estimate

estimate · analyze · plan · control

QuickCost 6.0

A Parametric Cost Model for Space Science Missions

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QuickCost 6.0 Introduction and Background

What's New?

- Previous versions of QuickCost…
  - Estimated WBS 5 Payload suite and WBS 6 Spacecraft bus as a lump sum
    - And mushed into the above lump sum, WBS 1 Project Management, WBS 2 Systems Engineering 3 S&MA
  - Did not estimate WBS 4 Science and Technology
  - WBS 7 Mission Operations Systems and WBS 9 Ground Systems estimated as a lump sum
  - Excluded WBS 8 Launch Vehicle/Services (generally)
  - Did not discretely estimate WBS 11 E&PO
  - Estimated MO&DA
  - Estimated Life Cycle Cost
  - Estimated total mission development schedule duration

- QuickCost 6.0…
  - Discretely estimates each of the 11 NASA WBS elements
    - Including multiple individual instruments in WBS 5 Payload
  - Estimates MO&DA
  - Estimates Life Cycle Cost
  - Estimates mission development schedule duration

- And QuickCost 6.0 has (temporarily?) dropped several ancillary databases and cost models which were part of QuickCost 5.0 and earlier versions
  - Satellites Trades
  - Module and Transfer Vehicles
  - X-Vehicles
  - Liquid Rocket Engines

QuickCost Versions Over The Years

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	QuickCost 1.0	QuickCost 2.0	QuickCost 3.0	QuickCost 4.0	QuickCost 5.0	QuickCost 6.0
	Dissertation Proposal	Dissertation In Work	Dissertation Final	CAD Funded 2009	CAD Funded 2010	CAD Funded 2015
Release date	October 1, 2004	December 1, 2005	February 1, 2006	September 1, 2009	January 31, 2011	March 31, 2016
R^2 adjusted	82.8%	77.0%	86.0%	88.4%	86.1%	74.8% bus/70.8% instr
Number data points	122	131	120	120	132	72 bus, 325 instr
Total mass	x	x	x	x	x	
Bus mass						x
Instrument mass						x
Total Power	x	x		x	x	
Instrument power						x
Design life	x	x		x	x	x
Year tech/ATP date	x	x		x	x	
Reqmts stability/volatility	x					
Funding stability	x					
Test	x					
Number instruments	x					
Pre-development study	x					
Team	x			x		
Apogee		x				
Percent new		x		x		
Bus new					x	x
Instrument new					x	x
Planetary/Destination			x	x	x	x
ECMPLX			x			
MCMPLX			x			
Data rate%				x		
Instrument complexity%						
				x	x	

QuickCost 6.0 Database

QuickCost 6.0 Database

- QuickCost 5.0 had 132 missions in its database
  - Missions going back to the 1960s
    - With data from various sources, some of dubious pedigree
- The CAD directed (and we agreed) that QuickCost 6.0 should limit itself to....
  - Only missions for which a EOM or LRD or CADRe+ exists
- This resulted in analyzing **72 missions for QuickCost 6**
  - **Including 325 instruments**
    - (12 of the 325 are actually instrument suites where CADRe reported the total WBS 5 Payload cost as a lump sum)
      - We included the total suite cost, mass and power in the regression analysis just as though they were stand alone instruments

Database (Chart 1 of 2)

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1	AIM (Aeronomy of Ice in the Mesosphere)
2	Aqua (Latin For Water) [formerly named PM-1 mission]
3	Aquarius/SAC-D
4	AURA [formerly named CHEM-1 or Chemistry Mission]
5	CALIPSO (Cloud Aerosol Lidar and Infrared Pathfinder Satellite Observations)
6	Cassini & Huygens Probe
7	CHIPSat (Cosmic Hot Interstellar Plasma Spectrometer Satellite)
8	CloudSat
9	COBE (Cosmic Background Explorer)
10	Dawn
11	Deep Impact Flyby Spacecraft & Impactor
12	Deep Space 1 (DS-1)
13	EO-1 (Earth Observing 1)
14	FAST (Fast Auroral Snapshot Explorer)
15	GALEX (Galaxy Evolution Explorer)
16	Galileo Orbiter & Probe
17	Genesis
18	GLAST (Gamma Ray Large Area Space Telescope) [Renamed Fermi Gamma-ray Space Telescope]
19	GLORY
20	GOES I (Geostationary Operational Environmental Satellite)
21	GPM (Global Precipitation Measurement)
22	GRACE (Gravity Recovery and Climate Experiment)
23	GRAIL (Gravity Recovery and Interior Laboratory)
24	IBEX (Interstellar Boundary Explorer)
25	ICESat (Ice, Cloud and Land Elevation Satellite)
26	IMAGE (Imager for Magnetopause-to-Aurora Global Exploration)
27	IRIS (Interface Region Imaging Spectrograph)
28	JASON 1 (Joint Altimetry Satellite Oceanography Network)
29	JUNO
30	KEPLER
31	LADEE (Lunar Atmosphere and Dust Environment Explorer)
32	LANDSAT-7
33	LCROSS (Lunar CRater Observation and Sensing Satellite)
34	LDCM (Landsat Data Coninuity Mission)
35	LRO (Lunar Reconnaissance Orbiter)
36	Mars Odyssey [Mars Surveyor 2001 Orbiter]

Database (Chart 2 of 2)

37	Mars Pathfinder
38	MAVEN (Mars Atmosphere and Volatile EvolutioN)
39	MER (Mars Exploration Rover) Lander
40	MGS (Mars Global Surveyor)
41	MRO (Mars Reconnaissance Orbiter)
42	MSL (Mars Science Laboratory) (Curiosity Rover)
43	NEAR (Near Earth Asteroid Rendezvous) [renamed NEAR Shoemaker]
44	New Horizons
45	NOAA-N (National Oceanic and Atmospheric Administration-N)
46	NOAA-N Prime (National Oceanic and Atmospheric Administration N Prime)
47	NuSTAR (Nuclear Spectroscopic Telescope Array)
48	OCO (Orbiting Carbon Observatory)
49	OCO-2 (Orbiting Carbon Observatory-2)
50	OSTM (Ocean Surface Topography Mission, Jason-2)
51	Phoenix
52	QuikSCAT (Quick Scatterometer)
53	RHESSI (Reuven Ramaty High Energy Solar Spectroscopic Imager)
54	SDO (Solar Dynamics Observatory)
55	SOFIA
56	SORCE (Solar Radiation and Climate Experiment)
57	Spitzer Space Telescope (formerly SIRTF-Space Infrared Telescope Facility)
58	Stardust & Sample Return Capsule
59	STEREO (Solar Terrestrial Relations Observatory)
60	Suomi NPP (Suomi National Polar-orbiting Partnership) (Previously known as the National Polar-orbiting Operational Environmental Satellite System Preparatory Project (NPP))
61	Suzaku (formerly Astro-E2)
62	SWAS (Submillimeter Wave Astronomy Satellite)
63	TDRS K (Tracking and Data Relay Satellite)
64	THEMIS (Time History of Events and Macroscale Interactions during Substorms)
65	Terra (Latin for "Land") [Formerly named AM-1 mission]
66	TIMED (Thermosphere-Ionosphere-Mesosphere Energetics and Dynamics Mission)
67	TRACE (Transition Region and Coronal Explorer)
68	TRMM (Tropical Rain Measuring Mission)
69	VAP (Van Allen Probes) (previously known as Radiation Belt Storm Probe (RBSP))
70	WIRE (Wide Field Infrared Explorer)
71	WISE (Wide-field Infrared Survey Explorer)
72	WMAP (Wilkinson Microwave Anisotropy Probe)

But Some Data Was Not Used

- We eliminated 10 spacecraft buses from the regression analysis
  - 7 buses were by **international partners** and were not used
    - But we harvested the U.S. instruments for the instrument database
  - Dropped SOPHIA
  - Dropped ChipSat and THEMIS **microsatellites**
  - **72-10 = 62 satellite buses included in the regression analysis**
- We eliminated 145 instrument data points prior to the regression analysis
  - Eliminated 57 instruments that were contributed (or partially contributed) by **international partners**
  - Eliminated the 7 SOPHIA instruments (just out of plain meanness)
  - Eliminated 76 **instruments that didn't have cost reported** in CADRe (most of these were instances where we included their mass and power in a instrument suite "one level up")
  - Eliminated 5 instruments which were **missing delineated mass and/or power** in the CADRE (was booked in other elements but not discretely identifiable)
    - This included 3 QuikScat instruments which will become available when QuikScat CADRe Part C becomes available
  - **325-145 = 180 instruments included in the regression analysis**

QuickCost 6.0 Database Mining

- We used the ONCE automated data mining software to download cost data

- However, in the end we ended up checking almost every cost number "by hand" (i.e. looking it up in Part C)

