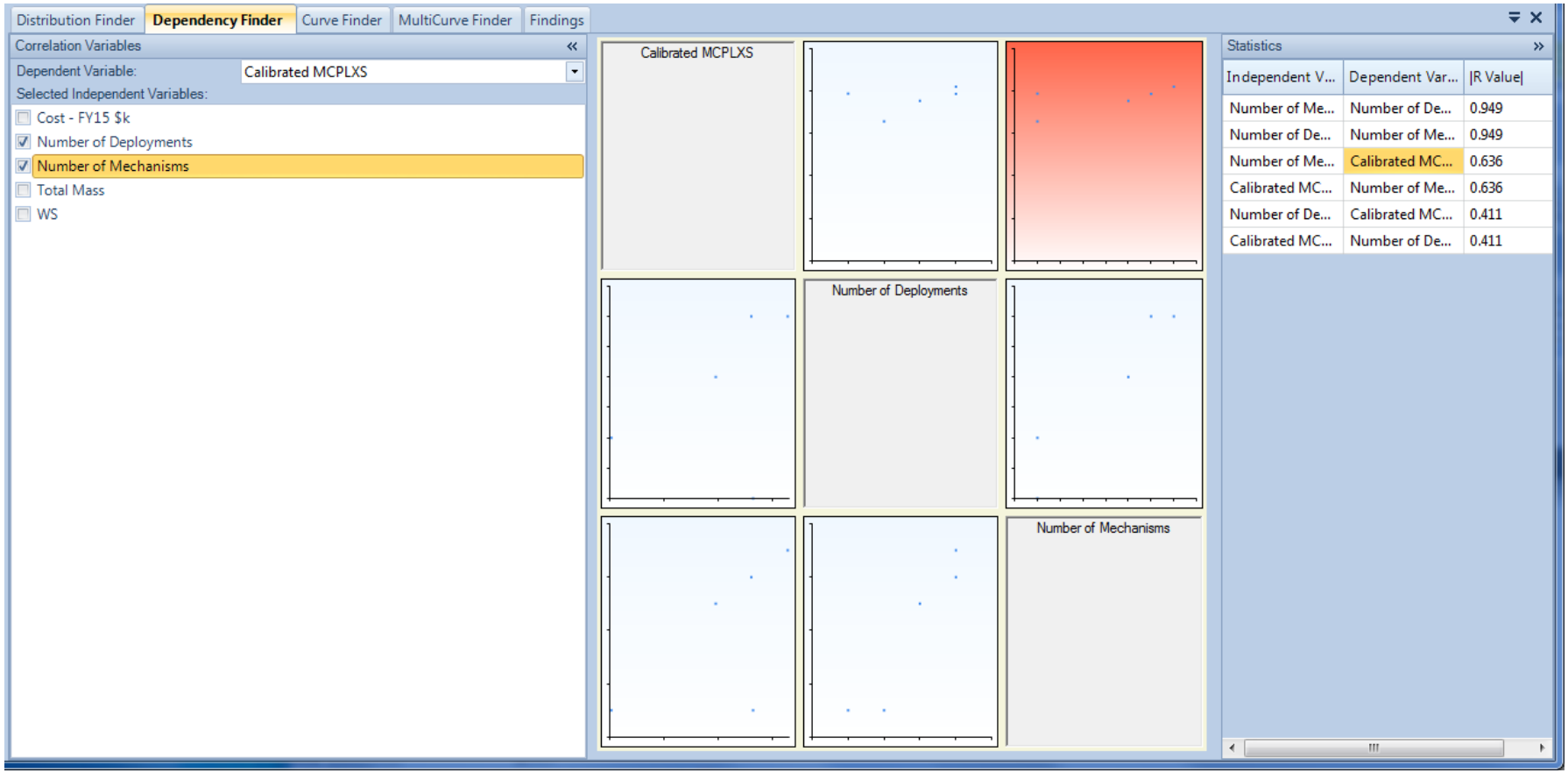
MCPLXS is highly Correlated to Solar Array Area

Power Subsystem Equation for MCPLXS

- Polynomial Curve → R^2 = .86
- MCPLXS(Solar Array Area)



