NASA Instrument Cost Model

NICM

Joe Mrozinski
Hamid Habib-Agahi
George Fox

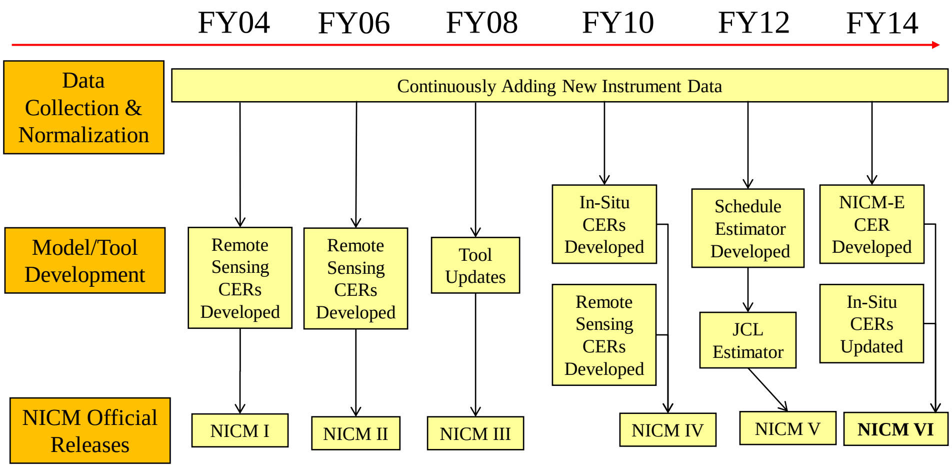
June, 2014

Jet Propulsion Laboratory
California Institute of Technology

NICM Introduction

- NICM is the NASA Instrument Cost Model
  - Parametric cost model for NASA's space flight instruments
    - Operates at the Instrument System and Subsystem Levels
    - Supports Remote Sensing and In-situ instruments
  - NICM is used across all NASA centers and is also available to restricted release to external organizations.
  - Built off 174 previously flow instruments

NICM Evolution FY 2004-2014



Page 3

Current NICM Dataset

- Collected data for 262 instruments
- Normalized database
  - 174 of the 262 normalized
    - 111 remote sensing instruments
    - 49 in-situ instruments
- Remote Sensing Instruments Types:
  - Optical, Active micro/sub-millimeter wave, Passive micro/sub-millimeter wave, Particles, and Fields
- In-situ Types based on instrument mounting:
  - Body, Arm/Mast, Atmospheric Probe.

Page 4

Data Ground Rules & Assumptions

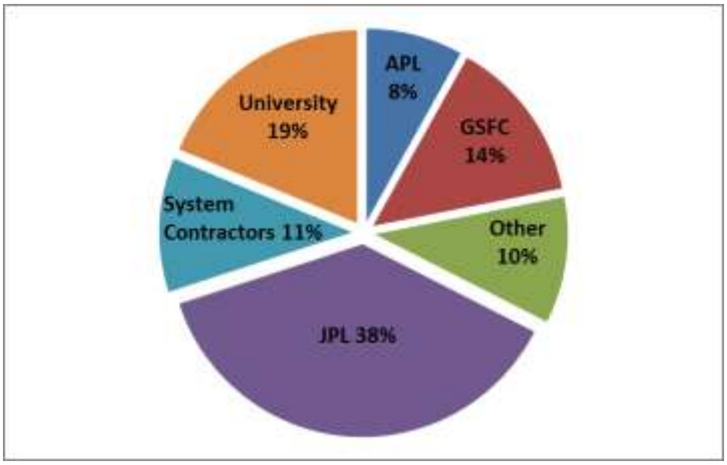
- Includes only instruments launched 1985 and after
- Excludes 100% foreign built instruments
  - However includes some foreign contributed subsystems
- Includes space flight remote sensing and in-situ instruments only
- Includes costs of development summed over phases B,C & D (through Launch + 30 days)
  - Excludes advance studies, pre-phase A and phase A costs.
- Excludes advanced technology development costs
  - TRL 1, 2, 3
- Excludes costs for science teams, ground data development and mission operations.
- Includes only development of 1st unit cost
  - Excludes subsequent modified builds or copies
  - Did not estimate nonrecurring or recurring cost

Data Ground Rules & Assumptions

- Database costs are expressed in FY04 $K. The tools have the capability to express costs in any fiscal year's dollars using the NASA New Start Inflation Indices.
- Full cost accounting practice is assumed for all NASA centers.
- Cost data are assumed to include fee.