  - In order to make Full Cost adjustments

  - In order to adjust multiple spacecraft projects down to DDT&E and one TFU

  - In order to correct a few miss-bookings

    - Typically WBS 5 Payload wraps (Management and Systems Engineering)

  - To capture a few costs that were booked in out of the way places in Part C

    - Typically Level 2 Systems Engineering effort

- **Lesson learned: Each CADRe is somewhat different and you really have to watch the fine print and numbers "off in the corners"**

QuickCost 6.0 Groundrules And Assumptions

- All costs in the QuickCost 6.0 database are in **FY2012 dollars**
  - A ONCE restriction at the time the data was pulled in early 2015
  - However, QuickCost 6.0 will output results in any constant year dollars desired

- Missions with pre-FY2004 work were converted to **Full Cost**
  - Some pre-FY2004 CADRe data is already in Full Cost (e.g. STEREO, GSFC NOAA missions)

- For missions having multiple spacecraft (GOES, GRACE, GRAIL, MER, STEREO, TDRS, THEMIS, Van Allen Belt Probes/RSTP, NOAA-N and NOAA-N Prime) we remodeled the **cost to reflect only DDT&E and the TFU**
  - We did this for both the spacecraft bus and the instruments
  - And in so doing, we maintained the original percentages for WBS 1, 2 and 3 but the percentage now is "operating" on a lower WBS 5 and 6 cost
  - We also reduced launch cost by $1/n$ where n= the number of satellites in the mission

- All WBS element cost estimates by QuickCost 6 are **Phase B through D** (they do not include Phase A costs [generally] nor Phase E costs)
  - All Phase E costs (for all WBS elements) were booked in a "Phase E" database field and is the basis for a **MO&DA C**ER that estimates all of Phase E for all WBS elements

- The QuickCost 6.0 **confidence level accounts is calculated using the prediction interval of the CER**

A One Chart Explanation of How We Adjusted Non Full Cost to Full Cost

- Two charts are in backup with gory details but here is the 40,000 view

- We made **several assumptions** (based on data and experience)....

  - About how NASA mission cost typically breaks between DDT&E and the TFU

  - About how NASA DDT&E and TFU typically breaks between labor, material, purchased parts, subcontracts and support contractors

    - Here we mean the support contractors that work inside NASA Field Centers that assist with in-house projects

- We reviewed each CADRe carefully to make sure it wasn't already in Full Cost

  - Some CADRes have already been adjusted by the CADRe developer (e.g. FAST, STEREO)

  - Some pre FY2004 work was done originally in Full Cost (e.g. GSFC work for NOAA)

  - And of course, even with "in-house" projects, any contracted parts were assumed to be in Full Cost already and were not adjusted

  - Said another way, **adjustments were only made for civil service labor pre FY2**004

- We **documented our Full Cost adjustments** in narrative form in a database field "Full Cost Accounting Adjustments" and in comments to cells containing adjusted costs

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QuickCost 6.0 Tabs

- Database is an Excel flat file with a row for each mission and **126 data fields** (aka columns)
  - The full database is on a tab called "**SpacecraftDb**"
    - Which contains a lot of mission level information, technical data on the bus, etc.
    - As well as the WBS 1-11 and MO&DA cost (in millions of FY2012$)
  - And the instruments and their technical and cost data are listed on a separate tab called "**InstrumentDb**"
  - There are also tabs, which can largely be ignored, called "SpacecraftDbRegression" and "InstrumentDbRegression" which contain only the missions/instruments carried forward into the regression analysis
- The actual cost model for all 11 WBS elements (and MO&DA) is on a tab called "**Model**"
- And MNGSE is on a tab called "**MNGSE**"

QuickCost 6.0 Regression Analysis

QuickCost 6.0 Regression Analysis

- We analyzed scores of potential independent variables against cost and schedule span

- As has been the case with previous versions of QuickCost, only a handful of variables passed the t-tests for significance

- The final variables used in the model are...

  - For the satellite bus...
    - Dry mass, destination and "percent new design"

  - For the instruments...
   - Dry mass, average power, design life and "percent new design"

Some Heartbreaks

- Several variables did not pass the t-tests
  - An indicator variable for AO Competed vs Directed missions
    - Theoretically Directed Missions typically have lower TRLs, higher complexity, longer schedule durations than Competed Missions
      - While the indicator variable did show saving for AO Competed Missions, However, the difference in cost did not turn out to be statistically significant with a $p = 0.253$
  - A variable for PI-Led Missions showed slightly higher cost for PI-Led missions (counterintuitive?) but in any event has a terrible t-statistic at $p = 0.915$
  - A variable for Significant NASA In-house Work (including JPL) also showed slightly higher cost (counterintuitive?) and also failed the t-test with $p = 0.169$

Spacecraft Bus CER Scatterplots
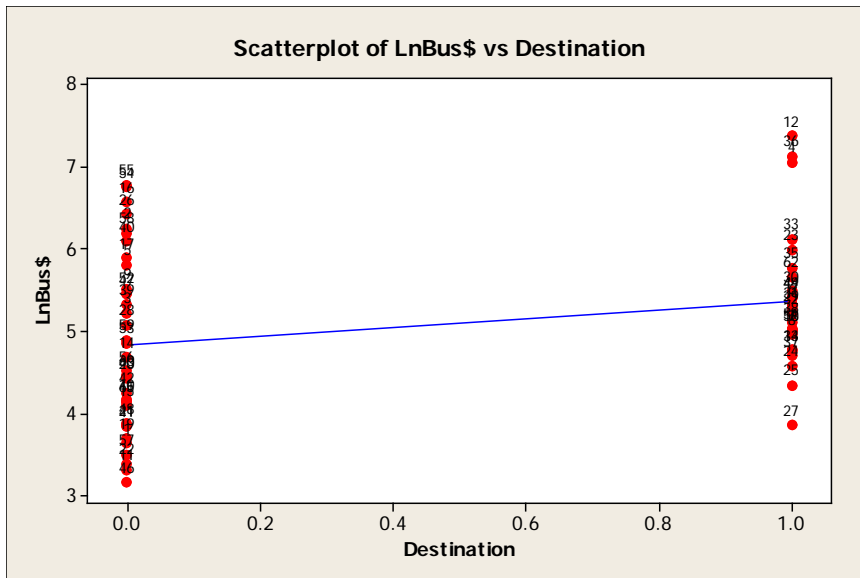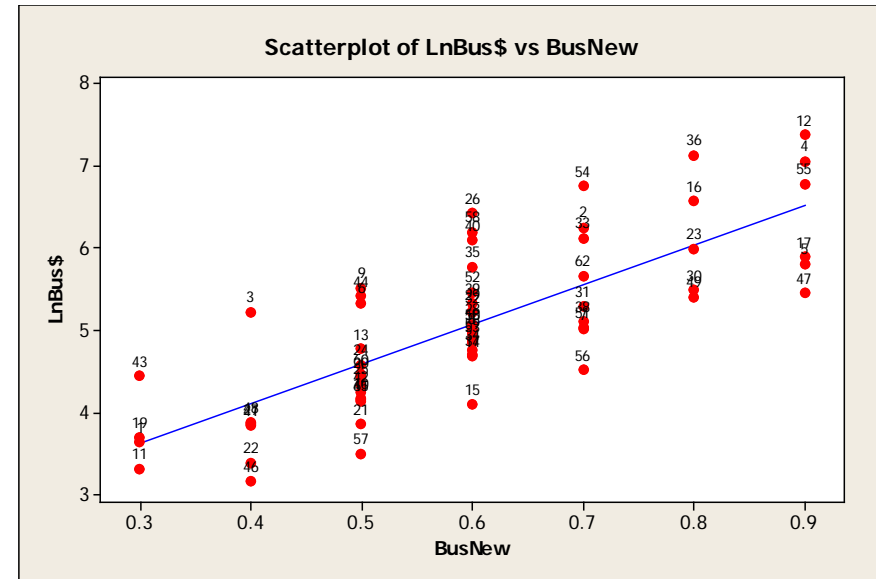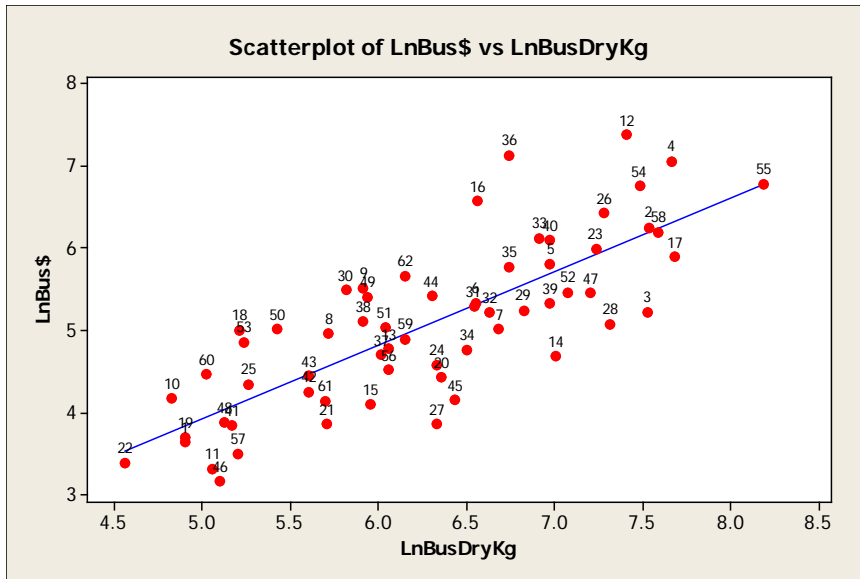
Spacecraft Bus Residual Plots
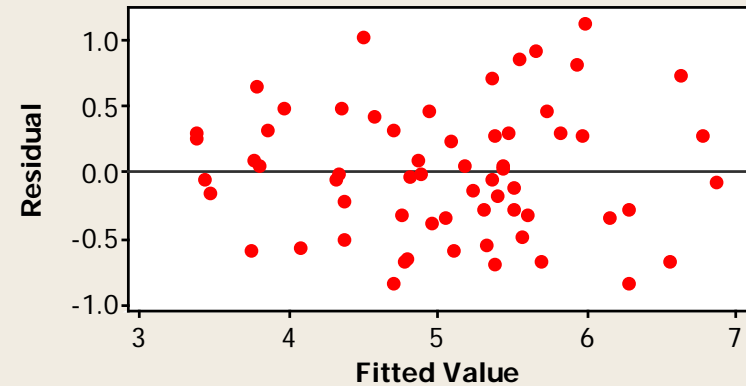## (For CER Using Mass, BusNew, Destination)

