

Mission Operations Cost Estimation Tool (MOCET)

Marc Hayhurst, Shirin Eftekharzadeh, Brian Wood, Vishnu Jyothindran, Robert Kellogg
The Aerospace Corporation

Cindy Daniels, Lissa Jordin, Washito Sasamoto
NASA Langley Research Center

2015 NASA Cost Symposium
25-27 August 2015

Overview



- Introduction
- Development Approach and Database
- Mission Phases
- Model Development
- Validation
- Excel Tool Overview
- Summary

Introduction

- Motivation for a new Phase E Model
 - *Several recent studies on mission operations cost of NASA missions have found significant cost growth exists in Phase E*
 - One study found average growth from the Phase B estimate to be ~50% versus actual*
- Goals for model development
 - *Develop a model with few subjective inputs, which could be used by even inexperienced users*
 - *Investigate whether a cost model could be constructed by breaking the mission operations into phases*
- Mission Operations Cost Estimation Tool (MOCET)
 - *A new capability for Phase E estimation jointly developed by Aerospace and NASA Science Office for Mission Assessments (SOMA)*
 - *Based on actual costs of historical missions with emphasis on competed missions*
 - *Constructed by breaking the mission operations cost into the various phases*
 - *Has few subjective inputs*
 - *Implemented entirely in Excel and requires no additional software or tools*
 - *Also includes a user manual which provides additional instruction and background*

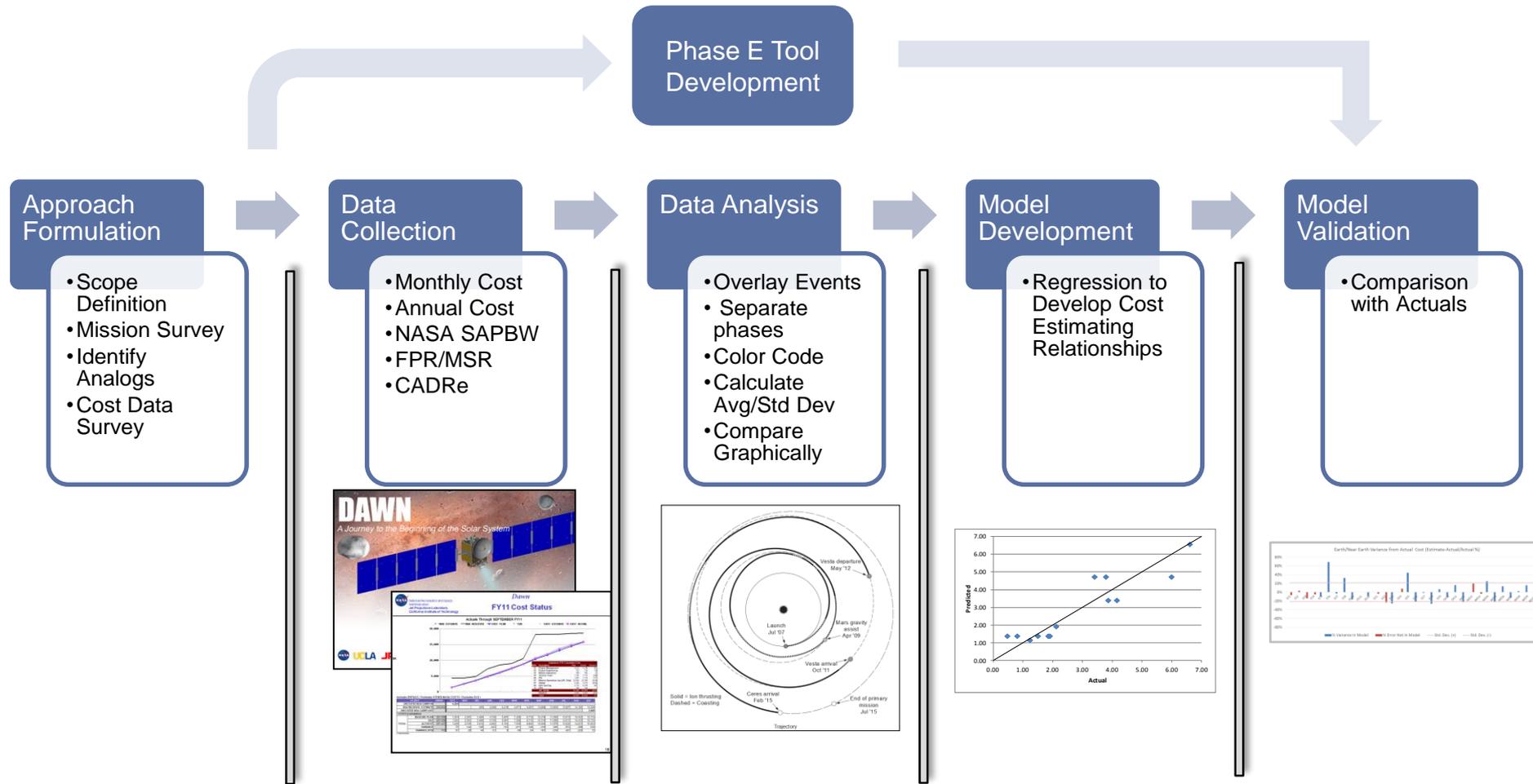
*AIAA-2012-5138: "Phase E Cost Analysis for NASA Science Missions," 2012 R. Bitten, M. Hayhurst, D. Emmons, C. Frenner, and V. Roem