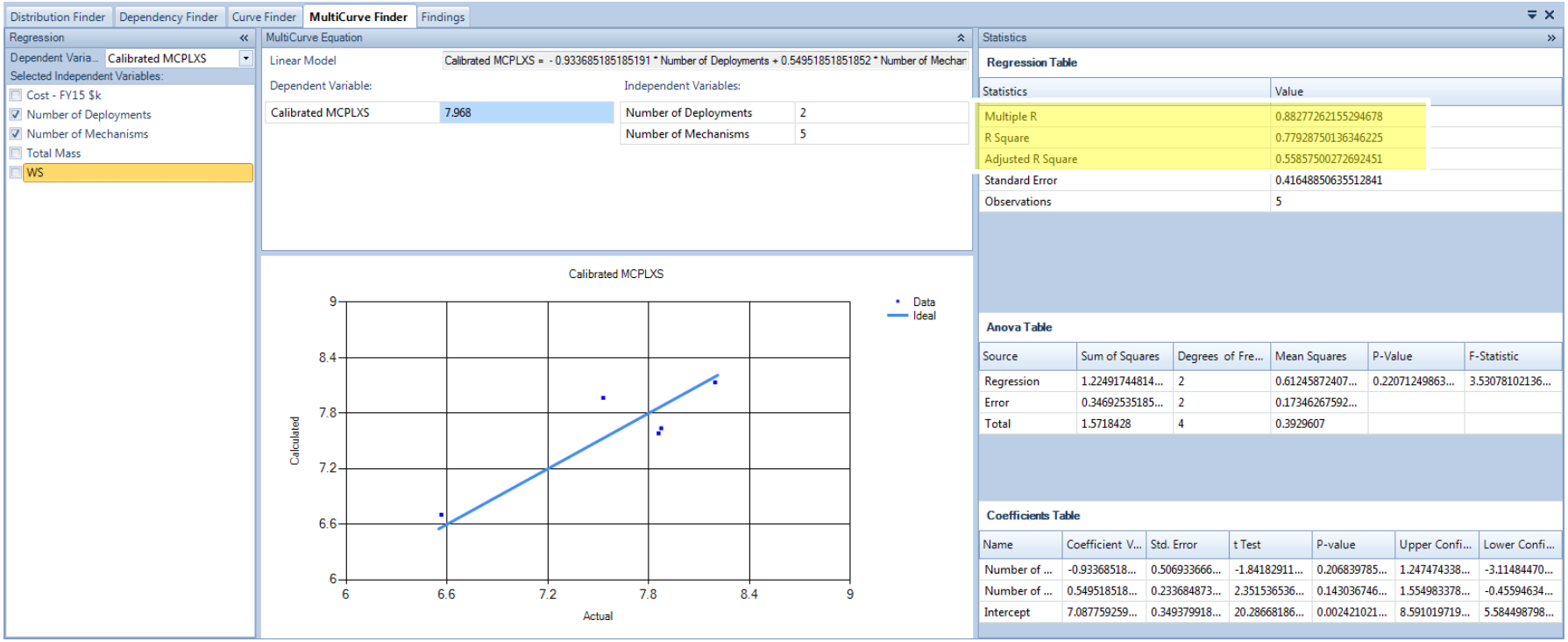
Mechanical Subsystem – Correlation w/ Tech Drivers



Number of Mechanisms and Number of deployments have a relationship with Mechanical MCPLXS

Mechanical Subsystem Equation for MCPLXS

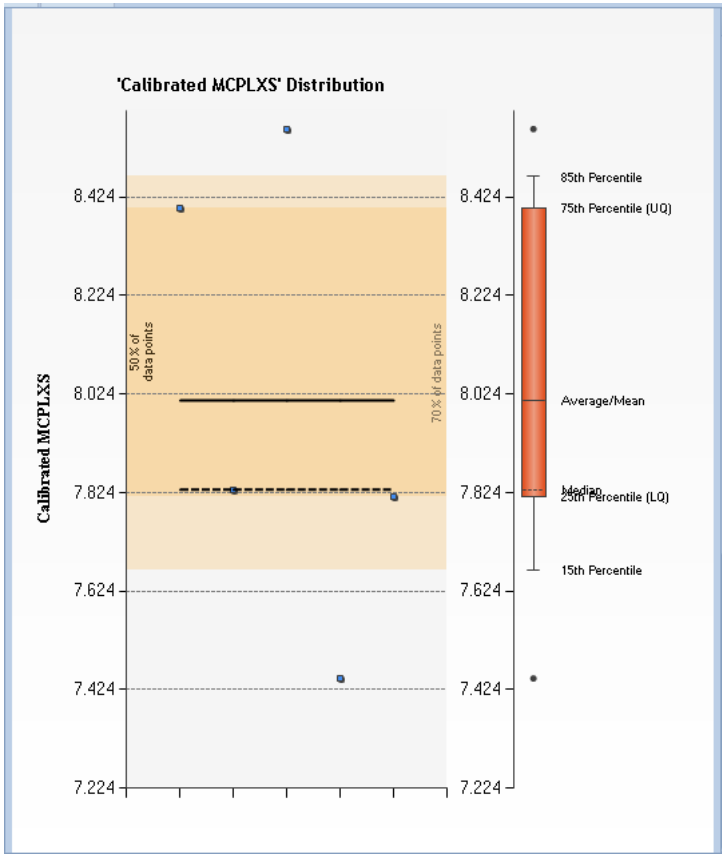
- MCPLXS (#Mechanisms, #Deployments)
- R^2 = .78