G A L O R A T H

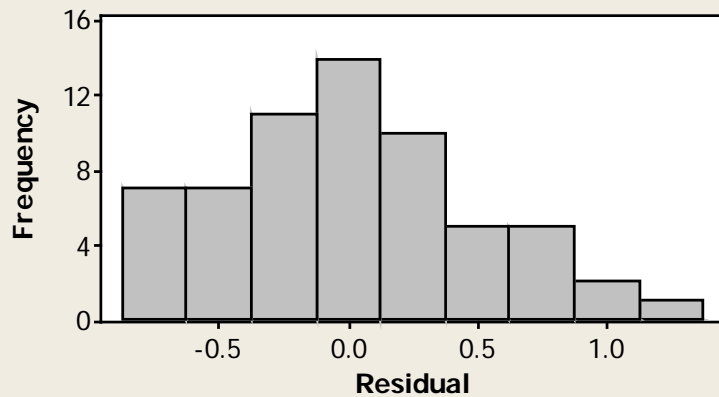

Residual Plots for LnBus$
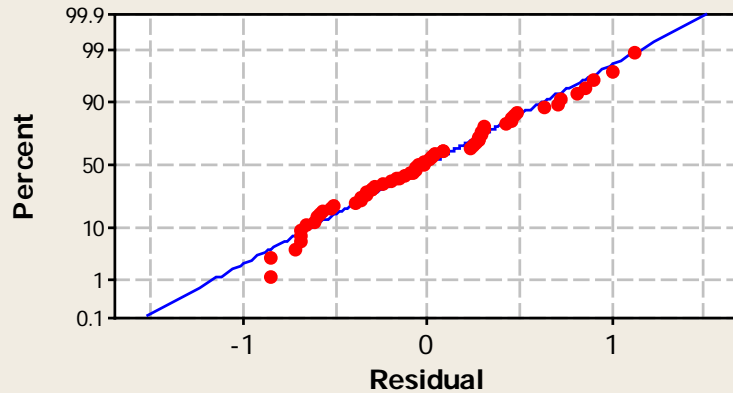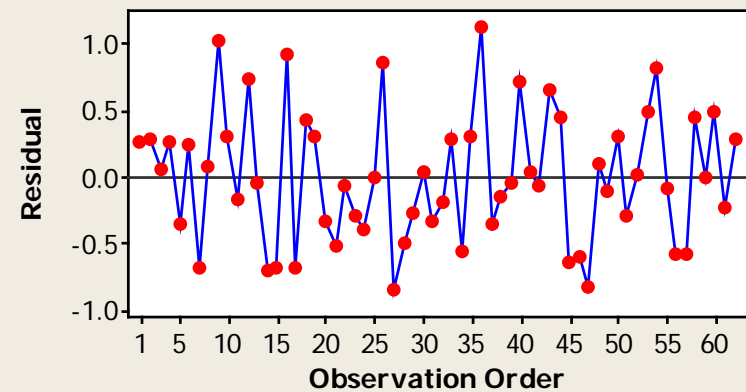
Instrument CER Scatterplots
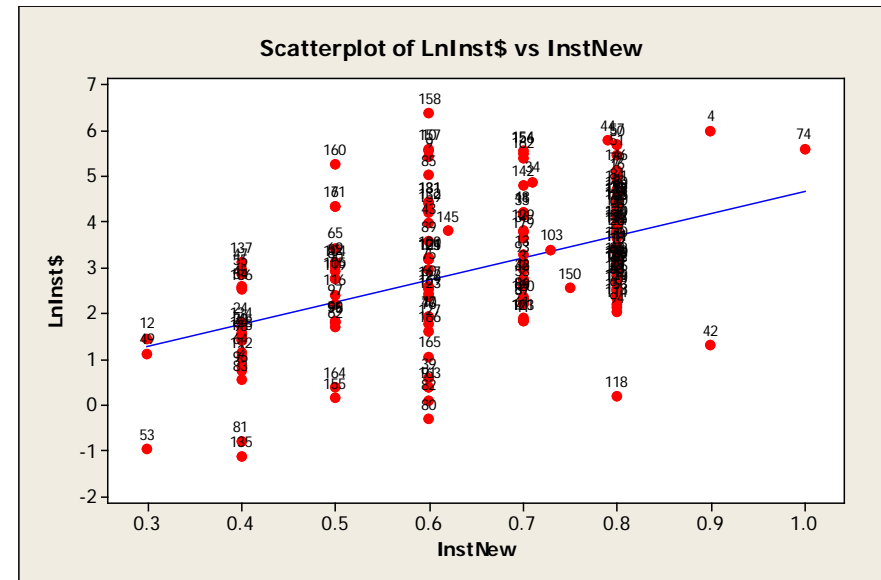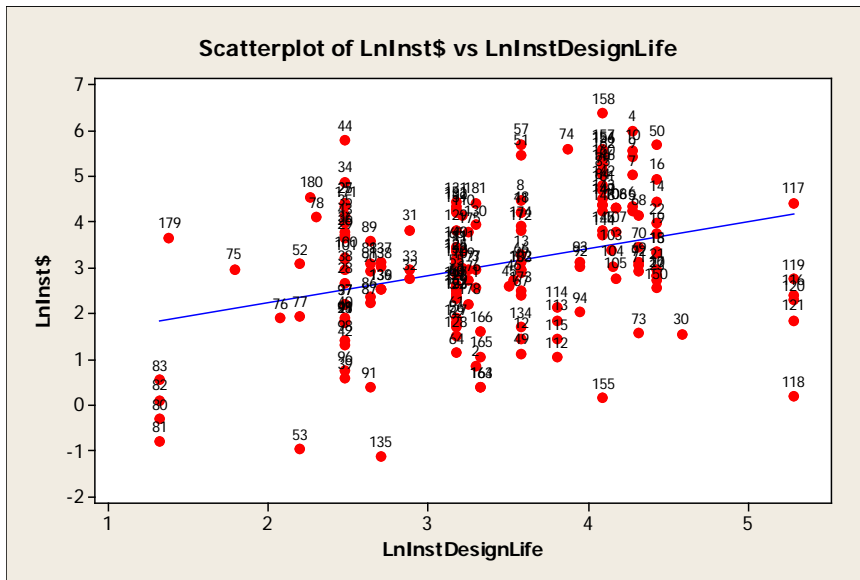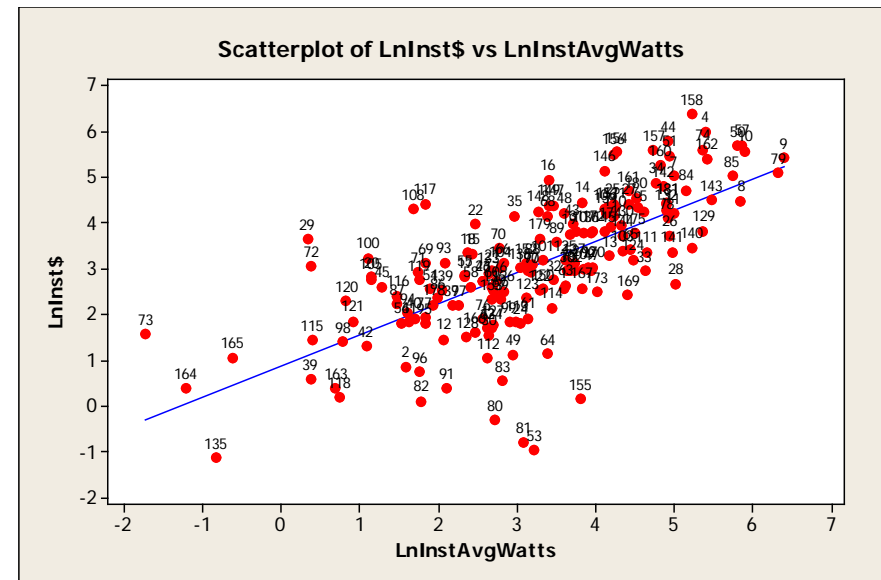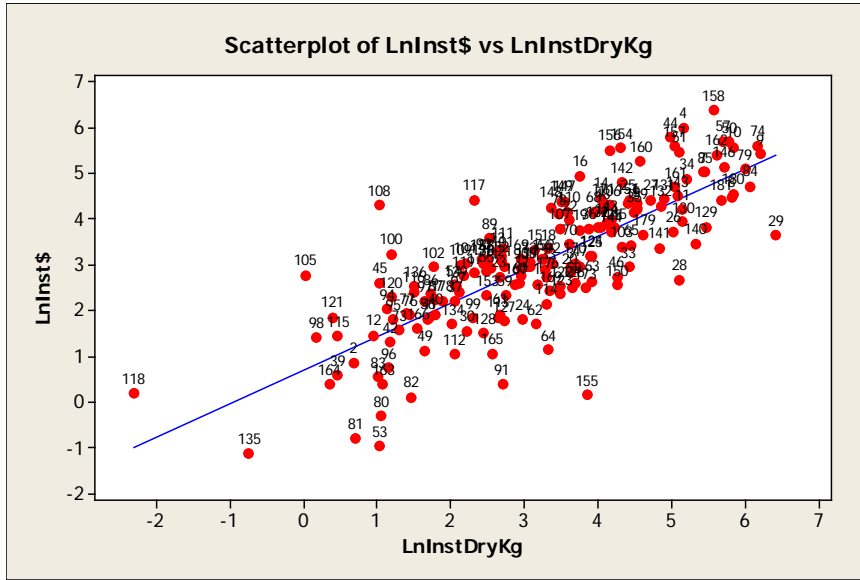
Instrument Residual Plots
(For CER Using Mass, Power, Design Life and InstNew)