Overview



- Introduction
- Development Approach and Database
- Mission Phases
- Model Development
- Validation
- Excel Tool Overview
- Summary

Development Approach Process Overview



Model Database

- Data Sources consulted and utilized include:
 - *NASA SAP Business Warehouse*
 - Monthly Expenditures
 - *Monthly Flight Project Reviews (FPR) and Monthly Status Reviews (MSR)*
 - Monthly Expenditures, Mission Events & Schedule
 - *NASA Cost Analysis Data Requirements (CADRe)*
 - Project development costs used to assign mission class

Mission/CER Type	Program	Missions
Planetary	Discovery	MESSENGER, Dawn, Stardust, Deep Impact, GRAIL, NEAR
	Mars Scout	Phoenix
	Lunar Quest	LRO
	New Frontiers	Juno, New Horizons
	Mars Exploration	MRO, Odyssey, MER, MSL
Earth Science	Earth System Science Pathfinder (ESSP)	GRACE, CloudSat, CALIPSO, Aquarius
	Earth Systematic Missions (ESM)	ACRIMSAT, Aqua, Aura, Terra, Jason-1, OSTM, ICESat
Explorers	Mission of Opportunity (MO)	Suazku, TWINS, CINDI
	Small Explorers (SMEX)	NuSTAR, IRIS, IBEX, AIM, GALEX, RHESSI
	Medium Explorers (MIDEX)	THEMIS, Swift, WISE
Near Earth Discovery Helio-Astro	Discovery	Genesis, Kepler
	Solar Terrestrial Probes (STP)	STEREO, TIMED
	Living With a Star (LWS)	RBSP, SDO
	Gravity Probe B (GP-B)	GP-B
	Cosmic Origins	Spitzer
	Physics of the Cosmos	Fermi, Chandra

Assumptions

- Cost data is total cost by month
 - *No insight into lower level WBS elements*
 - *Expenditures used to develop models, not obligations*
 - *All monthly data inflated to FY13\$*
- Launch month ignored
 - *Excluded from all missions*
 - *Contains disproportionate and highly variable development costs*
 - *Typically covered by Phase B-D models*
- Cost data matched to actual project events
 - *Events obtained from actual project schedules, monthly reports, and project websites*
 - *Events then overlaid with monthly cost and matched to trends*
 - *Cost data then separated into phases consistently across all missions for model development*
- Model development sought to address as many phases as possible but it was not possible to cover everything
 - *Some phases had too little data or showed no apparent trend*
 - *No attempt was made to address phases with no historical analog (e.g., Mars sample return)*
 - *Tool does allow for a user-defined phase to be input*

Overview

- Introduction
- Development Approach and Database
-  • Mission Phases
- Model Development
- Validation
- Excel Tool Overview
- Summary