Using both # of Mechanisms and # of Deployments for the Mechanical equation improved the correlation statistics

Thermal Subsystem

- Measures of Central Tendency or Analogy



Statistics

Chart Type: Box Plot — Observations: 5

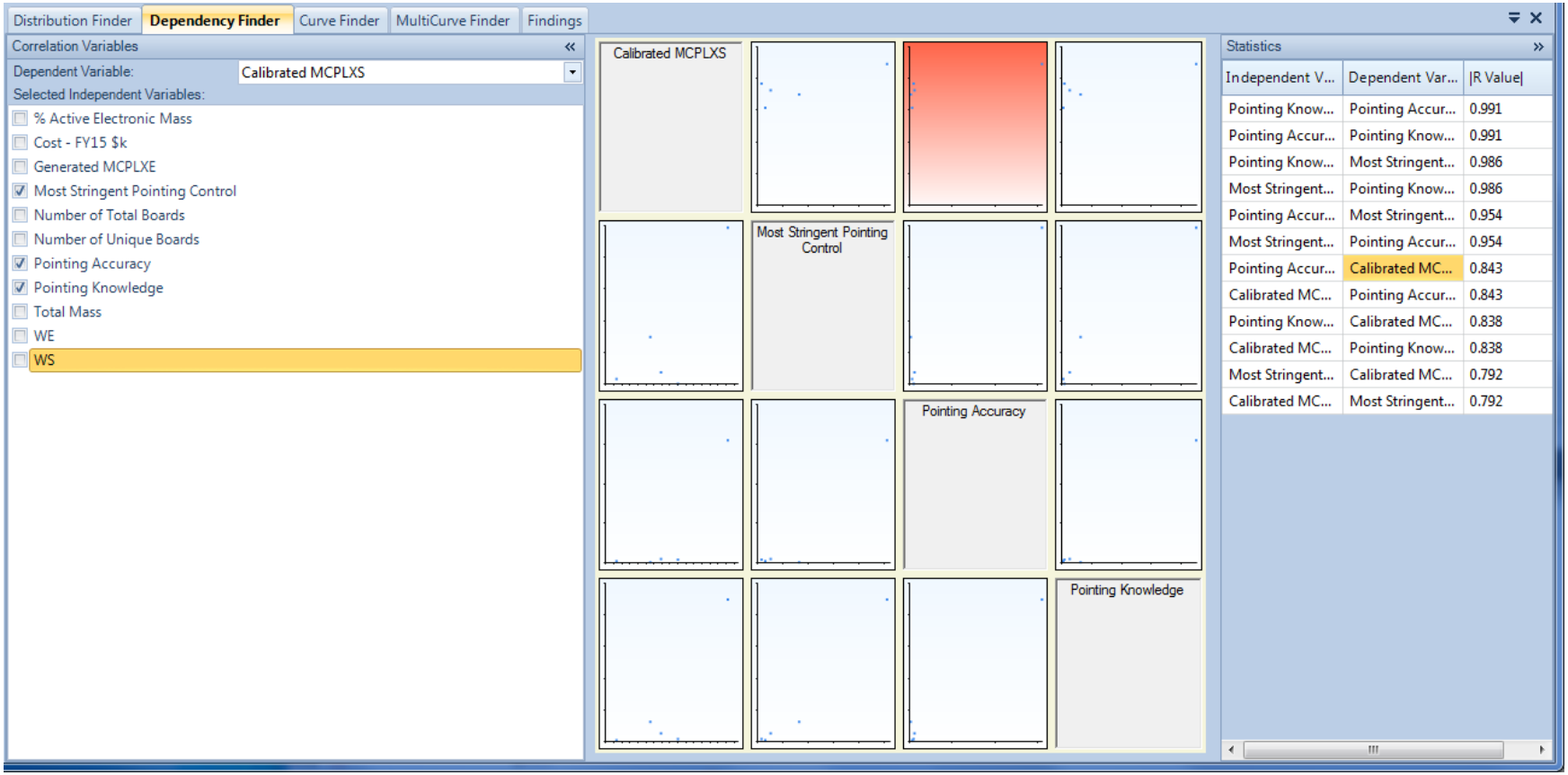
Statistics	Data	LogNormal	Normal	Triangular
Min	7.447			
Max	8.562			
25%	7.815			
75%	8.401			
Mean	8.011	8.0136256261075154	8.011	8.1366666666666667
Median	7.83	8.0004729520771889	8.011	8.1762838953384342
Mode	8.401	7.9742323305954219	8.011	8.401
Standard Deviation	0.4596123366490501	0.4596969957313557	0.4596123366490501	0.22759842193360333
Coefficient of Variation	0.057372654680944969	0.057364421197031362	0.057372654680944969	0.027971948619451452