G A L O R A T H

Residual Plots for LnInst$
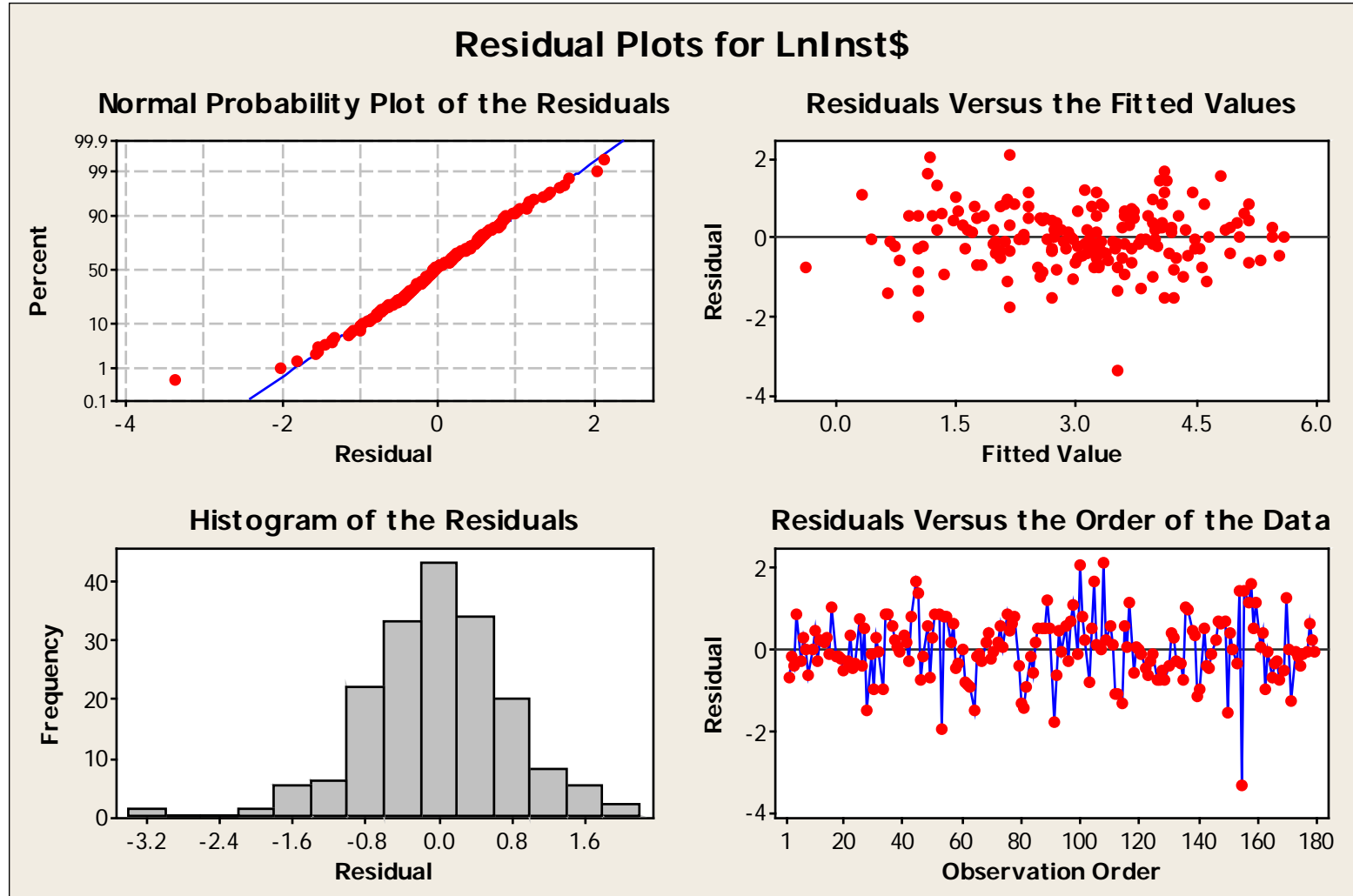
Spacecraft Bus CERs

```
The regression equation is
LnBus$ = - 0.578 + 0.899 LnBusDryKg


Predictor        Coef   SE Coef      T       P
Constant      -0.5784    0.5729   -1.01   0.317
LnBusDryKg    0.89897   0.09041    9.94   0.000


S = 0.620133   R-Sq = 62.2%   R-Sq(adj) = 61.6%


Analysis of Variance

Source           DF      SS      MS      F      P
Regression        1   38.022  38.022  98.87  0.000
Residual Error   60   23.074   0.385
Total            61   61.096
```

```
The regression equation is
LnBus$ = - 0.181 + 0.561 LnBusDryKg + 2.89 BusNew


Predictor        Coef   SE Coef      T      P   VIF
Constant      -0.1808    0.4775   -0.38  0.706
LnBusDryKg    0.56053   0.09715    5.77  0.000   1.7
BusNew        2.8853     0.5318    5.43  0.000   1.7


S = 0.510805   R-Sq = 74.8%   R-Sq(adj) = 73.9%


Analysis of Variance

Source           DF      SS      MS      F      P
Regression        2   45.702  22.851  87.58  0.000
Residual Error   59   15.394   0.261
Total            61   61.096
```

```
The regression equation is
LnBus$ = - 0.652 + 0.882 LnBusDryKg + 0.426 Destination


Predictor        Coef   SE Coef      T       P   VIF
Constant      -0.6522    0.5431   -1.20   0.235
LnBusDryKg    0.88226   0.08582   10.28   0.000   1.0
Destination   0.4261     0.1515    2.81   0.007   1.0


S = 0.587242   R-Sq = 66.7%   R-Sq(adj) = 65.6%


Analysis of Variance

Source           DF      SS      MS      F      P
Regression        2   40.750  20.375  59.08  0.000
Residual Error   59   20.346   0.345
Total            61   61.096
```

```
The regression equation is
LnBus$ = - 0.260 + 0.585 LnBusDryKg + 2.60 BusNew + 0.231 Destination


Predictor        Coef   SE Coef      T      P   VIF
Constant      -0.2597    0.4724   -0.55  0.585
LnBusDryKg    0.58453   0.09667    6.05  0.000   1.7
BusNew        2.6034     0.5492    4.74  0.000   1.9
Destination   0.2311     0.1361    1.70  0.095   1.1


S = 0.502847   R-Sq = 76.0%   R-Sq(adj) = 74.8%


Analysis of Variance

Source           DF      SS      MS      F      P
Regression        3   46.431  15.477  61.21  0.000
Residual Error   58   14.666   0.253
Total            61   61.096
```