Mission Phases in the Model

Planetary

- There were ~18 phases identified among the 14 planetary missions in the data set
 - ■ The model directly addresses 13 of these phases
 - ■ Another 4 are indirectly addressed by overlap with other phases or there was no observable difference in these phases
 - ■ The sample return phase was not addressed due to insufficient data

Phase	Brief Description	MOCET Status	Phase	Brief Description	MOCET Status	Phase	Brief Description	MOCET Status
Cruise	Travel between two celestial bodies.		Flyby /Encounter	The close approach of spacecraft to a celestial body to make detailed observations without orbiting or landing.		Cruise Return	Travel from one celestial body to Earth.	Did not significantly differ from outbound Cruise
Checkout during Cruise	Phase begins immediately after launch. For planetary spacecraft, the checkout typically occurs concurrently with the cruise phase in order to meet the escape trajectory window.		Data Analysis	Analysis of data that occurs after mission operations have ceased.		Gravity Assist	A pass of a spacecraft by a celestial body to gain energy or change trajectory from the gravitational field of that body.	Did not significantly differ from Cruise
Quiescent Cruise	Mode may be employed during extended periods of cruise to reduce mission operations and DSN costs. There are minimal contacts which only allow ground personnel to assess spacecraft health.		Sample Analysis	Analysis of physical samples returned after mission operations have ceased.		Data Retrieval	The act of collecting and returning science data to Earth.	Concurrent with Orbital/Landed/Encounter Operations
Orbit Insertion	Adjustment of a spacecraft's momentum to achieve stable orbit around a celestial body.		Descent Ops	The approach, entry, descent and landing of a space vehicle on the surface of a celestial body.		Sample Retrieval	The act of collecting physical samples for eventual return to Earth.	Concurrent with Orbital/Landed/Encounter Operations
Orbital Operations	All activities taking place while a spacecraft is in stable orbit around a celestial body: navigation, observations/taking of data, transmitting data etc..		First Landed Month	The first 30 days after EDL occurs for landed missions.		Sample Return	Earth approach and collector release and recovery, followed by spacecraft diversion maneuver from Earth.	Insufficient data
Extended Orbital Ops	An extended or renewed orbital operations phase, in which additional science goals beyond the initial prime mission are pursued.		Landed Ops	All activities taking place while a space vehicle is on the surface of a celestial body: rover navigation, observations/taking of data, transmitting data etc..				
			Extended Landed Ops	An extended or renewed landed operations phase, in which additional science goals beyond the initial prime mission are pursued.				

Mission Phases in the Model

Earth Science, Explorers, Near Earth Discovery Helio-Astro

Phase	Brief Description	MOCET Status
Checkout for Earth Science, Explorers, and Near Earth Discovery Helio Astro	Phase begins immediately following acquisition of the spacecraft signal on-orbit after launch and generally lasts from 30-90 days.	
Prime Operations for Earth Science	Phase begins immediately following the checkout phase. During this phase, science data is collected to satisfy the goals and requirements laid out prior to launch.	
Prime Operations for Explorers	Phase begins immediately following the checkout phase. During this phase, science data is collected to satisfy the goals and requirements laid out prior to launch.	
Prime Operations for Near Earth Discovery Helio Astro	Phase begins immediately following the checkout phase. During this phase, science data is collected to satisfy the goals and requirements laid out prior to launch.	
Extended Operations	An extended or renewed orbital operations phase, in which additional science goals beyond the initial prime mission are pursued.	No trend. Extended Ops cost showed both increase and decrease
Data Analysis	Analysis of data that occurs after mission operations have ceased.	Insufficient Data

- Earth and Near-Earth orbiting missions typically have the same ~4 phases
 - *Checkout, Prime Operations, Extended Operations, Post-Mission Data Analysis*
- The Extended Operations and Post-Mission Data Analysis phases are not addressed
 - *No discernible trend was seen in Extended missions*
 - *Too few data points for Post-Mission Data Analysis*

Overview

- Introduction
- Development Approach and Database
- Mission Phases
-  • Model Development
- Validation
- Excel Tool Overview
- Summary