Settings

Whiskers Percentiles: 15/85th Percentile — Remove Outliers

Not enough data points to allow for filter on Active/Passive—
Test Mean/Average MCPLXS

GNC Subsystem – Correlation w/ Tech Drivers



Pointing Accuracy has highest correlation to GNC MCPLXS

GNC Equation for MCPLXS

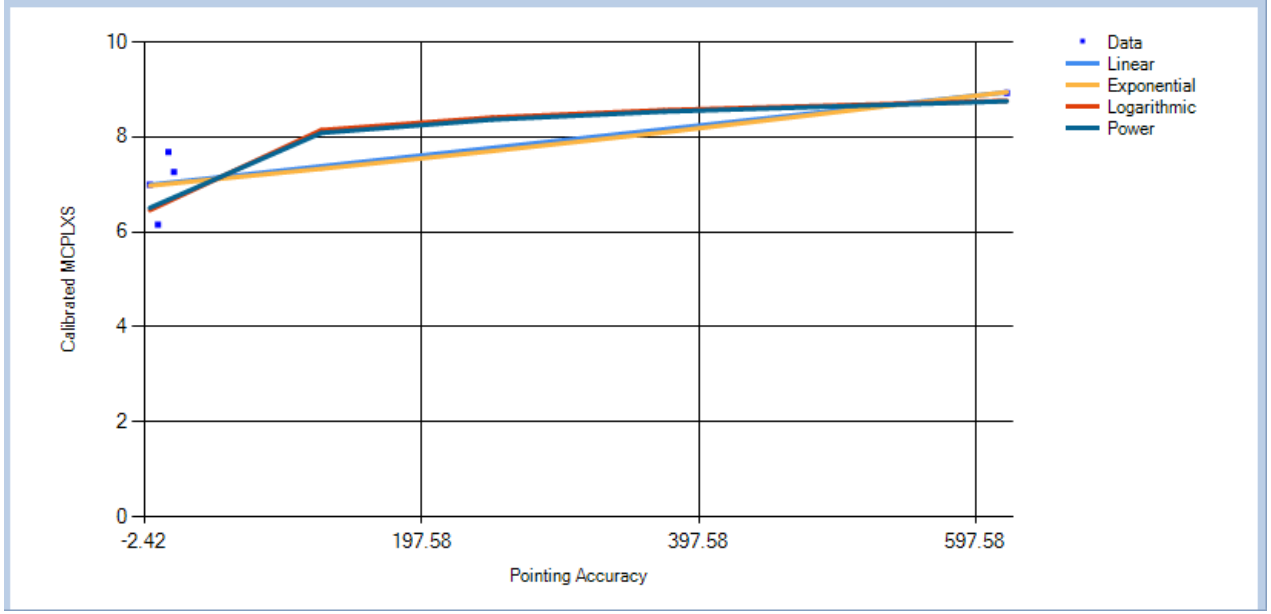
- MCPLXS(Pointing Accuracy) → R^2 = .71

Curve Equation

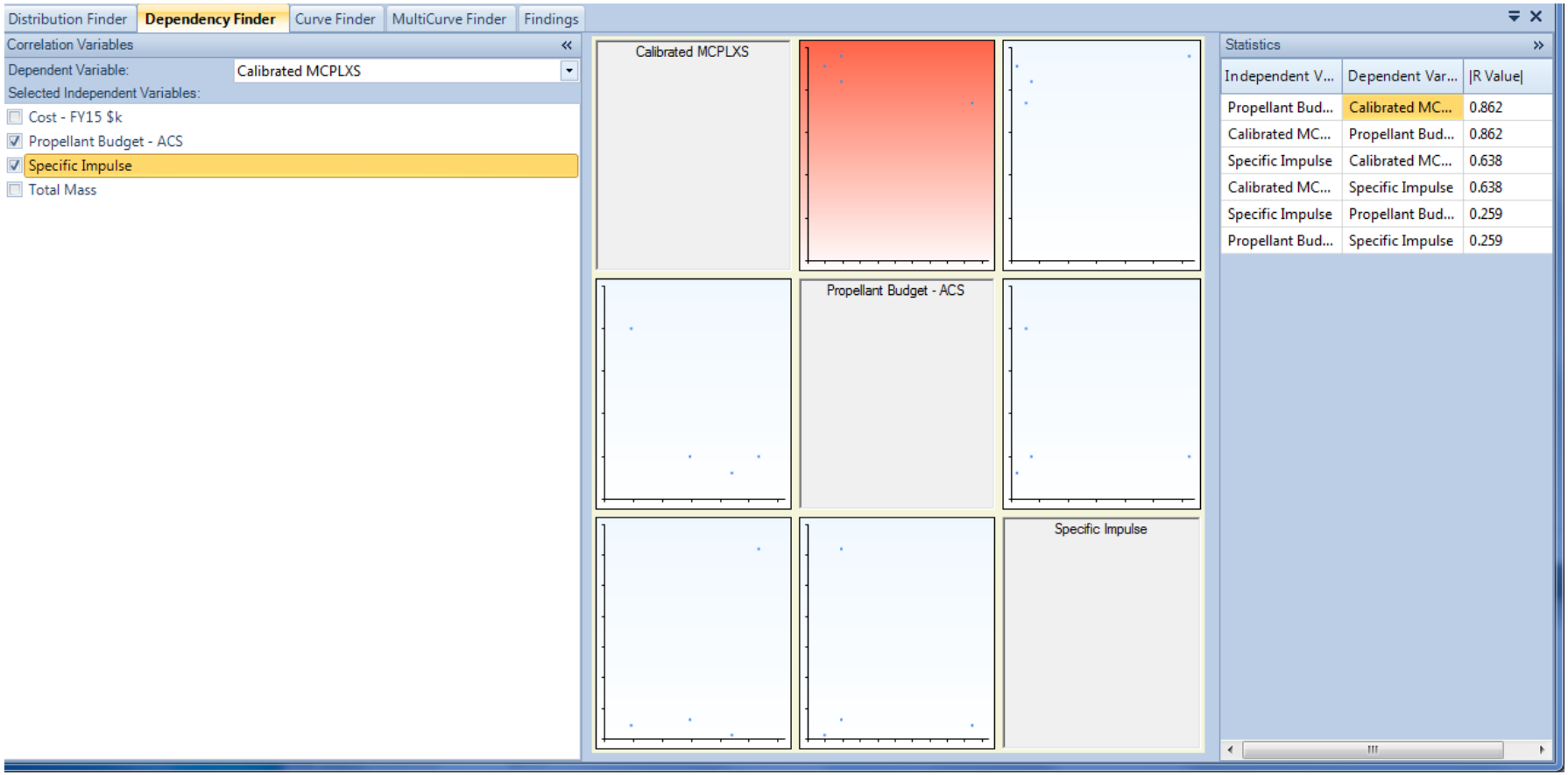
Define [Pointing Accuracy] =

Observations: 5

	Trendline	Solved [Calibrat...	Equation	R^2	Standard Error
☐	Polynomial		-6.58661572452853E-05*([Pointing Accuracy]^2) + 0.0446661901620363*[Point...	0.781	0.674
☑	Linear		0.00314979743373012[Pointing Accuracy] + 6.99011166190792	0.71	0.633
☑	Logarithmic		0.384869962625118*ln([Pointing Accuracy]) + 6.28854085585612	0.689	0.655
☑	Exponential		6.97080106537121*e^(0.000402460917810443*[Pointing Accuracy])	0.652	0.694
☑	Power		6.36690022386635*([Pointing Accuracy]^0.0495115493497623)	0.641	0.705