Spacecraft Bus Coefficient Plot
(For CER Using Mass, BusNew, Destination)
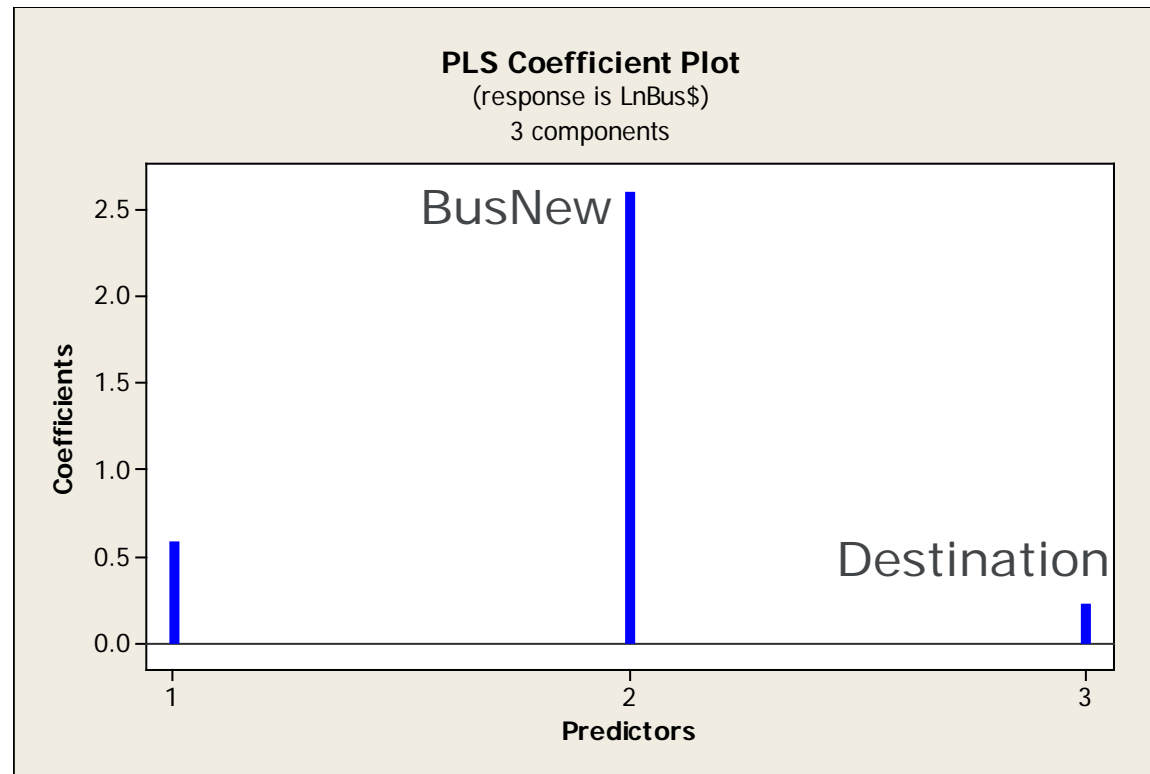
G A L O R A T H

PLS Coefficient Plot
(response is LnBus$)
3 components

- Partial Least Squares (PLS) regression coefficient plot shows the relative importance of the variables, in this case..
  - BusNew
  - Mass
  - Destination

Instrument CERs

```
The regression equation is
LnInst$ = 0.699 + 0.735 LnInstDryKg


Predictor          Coef   SE Coef       T       P
Constant         0.6988    0.1510    4.63   0.000
LnInstDryKg     0.73455   0.04215   17.42   0.000


S = 0.885364    R-Sq = 63.0%    R-Sq(adj) = 62.8%


Analysis of Variance

Source           DF      SS      MS       F       P
Regression        1  238.01  238.01  303.63   0.000
Residual Error  178  139.53    0.78
Total           179  377.53
```

```
The regression equation is
LnInst$ = 0.573 + 0.612 LnInstDryKg + 0.162 LnInstAvgWatts


Predictor            Coef   SE Coef      T       P   VIF
Constant           0.5727    0.1602   3.58   0.000
LnInstDryKg       0.61174   0.06991   8.75   0.000   2.8
LnInstAvgWatts    0.16195   0.07399   2.19   0.030   2.8


S = 0.876083    R-Sq = 64.0%    R-Sq(adj) = 63.6%


Analysis of Variance

Source           DF      SS       MS       F       P
Regression        2  241.68   120.84  157.44   0.000
Residual Error  177  135.85     0.77
Total           179  377.53
```

```
LnInst$ = - 0.827 + 0.539 LnInstDryKg + 0.215 LnInstAvgWatts
            + 0.430 LnInstDesignLife


Predictor             Coef   SE Coef       T       P   VIF
Constant           -0.8269    0.2835   -2.92   0.004
LnInstDryKg        0.53871   0.06551    8.22   0.000   2.9
LnInstAvgWatts     0.21543   0.06866    3.14   0.002   2.9
LnInstDesignLife   0.42985   0.07442    5.78   0.000   1.0


S = 0.805526    R-Sq = 69.8%    R-Sq(adj) = 69.2%


Analysis of Variance

Source           DF       SS      MS       F       P
Regression        3  263.333  87.778  135.28   0.000
Residual Error  176  114.201   0.649
Total           179  377.534
```

```
The regression equation is
LnInst$ = - 1.46 + 0.475 LnInstDryKg + 0.223 LnInstAvgWatts
            + 0.386 LnInstDesignLife + 1.44 InstNew


Predictor             Coef   SE Coef       T       P   VIF
Constant           -1.4589    0.3375   -4.32   0.000
LnInstDryKg        0.47533   0.06670    7.13   0.000   3.2
LnInstAvgWatts     0.22284   0.06690    3.33   0.001   2.9
LnInstDesignLife   0.38611   0.07370    5.24   0.000   1.1
InstNew             1.4392    0.4421    3.26   0.001   1.3


S = 0.784423    R-Sq = 71.5%    R-Sq(adj) = 70.8%


Analysis of Variance

Source           DF       SS      MS       F       P
Regression        4  269.853  67.463  109.64   0.000
Residual Error  175  107.681   0.615
Total           179  377.534
```

Instrument PLS Coefficient Plot
(For CER Using Mass, Power, Design Life and InstNew)
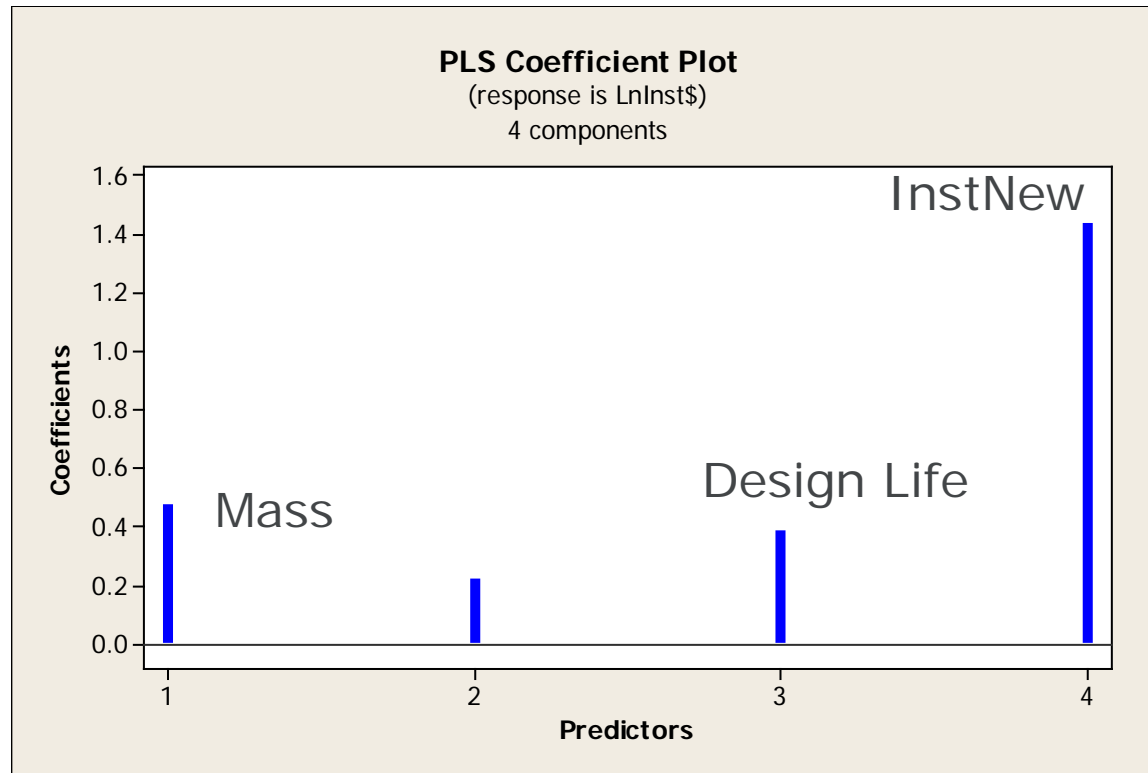
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PLS Coefficient Plot
(response is LnInst$)
4 components

Chart with y-axis "Coefficients" ranging from 0.0 to 1.6 and x-axis "Predictors" labeled 1 to 4. Bars: Mass (~0.47) at predictor 1, (~0.22) at predictor 2, Design Life (~0.39) at predictor 3, InstNew (~1.44) at predictor 4.