Cost Drivers

- There are numerous cost drivers that can subtly affect the operations cost of any mission such as distinct characteristics of the spacecraft or ground system
- The data set present for the development of this model was best suited for higher level parameters and the tendency was to favor inputs that were simple, objective, and readily available
- Examples of prominent cost drivers found across various CERs in the model include:
 - Mission Class – based on development cost (without ops and contributions) and program (Discovery, Explorers, ESSP etc.)
 - Reflective of staffing and science team size pre and post launch
 - Number of Instruments
 - Reflective of number of data sets and different types of analyses that can be performed

Mission Class

Planetary

Mission Class	NASA Funded Dev Cost*	Planetary Programs	Latest Cost Cap** (\$M)	Example Missions
Medium	<\$400	Discovery Mars Scout	\$450 (FY15 w/o Ops) \$325 (FY03 w/LV/Ops)	GRAIL Phoenix
Large	\$400-\$800	Discovery New Frontiers Directed Survey	\$450 (FY15 w/o Ops) \$800 (w/Ops)	Juno MRO
Flagship	>\$800	Mars Exploration		MER, MSL

*FY13\$M Excludes contributions, launch vehicle and operations costs

**Sources:

1) Discovery 2014 Announcement of Opportunity, as amended

<http://nspires.nasaprs.com/external/viewrepositorydocument/cmdocumentid=438340/solicitationId=%7BFE7B4C63-873D-63C1-4D15-1D46E2FEA949%7D/viewSolicitationDocument=1/discovery-2014-amend1.pdf>

2) <http://newfrontiers.larc.nasa.gov/index.html>

3) <http://www.nasa.gov/centers/langley/news/releases/2002/02-090.html>

Mission Class

Earth Science, Explorers, and Near Earth Discovery Helio Astro

Mission Class	NASA Funded Dev Cost*	Programs	Latest Cost Cap** (\$M)	Example Missions
Micro	<\$60	Missions of Opportunity (MO) Earth Venture-Instrument (EVI) Earth Systematic Missions (ESM)	\$55 \$90 for all selected	Suzaku ACRIMSAT
Small	\$60-\$120	Earth Venture-Instrument (EVI) Small Explorers (SMEX) Earth Systems Science Pathfinder (ESSP) Earth Systematic Missions (ESM)	\$90 for all selected \$120	TEMPO GALEX GRACE SORCE
Medium	\$120-\$400	Earth Venture-M Medium Explorers (MIDEX) Explorers (EX) Earth Systems Science Pathfinder (ESSP) Earth Systematic Missions (ESM) Discovery Solar Terrestrial Probes (STP)	\$150 \$180 \$200 \$450 (FY15 w/o Ops)	CYGNSS Swift TESS CloudSat ICESat Genesis TIMED
Large	\$400-\$800	Earth Systematic Missions (ESM) Discovery Solar Terrestrial Probes (STP) Living With a Star (LWS) Physics of the Cosmos (PCOS)	\$450 (FY15 w/o Ops)	LDCM Kepler STEREO SDO Fermi
Flagship	>\$800	Earth Systematic Missions (ESM) Cosmic Origins (COR) Physics of the Cosmos (PCOS)		Aqua, Aura Spitzer Chandra

*FY13\$M Excludes contributions, launch vehicle and operations costs

**Sources:

1) Explorers: <http://explorers.gsfc.nasa.gov/missions.html>; Explorers (EX) class specified FY11 dollars and excludes the launch vehicle. Missions of Opportunity (MO) on a no-exchange-of-funds basis. Year dollars unspecified for all others and includes launch and operations.

2) Earth Science: <http://nspires.nasaprs.com/external/>

Announcement of Opportunity NASA's Second Stand Alone Missions of Opportunity Notice (SALMON-2). FY14 dollars, excludes launch vehicle and integration to platform costs. Includes operations.

Announcement of Opportunity Earth Venture – 2 Released June 17, 2011; Amended September 1, 2011. FY14 dollars, Includes launch vehicle and operations.