NICM Dataset By Instrument Lead Organizations

Total Normalized Instruments: 160



Page 7

Remote Sensing Instrument Types

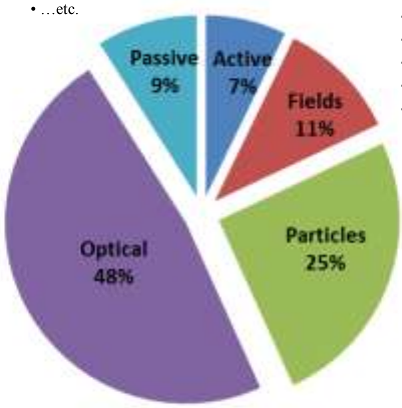
Total Normalize Instruments: 111

- Microwave Radiometer,
- Microwave Imager,
- Microwave Limb Sounder,
- …etc.

- Radar,
- Altimeter,
- Scatterometer,
- …etc.

- Magnetometer,
- Magnetic Field Instrument,
- Electric Field Instrument,
- Plasma Wave Instrument,
- ….etc.

- Camera,
- Spectrometer,
- Infrared Sounder,
- Laser Altimeter,
- Photometer,
- ….etc.

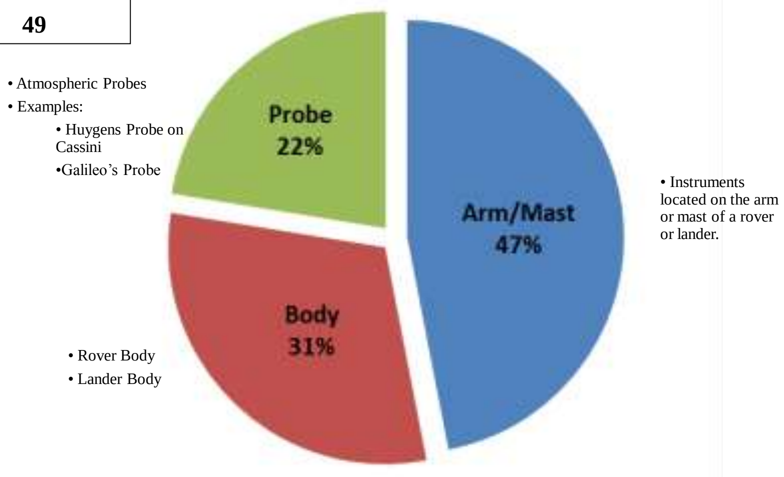


- Particle Detector,
- Gamma Ray Spectrometer,
- X-Ray Imager,
- Magnetospheric Imaging Instrument,
- Plasma Spectrometer,
- ….etc.

Page 8

In-Situ Instrument Mounting Types

Total Normalize Instruments: 49



Page 9

NICM Tool Strengths

- Based on high quality dataset
  - Models validated by statistical analysis
  - Reviewed by subject area experts
  - Complete audit trail and documentation
- Provides probabilistic cost predictions
  - Allows uncertainty for inputs
  - Calculates S-curve for cost & schedule
- Captures Objective Information
  - No adjustable "knobs"
- User friendly database search engine
  - Searches the normalized database for analogy instruments
- Provides Joint Confidence Level (JCL) Analysis