- Partial Least Squares (PLS) regression coefficient plot shows the relative importance of the variables, in this case..

  - InstNew

  - Mass

  - DesignLife

  - Power

Outliers

- As in previous versions of QuickCost, there are a number of potential outliers

  - Visual outliers on scatter plots

  - Outliers identified by Minitab diagnostics

  - In addition, arguably, some data points could be dropped out of functional heterogeneity

    - Mars Pathfinder, MER, MSL, SOPHIA

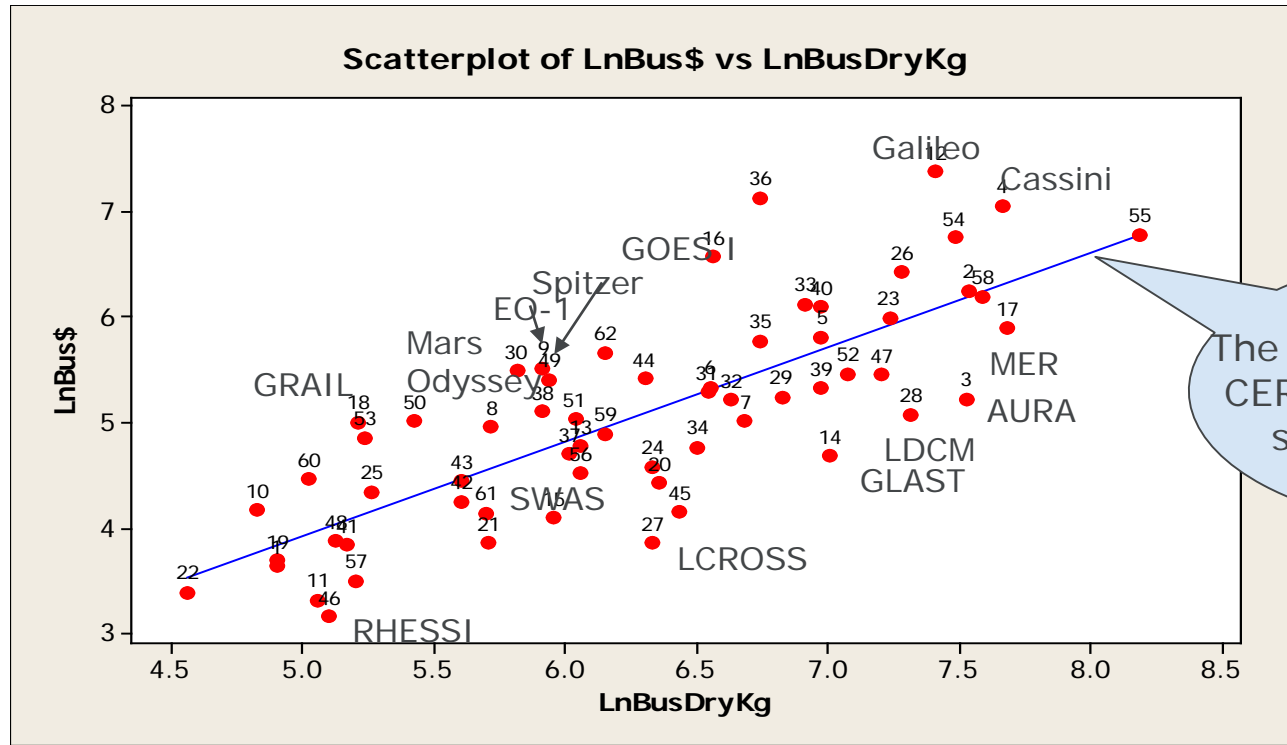| Mission	Red Flags						
	Visual Outlier	Minitab Influential Outlier Flag	Age (Launch Date)	Functional Homogeneity	Number of Red Flags	High/Low	Recommendation
Aura	Yes	Yes	2004	Yes	2	Low	Keep
Cassini	Yes	Yes	1997	Yes	3	High	Delete
EO-1	Yes	No	2000	Yes	1	High	Keep
Galileo	Yes	Yes	1989	Yes	3	High	Delete
GLAST	Yes	No	2008	Yes	1	Low	Keep
GRAIL	Yes	Yes	2011	Yes	2	High	Keep
GOES I	Yes	Yes	1994	Yes	3	High	Keep
LCROSS	Yes	No	2009	Yes	1	Low	Keep
LDCM	Yes	No	2013	Yes	1	Low	Keep
Mars Odyssey	Yes	No	2001	Yes	1	High	Keep
Mars Pathfinder	No	No	1996	No (Rover)	2	On the line	Keep
MER	Yes	No	2003	No (Rover)	2	High	Keep
MSL	Yes	Yes	2011	No (Rover)	3	High	Delete
Spitzer	Yes	No	2003	Yes	1	High	Keep
SWAS	Yes	Yes	1998	Yes	3	High	Keep
RHESSI	Yes	Yes	2002	Yes	2	Low	Delete

Outliers Have <u>Not</u> Been Eliminated (Yet)

Scatterplot of LnBus$ vs LnBusDryKg

The slope of this mass only CER is 0.88. More typical slopes are 0.5 to 0.6

- Current mass only and mass, destination spacecraft bus CERs have slopes on mass ~0.9 which is too high

- Deletion of Cassini, Galileo, MSL and RHESSI would help this problem

- Regardless of which data points are deleted from CER regression analyses, all data points remain in the database and can be used to calibrate the model

- Calibrating QuickCost 6.0 is our next subject

The Concept of First Kilogram Cost

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Scatterplot of LnBus$ vs LnBusDryKg
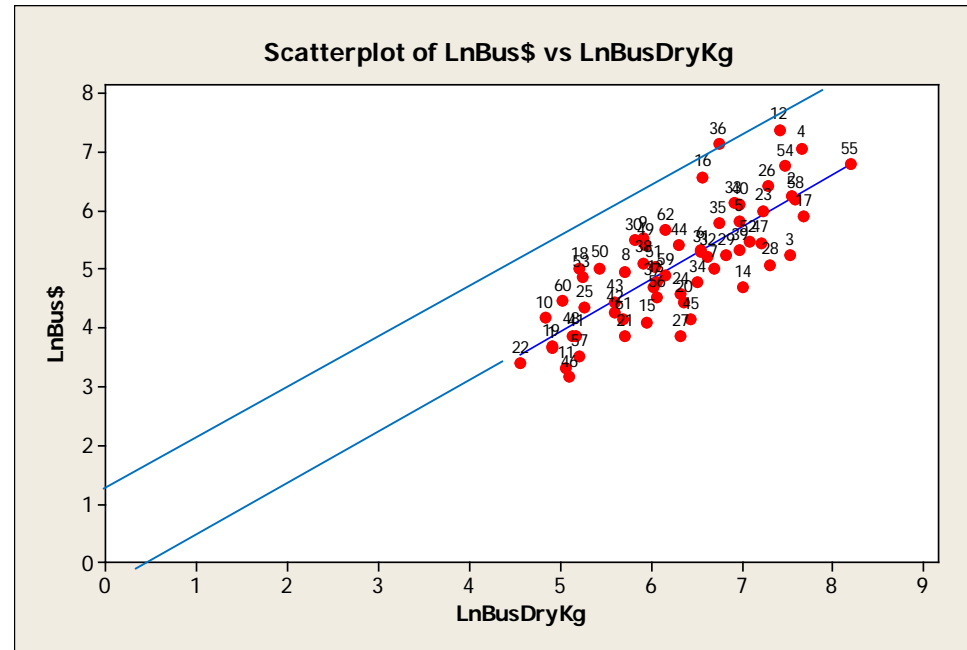
- Think of "**First Kilogram Cost**" as a **measure of relative complexity** between missions in the database