- Correlations



Propellant Budget and Specific impulse have a correlation to Prop MCPLXS

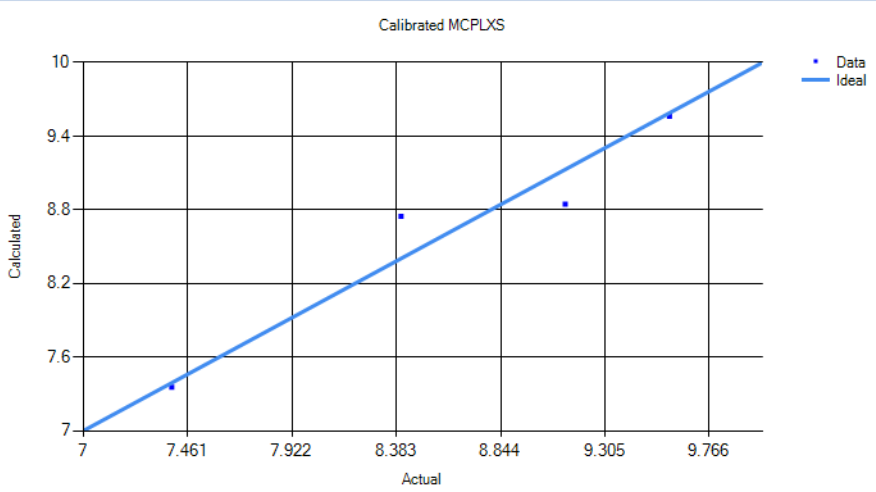
Propulsion Equation for MCPLXS

- MCPLXS(Propellant Budget, Specific Impulse)

MultiCurve Equation

Linear Model	Calibrated MCPLXS = - 0.00910108966025256 * Propellant Budget - ACS + 0.000293084803605985 * Specific Im

Dependent Variable:		Independent Variables:	
Calibrated MCPLXS	7.355	Propellant Budget - ACS	150
		Specific Impulse	224



Statistics

Regression Table

Statistics	Value
Multiple R	0.96317185888241574
R Square	0.92770002974300814
Adjusted R Square	0.78310008922902441
Standard Error	0.44644793952352652
Observations	4

Anova Table

Source	Sum of Squares	Degrees of Fre...	Mean Squares	P-Value	F-Statistic
Regression	2.55747323729...	2	1.27873661864...	0.26888653788...	6.41563216724...
Error	0.19931576270...	1	0.19931576270...		
Total	2.75678899999...	3	0.91892966666...		

Coefficients Table

Name	Coefficient V...	Std. Error	t Test	P-value	Upper Confi...	Lower Confi...
Propellant B...	-0.00910108...	0.003390877...	-2.68399230...	0.227048362...	0.033984096...	-0.05218627...
Specific Imp...	0.000293084...	0.000183729...	1.595198912...	0.356475783...	0.002627587...	-0.00204141...
Intercept	8.654651946...	0.317687084...	27.24269372...	0.023357971...	12.69124908...	4.618054807...

Validation using Technical Driver equation to predict MCPLXS

JPL WBS #	Description	Mission A	Mission B	Mission C	Mission D	Mission E	Average Estimate Delta	Absolute Estimate Delta
WBS 01-03	PM Management, Sys Eng'g, and SMA.	-29%	-38%	36%	61%	-2%	**6%**	**33%**
WBS 06.01- 06.03 & WBS 06.161-06.16.03	Spacecraft and Spacecraft Contractor Mgmt., Sys Eng'g, and Prod Assur	46%	67%	-29%	-33%	-15%	**7%**	**38%**
WBS 06.04	Power Subsystem	-6%	6%	54%	13%	3%	**14%**	**16%**
WBS 06.05*	C&DH Subsystem	20%	-1%	30%	-11%	-1%	**8%**	**13%**
WBS 06.06*	Telecomm Subsystem	-10%	-8%	1%	-3%	0%	**-4%**	**5%**
WBS 06.07	Mechanical Subsystem (incl Harness)	7%	-13%	29%	-4%	-14%	**1%**	**13%**
WBS 06.08	Thermal	-20%	11%	-27%	39%	11%	**3%**	**22%**
WBS 06.09	Propulsion	N/A	-15%	-2%	-2%	22%	**1%**	**8%**
WBS 06.10	GN&C	59%	-6%	51%	28%	-18%	**23%**	**32%**
WBS 06.11	Harness	incl in 06.07	incl in 06.07	incl in 06.07	incl in 06.07	incl in 06.07	**incl in 06.07**	**incl in 06.07**
WBS 06.12	Flight Software	0%	0%	0%	0%	0%	**0%**	**0%**
WBS 06.13 -06.15 & WBS 10	Spacecraft and Project System I&T	-48%	-4%	-4%	-3%	6%	**-11%**	**13%**
	Total:	**3%**	**-3%**	**7%**	**1%**	**-3%**	**1%**	**3%**