Page 10

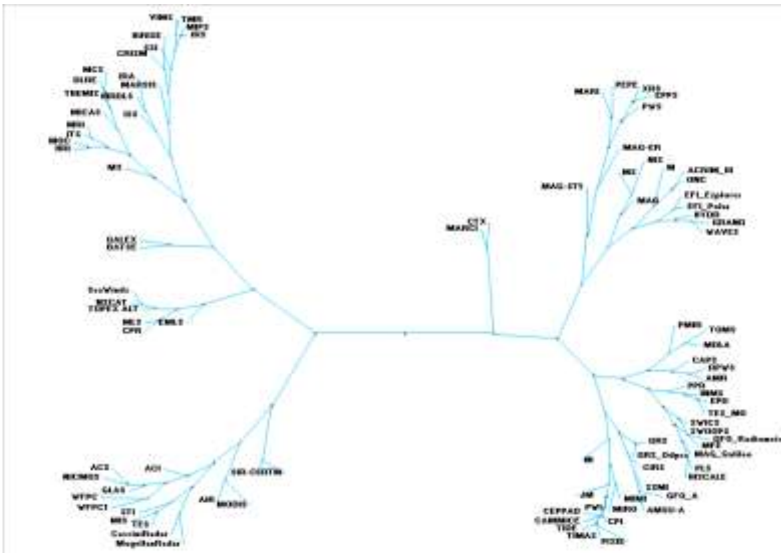
Model Limitations

- NICM VI costing tool does not estimate the following:
  - Airborne instruments
  - Suites of instruments
  - Specialty subsystems, e.g. engineering experiments or demonstrations (e.g. Electra on MRO).
  - Advanced technology developments
  - Nonrecurring or recurring costs
  - Copies/multiple builds
  - Resource estimates, e.g. labor, materials, services, etc.

Methodology

- Cluster Analysis
  - Identifies Instrument Groupings from Attribute Values
  - Assesses Consistency of Groups with Instrument Types
- Principal Components Analysis
  - Standard Data Mining Technique that
    - Finds Significant Cost Drivers from Instrument Attributes
    - Identifies Instrument Data Outliers – Revisit data with technical experts
- Bootstrap Cross Validation
  - *Bootstrap*: Process for generating meaningful statistics without assuming asymptotic normality.
  - *Cross Validation*: Partitioning of data set into training and testing sets. Out-of-sample validation.

Cluster Analysis – Remote Sensing Instrument



Page 13

Bootstrap Cross Validation

- Explanation of “.632” Bootstrap Cross-validation
  - Apply the following procedure for each CER (& associated dataset)
    - Sample *with replacement* from the dataset (using sample size same as dataset)
    - Fit regression model to trial sample selection
    - Predict cost with model for instruments in original dataset that were not selected by trial sampling for testing
    - Repeat above steps 999 times, saving cost deltas for each instrument tested
    - Calculate average model variance (= cost delta^2) for all 999 trials. Average with *apparent error* of original regression. This approximates the prediction error of the original CER.

Instrument #	Trial #1	Trial #2	…	Trial #999
1	//	//	…	$\Delta_{1,999}$
2	/	$\Delta_{2,2}$	…	//
3	/	/	…	$\Delta_{3,999}$
4	$\Delta_{4,1}$	/	…	/
5	//	//	…	///
6	/	/	…	/
7	$\Delta_{7,1}$	$\Delta_{7,2}$	…	$\Delta_{7,999}$
8	/	/	…	/
9	//	/	…	//
10	$\Delta_{10,1}$	/	…	$\Delta_{10,999}$

$$\sigma^2_{(BCV)} = \left(\Sigma_i \left(\Sigma_t \Delta^2_{i,t} / \mathbf{N}_i\right) / |\#\mathbf{I}|\right.$$

$$\sigma^2_{(\text{“632”})} = 0.368\, \sigma^2_{(app)} + 0.632\, \sigma^2_{(BCV)}$$

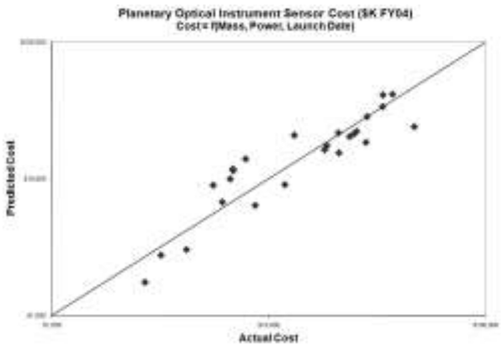
N_i = # of times the instrument was used for testing
#I = Total number of instruments