- Graphically, "First Kilogram Cost" is arrived at by scaling any data point on the LnCost/LnKg scatterplot back down the scatter plot…

  - To the y-intercept which is at a mass of 1 kilogram (i.e. the "First Kilogram Cost")

  - Using an assumed slope (which can be the overall slope from the regression or a heuristic like b=0.55)

- A database field in QuickCost 6.0 algebraically calculates the "First Kilogram Cost" in millions of dollars per kilogram

Calibrating QuickCost Using "First Kilogram Cost"

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No.	SubNo	Primary Data Source	Mission Name	Short Name	First Kilogram Cost for Total Bus + Instrument DDT&E + TFU	Select Analogous Missions ☑ Select All	if true = copy over value, if false no value
40	0	CADRe Plus	MGS (Mars Global Surveyor)	MGS	5.598	☑ MGS TRUE	5.598
41	0	EOM CADRe	MRO (Mars Reconnaissance Orbiter)	MRO	17.961	☑ MRO TRUE	17.961
42	0	LRD CADRe	MSL (Mars Science Laboratory) (Curiosity Rover)	MSL	37.465	☑ MSL TRUE	37.465
43	0	CADRe Plus	NEAR (Near Earth Asteroid Rendezvous) [renamed NEAR Shoemaker]	NEAR	6.608	☑ NEAR TRUE	6.608
44	0	LRD CADRe	New Horizons	New Horizons	14.254	☑ New Horizons TRUE	14.254

- Native QuickCost 6.0 has all the missions selected so it is calibrated to the overall average of the 62 missions in the "SatelliteRegression" database (i.e. tab)

- But if you believe a subset of the missions are more analogous to the mission being estimated, **check the boxes** of that/those missions (1 to 61 conceptually)
  - For example, JPL using QuickCost 6.0 might check all or some JPL missions

- QuickCost then calculates the average "First Kilogram Cost" for the selected mission and divides it by the overall average "First Kilogram Cost" of all 62 missions

- This provides a **calibration factor** which then is used as a **multiplier** in the bus CER

- The same process is used in calibrating the instrument CER to one or more specific instruments

Upside-Down Tomato Plant

- Like an upside-down tomato plant, **QuickCost 6.0 estimates the NASA WBS elements in this order**:

  - WBS 6 Satellite bus

  - WBS 5 Instruments

  - Then, WBS 1, 2, 3, 4, 7, 9, 10, 11 which are all estimated as percentage "wrap costs" to WBS 6 and 5

  - We will discuss WBS 8, Launch Services, two charts hence

WBS 1, 2 3, 4, 7, 9, 10, 11 Treated As Percentage Wraps
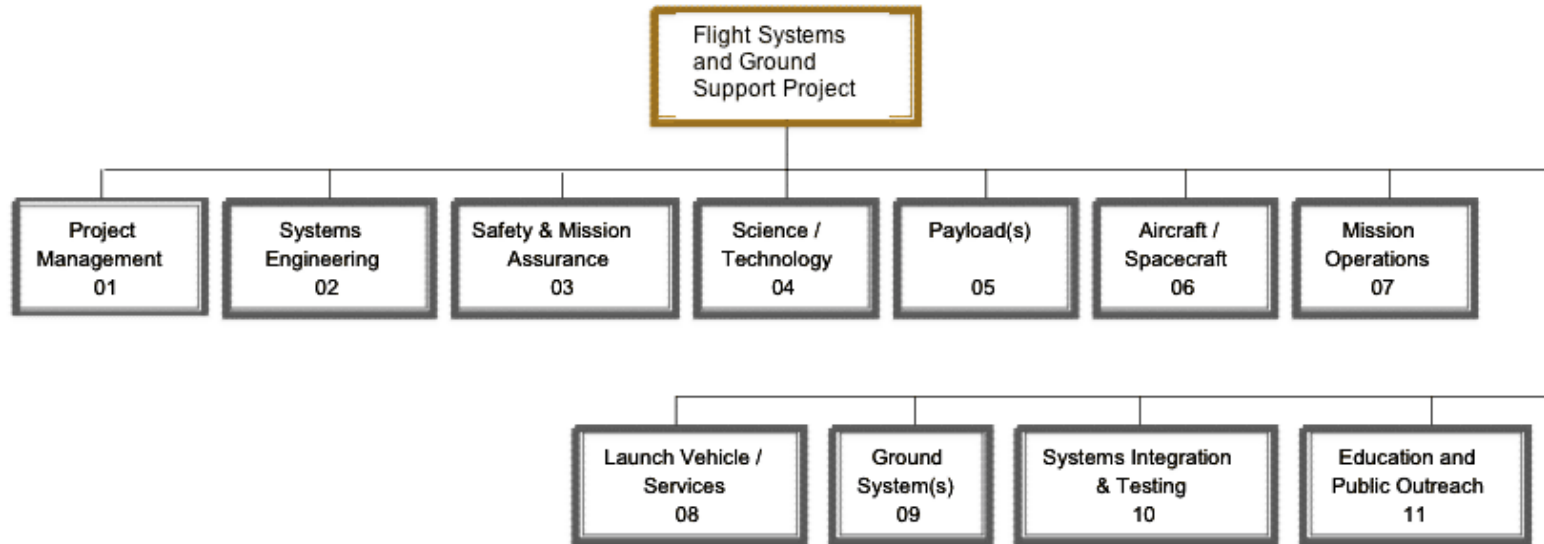
- QuickCost 6.0 discretely estimates WBS 1, 2, 3, 4, 7, 9, 10 and 11 as a percentage of the **_sum of WBS 5 + WBS 6_** which are the mean* percentages from the database

  - **WBS 1** Project Management **5%** of ∑(WBS 5 + WBS 6)

  - **WBS 2** Systems Engineering **4%** of ∑(WBS 5 + WBS 6)

  - **WBS 3** Safety & Mission Assurance **1%** of ∑(WBS 5 + WBS 6)

  - **WBS 4** Science & Technology **2%** of ∑(WBS 5 + WBS 6)

  - **WBS 7** Mission Operations System **5%** of ∑(WBS 5 + WBS 6)

  - **WBS 9** Ground Systems **6%** of ∑(WBS 5 + WBS 6)

  - **WBS 10** Systems Integration & Testing **2%** of ∑(WBS 5 + WBS 6)

  - **WBS 11** Education and Public Outreach **0.2%** of ∑(WBS 5 + WBS 6)

Earth Orbital vs Planetary PM, SE&I, S&MA

- Incidentally, there is little difference in the WBS 1, 2 & 3 percentages between Earth Orbital and Planetary

WBS	Total	Earth Orbital	Planetary
WBS 1 PM	5%	5%	4%
WBS 2 SE&I	4%	4%	4%
WBS 3 S&MA	1%	1%	2%

- Therefore QuickCost 6.1 just uses 5%, 4% and 1% for both earth orbital and planetary missions

Upside-Down Tomato Plant (Cont'd)

- You need to be desperate to depend on the QuickCost **WBS 8 Launch Ser**vices
  - Normally you will want either leave it out or throughput it

- But for the desperate, if you turn on WBS 8, Launch Services, it is estimated using:

  - The average launch cost from the QuickCost 6.0 database...

  - Binned into the 7 common launch destinations of NASA missions
    - Actually, automated spacecraft do not go to LEO ISS 51.6 but a cost is included for completeness

  - Otherwise you may either choose, from a drop down, to not include launch costs or to throughput a launch cost (in FY2012$M)

Destination	1) LEO 28.7	2) LEO ISS 51.6	3) GTO	4) LEO Polar 90	5) LEO Sun Synch 98.7	6) Planetary	7) GEO
Mean Launch Cost in FY12$	$35	$44	$78	$65	$74	$128	$78

QuickCost 6.0 Model Screenshot

GALORATH

QuickCost: A Spacecraft (Instruments + Bus) Project Cost Model. Version 6.0. March 31, 2016 Release. Developed by Joe Hamaker, Ron Larson and Kathy Kha, Galorath Federal