*In Phase 1, a technical driver equation was not determined for C&DH and Telecom, validation above uses the calibrated MCPLXS rather than the predicted for those subsystems.

** Flight software was handled as a pass-through using the software COTS object in TP

The predicted MCPLXS factors validate well against actuals. Overall estimate delta is < 1% and absolute estimate delta is <3%.

Summary of the Phase 1 Calibration Effort

- Study developed a mapping for TP cost outputs/activities to the JPL WBS:
  - However, the mapped results of System and Assembly costs compared to the JPL WBS actuals are somewhat inconsistent:
    - WBS 01-03 PM Management, Sys Eng'g, and SMA:
      - Two of the five data points have deltas of > -25%
      - Two of the five data points have deltas of > +25%
    - WBS 06.01- 06.03 & WBS 06.161-06.16.03 Spacecraft and Spacecraft Contractor Mgmt., Sys Eng'g, and Prod Assur
      - Two of the five data points have deltas of > -25%
      - Two of the five data points have deltas of >+25%
    - In all cases the SEIT costs at the Project and Spacecraft level offset each other which may point to a historical difference in our WBS mapping of actuals
- Established guidance for primary and secondary inputs based on validated results
- Derived estimating relationships tied to technical drivers for 6 out of the 8 H/W subsystems
  - Results produced overall deltas of less than 10% of the actual completed cost in all cases

Future Work

- Phase 2 of this activity will focus on collecting more technical data for several subsystems
  - Possible recalibration to MCPLXE where subsystems contain active electronics (Power, C&DH, Telecom, GNC)
  - May allow for better estimating relationships, specifically for C&DH and Telecom
- Adding additional data points to the study

Author Bios

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Milana Wood is a senior cost engineer in the Cost Estimation and Pricing Section and has over 13 years of JPL/NASA experience in cost estimating and analysis; Independent Cost Estimates, parametric cost estimating, process improvement, program business management, cost research, and risk analysis. She has led the development of numerous Independent Cost Estimates within JPL and NASA, most recently SWOT, M2020, and the Europa Mission. Mrs. Wood received her B.S, in Information Systems, Magna cum Laude, from California State University, Northridge and an M.B.A from the Marshall School of Business at University of Southern California.

Melissa J. Winter
PRICE Systems Solutions Consultant

Melissa has been with PRICE Systems for 3 years, acting as the Primary Solutions Consultant on the West Coast, training and mentoring NASA, the Army, and many contractors in the use of TruePlanning and other PRICE products. Before PRICE, Melissa worked at Raytheon SAS, where she performed parametric estimating for land-based, sea-based, airborne and space based solutions. Previous to this, she worked at Northrop Grumman, where she developed parametric estimates as well as bottom-up proposal.

Bryan D. Kobie
Group Supervisor

Bryan Kobie is the Group Supervisor of the Engineering Cost Estimation group at JPL. He has been at JPL since 2008, and he has experience in cost estimation, systems engineering, and mechanical engineering. He has worked on a variety of projects and proposals including InSight (Discovery Program), Europa, and Asteroid Redirect Robotic Mission. He received his M.S.E. and B.S.E. in Mechanical Engineering from the University of Michigan.

Fred G. Doumani
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Section 251, Cost Estimating and Pricing Section, Program Business Management Division

Fred Doumani is the Manager of the JPL Cost Estimating and Pricing Section and Manager of the Cost Commitment Office. Prior to that, he was the manager of the Costing Office, a position which he has held since coming to the Lab in January of 2003.
Before JPL, Fred spent 20 years at Boeing working in Contracts, Pricing, and Estimating. In addition, Fred held numerous management positions within the financial organization both in the aircraft and space segments of Boeing.