Page 14

Planetary Optical Instrument CER

Sensor Cost (FY04$K) = 276.7 $Mass^{0.426}$ $Power^{0.414}$ $DesignLife^{0.375}$

$R^2 = 0.76$ PE = 0.46 N = 32



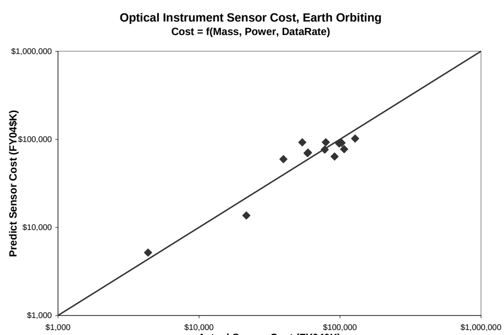
Optical Planetary Instruments in System CER		
CIRS	ITS	ONC
CRISM	MARCI	PMIRR
CTX	MCS	PPR
DLRE	MICAS	SSI
HiRISE	MIPS	TES_MO
HRI	MRI	THEMIS
IRAC	MSI	VIMS
IRS	NIMS	
ISS	NIS	

Page 15

Earth Orbiting Optical Instrument CER

Sensor Cost (FY04$K) = 980 $Mass^{0.328}$ $Power^{0.357}$ $DataRate^{0.092}$

$R^2 = 0.89$ PE = 0.59 N = 13



Optical Earth Orbiting Instruments in System CER		
ACIS	MISR	TOMS
ACRIM III	MODIS	WFPC1
ACS	NICMOS	WFPC2
GLAS	STIS	
HIRDLS	TES	

Page 16

Schedule Estimating Relationship

Schedule (months)

$$= \boldsymbol{A}_{\text{(Mission Type, Instrument Type)}} * \boldsymbol{Cost}^{0.107} * \boldsymbol{E}$$

$R^2 = 0.66$, $\sigma_{Predict} = 0.20$, $N = 148$

where ***Cost*** is in FY04$M and ***E*** is lognormal,
E = exp(ε), where ε is Normal with mean 0 & standard deviation $\sigma_{Predict}$

$\boldsymbol{A}_{\text{(Mission Type, Instrument Type)}}$ =

Instrument Type	non-Flagship Planetary	EO & Flagship Planetary
optical	31.3	43.1
active microwave	34.1	46.9
passive microwave	30.9	42.6
particle	34.0	46.7
fields	35.8	49.3
body	31.3	43.1
probe	39.4	54.1
arm/mast	33.4	45.9

Page 17

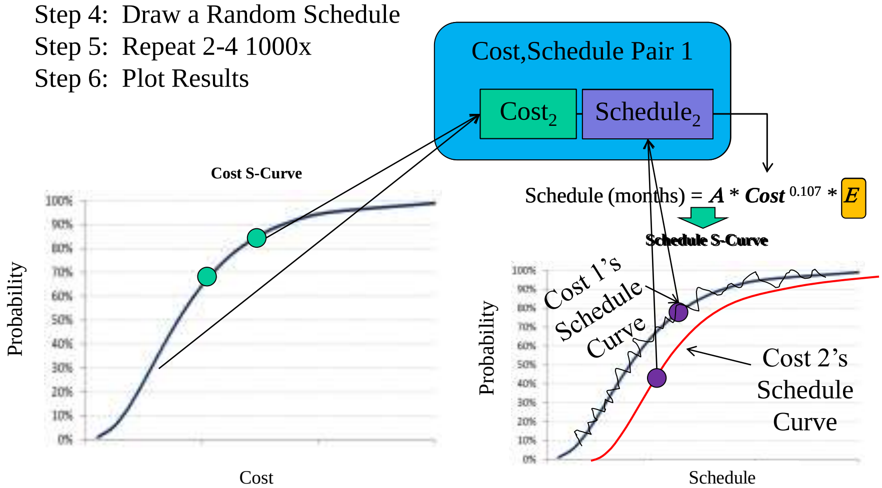
JCL Simulation

Goal: Determine the Joint Probability of building instrument below Cost Cap and Schedule Cap

Page 18

JCL Simulation

Step 1: Run the Cost Estimating Relationship, which yields a Cost S-Curve
Step 2: Draw a Random Cost
Step 3: Plug the Random Cost into the Schedule Estimating Relationship
Step 4: Draw a Random Schedule
Step 5: Repeat 2-4 1000x
Step 6: Plot Results



JCL Simulation

Joint Cost & Schedule Plot