Enter Project Name and Other descriptors in Box-->	Your Garden Vairiety Average Mission		Estimate 1	Estimate 2	Estimate 3	Estimate 4	Values From the Database					
Enter Inputs In Blue Cells Only	1.093	**Variable Units**					Minimum	1st Quartile (25%)	Median	Mean	2nd Quartile (75%)	Maximum
Year dollars of output (20XX)	2016	Year dollars of output in 4 digit Fiscal Year (20XX)										
Bus dry mass (kg)	760.0	Total mass of total spacecraft bus in kilograms	✔	✔	✔	✔	96	280	555	764	1,068	3,611
Bus percent new design (%)	60%	Total bus new design in percent from 0% to 100%		✔		✔	30%	50%	60%	60%	70%	90%
Destination (select earth orbit or escape)	GEO	Select from dropdown			✔	✔	0	0	0	0.42	1	1
Design Life (months)	47	Needed for MO&DA Cost Estimate Only					4	24	28	47	60	300
Desired Confidence Level (percentile)	70%	Desired confidence level in percent for cost and schedule										
WBS 6 Bus Cost at 50% Confidence Level (including DDT&E + TFU)			$238.5	$213.4	$197.9	$194.3	$23.5	$78.7	$152.0	$263.1	$279.6	$1,599.7
WBS 6 Bus Cost at Specifed Confidence Level (including DDT&E + TFU)			$353.8	$316.6	$293.5	$288.2						
Instrument 1												
Instrument dry mass (kg)	66.6	Mass of total instrument in kilograms	✔	✔	✔	✔	0.1	8.3	26.8	66.6	71.1	615.6
Instrument average power (watts)	60.4	Average power of the instrument in watts		✔	✔	✔	0.2	10.3	27.0	60.4	69.4	594.5
Instrument design life (months)	42	Design life of the instrument in months			✔	✔	4	15	27	42	60	197
Instrument percent new design (%)	65%	Total bus new design in percent from 0% to 100%				✔	30%	60%	70%	67%	80%	100%
WBS 5.1 Instrument 1 Cost at 50% Confidence Level (including DDT&E + TFU)			$44.0	$45.0	$50.7	$46.0	$0.3	$9.1	$20.3	$52.9	$63.8	$588.8
WBS 5.1 Instrument 1 Cost at Specified Confidence Level (including DDT&E + TFU)			$71.7	$73.3	$82.6	$74.9						
Instrument 2												
Instrument 3												

- QuickCost 6.0 automatically produces several estimates of the bus and instruments using several CERs

- Up to 10 instruments can be "un-collapsed"

  - And more can be copied and pasted if needed

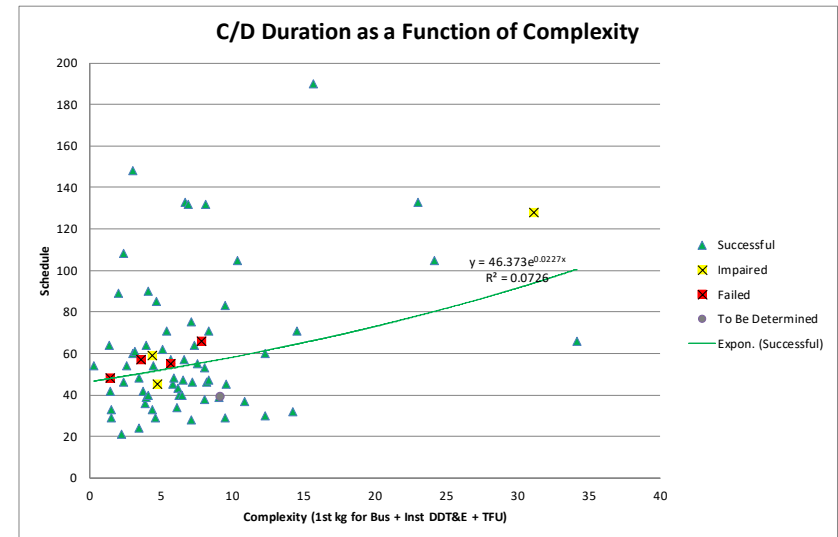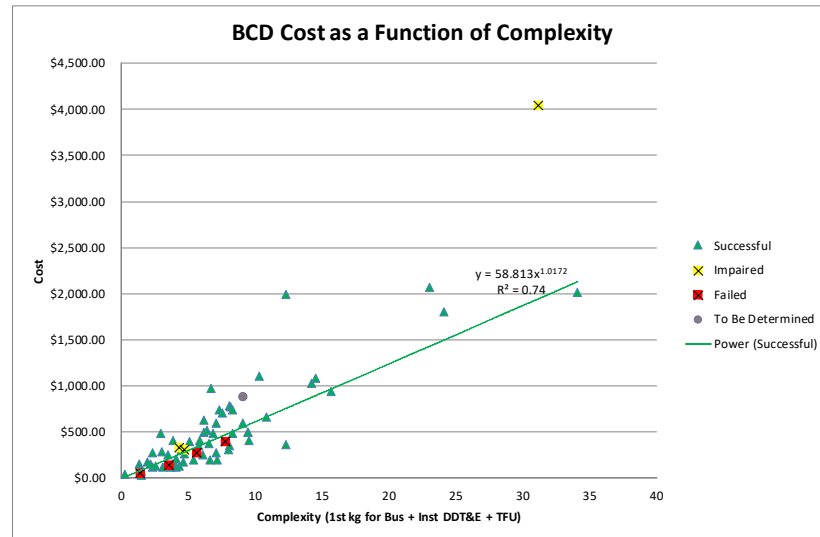# Multivariate NASA General System Estimation (MNGSE) Model

Multivariate NASA General System Estimation (MNGSE)

- Credit to Rey Carpio (ca 2003) for the model name and acronym

- MNGSE is intended to be
  - An in-house NASA version of the Aerospace COBRA Model
  - Will predict probability of mission success based on cost, schedule, mission class and other inputs, and when cost growth is likely to occur or when program's internal estimates are too optimistic
  - Will provide management the ability to determine when a budget and/or schedule has a negative impact on the chances of mission success, or when there is room to cut budgets or schedules while having a minimal effect on risk
  - NASA-specific tool based ONLY on NASA data

MNGSE

GALORATH

BCD Cost as a Function of Complexity

$y = 58.813x^{1.0172}$
$R^2 = 0.74$

Legend: Successful, Impaired, Failed, To Be Determined, Power (Successful)

Cost axis: $0.00 to $4,500.00
Complexity (1st kg for Bus + Inst DDT&E + TFU)

C/D Duration as a Function of Complexity

$y = 46.373e^{0.0227x}$
$R^2 = 0.0726$

Legend: Successful, Impaired, Failed, To Be Determined, Expon. (Successful)

Schedule axis: 0 to 200
Complexity (1st kg for Bus + Inst DDT&E + TFU)

- MNGSE plots any user entered cost and schedule on the cost and schedule MNGSE scatterplots of successful, impaired and failed missions

  - Providing a visual take on the risk of said cost and schedule

- For any user supplied cost and schedule, MNGSE plots the cost and schedule on the MNGSE scatter plots

- And MNGSE displays the confidence level of the user supplied cost and schedule from the QuickCost S-Curves

QuickCost 6.0 Distribution

- Pending re-direction by the CAD, we assume that QuickCost 6.0 is releasable to...

  - Any NASA civil servant

  - Any JPL, APL employees

  - Any NASA support contractor that has an "NASA Access Clause" in their contract

- However, we will provide the model to the CAD for posting on the ONCE Model Portal and leave distribution decisions in the hands of the CAD

- We also will be happy to work with the CAD on a version of the model without cost data for distribute to Prime Contractors if NASA desires

Winding Down….

- QuickCost 6.0 has not yet been field tested so be aware of that

- We (we Galorath) will be doing that in the coming weeks/months

  - And making any revisions/corrections that are warranted (and releasing "6.n" versions)

- We will work with the CAD/Eric Plumer to get QuickCost 6.0 on the models portal in ONCE

Future Work (Chart 1 of 2)

- Add several alternate CERs to the model including…
  - An indicator/dummy variable for heritage (0 minimal, 1 significant) as an alternative to specific "percent new"
  - An indicator for university led missions (0 no, 1 yes)
  - Add an indicator variable for > 4 major partners (0 no, 1 yes)
  - An indicator variable for mission class [1=Technology, SMEX/PI Led/Explorer/New Millennium 2=Discovery, ESSP (Pathfinders), Scout, STP, Earth Probe,   3=New Frontiers 4=Nominal (Flagship)]
  - Add an indicator variable for theme (Heliophysics, Earth Science, Astrophysics and Planetary)
  - Add an indicator variable for lander/rover (0 no, 1 yes)
- Adjust the database cost of JPL and APL planetary missions which missed their launch window and had uncompensated overtime
  - By conservatively estimating the cost of the uncompensated overtime and increasing the reported mission cost by that amount
- Add the capability to procure multiple identical buses and n identical instruments
- Run a sensitivity to ascertain any CER improvements from using Excel Solver and MUPE

Future Work (Chart 2 of 2)

- Eliminate the 4 problematic outliers from the regression (Cassini, Galileo, MSL and RHESSI)--but not the database--and revise CERs

- Use the 4 missions below (which are not in the current database) to check the model and then add these missions to database...

  - CONTOUR (CADRE+, Launched 2002)

  - Messenger (EOM CADRe, Launched 2004)

  - SMAP (LRD, Launched 2015)

  - SWIFT (CADRe+, Launched 2004)