3) Discovery 2014 Announcement of Opportunity, as amended <http://nspires.nasaprs.com/external/viewrepositorydocument/cmdocumentid=438340/solicitationId=%7B7BFE7B4C63-873D-63C1-4D15-1D46E2FEA949%7D/viewSolicitationDocument=1/discovery-2014-amend1.pdf>

MOCET Cost Estimating Relationships (CERs)

Planetary

CER Name	Equation	Inputs	R^2	SEE
Cruise CER	$Y = 1.2869^{MC} * 2.7334^{CO} * 0.6501^Q$	MC = Mission Class (1 Medium (Discovery), 2 Large (New Frontiers, Directed Survey)) CO = Checkout (0 No, 1 Yes), Q= Quiescent Ops (0 No, 1 Yes)	0.76	31.9%
Approach/Orbit Insertion/Reduction CER	$Y = 1.3111^{MC} * 1.0914^{Mo}$	MC = Mission Class (1 Medium (Discovery), 2 Large (New Frontiers, Directed Survey)), Mo = Months of Approach/Orbit Insertion/Orbit Reduction or Aerobraking (1 to N)	0.96	16.2%
Orbital Operations CER	$Y = 1.1072^{MC} * 1.1420^{OB} * 1.0455^{NI}$	MC = Mission Class (1 Medium (Discovery), 2 Large (New Frontiers, Directed Survey)), OB = Orbiting Body (1 Moon, 2 Asteroid, 3 Mercury, 4 Mars) NI = Number of Instruments (1 to N)	0.75	26.4%
Extended Orbital Ops CER	$Y = P * (-0.236 * \ln(N) + 0.8443)$	P = Prime mission average monthly cost, N = Number of times the mission is being extended or renewed (1 to N)	0.94	7.2%
Extended Landed Ops CER	$Y = P * (-0.209 * \ln(N) + 0.6128)$	P = Prime mission average monthly cost, N = Number of times the mission is being extended or renewed (1 to N)	0.99	3.1%
Flyby/Encounter	$Y = C * 1.90$	C = Estimated Preceding Cruise Phase Cost	0.98	8.8%
Approach EDL	$Y = C * 1.08$	C = Estimated Preceding Cruise Phase Cost	0.97	13.3%
First Landed Month	$Y = C * 1.12$	C = Estimated Preceding Cruise Phase Cost	0.97	13.1%
Landed Prime Operations	$Y = C * 0.76$	C = Estimated Preceding Cruise Phase Cost	0.70	31.0%
Data/Sample Analysis & Archiving	$Y = C * 0.75$	C = Estimated Preceding Prime Collection Phase Cost	0.99	5.6%

*Y = Average Monthly cost for phase (FY13)

MOCET Cost Estimating Relationships (CERs)

Earth Science, Explorers, and Near Earth Discovery Helio Astro

CER Name	Equation	Inputs	R ²	SEE
Earth Science, Explorers, and Near Earth Discovery Helio Astro Checkout CER	$Y = P * 1.95$	P = Prime mission operations average monthly cost	0.90	29.7%
Earth Science Prime Operations CER	$Y = 0.5338 * MC^{0.8868} * 0.7546^{IO} * NI^{0.1814}$	MC = Mission Class (0.25 Micro, 1 Small, 2 Medium, 6 Flagship) IO = Instrument Only (0 No, 1 Yes) NI = Number of Instruments (1 to N)	0.98	24.2%
Explorer Prime Operations CER	$Y = 0.4219 * MC^{0.6599} * ST^{0.4775} * NI^{0.1917}$	MC = Mission Class (0.25 Micro (MO), 1 Small (SMEX), 2 Medium (MIDEX)) ST = Science Therme (1 Heliophysics, 2 Astrophysics) NI = Number of Instruments (1 to N)	0.80	24.6%
Near Earth Discovery Helio Astro Prime Operations	$Y = 0.3071 * MC^{0.8717} * ST^{0.9699} * NI^{0.5718}$	MC = Mission Class (2 Medium, 3 Large, 6 Flagship) ST = Science Therme (1 Heliophysics, 2 Astrophysics) NI = Number of Instruments (1 to N)	0.94	20.6%

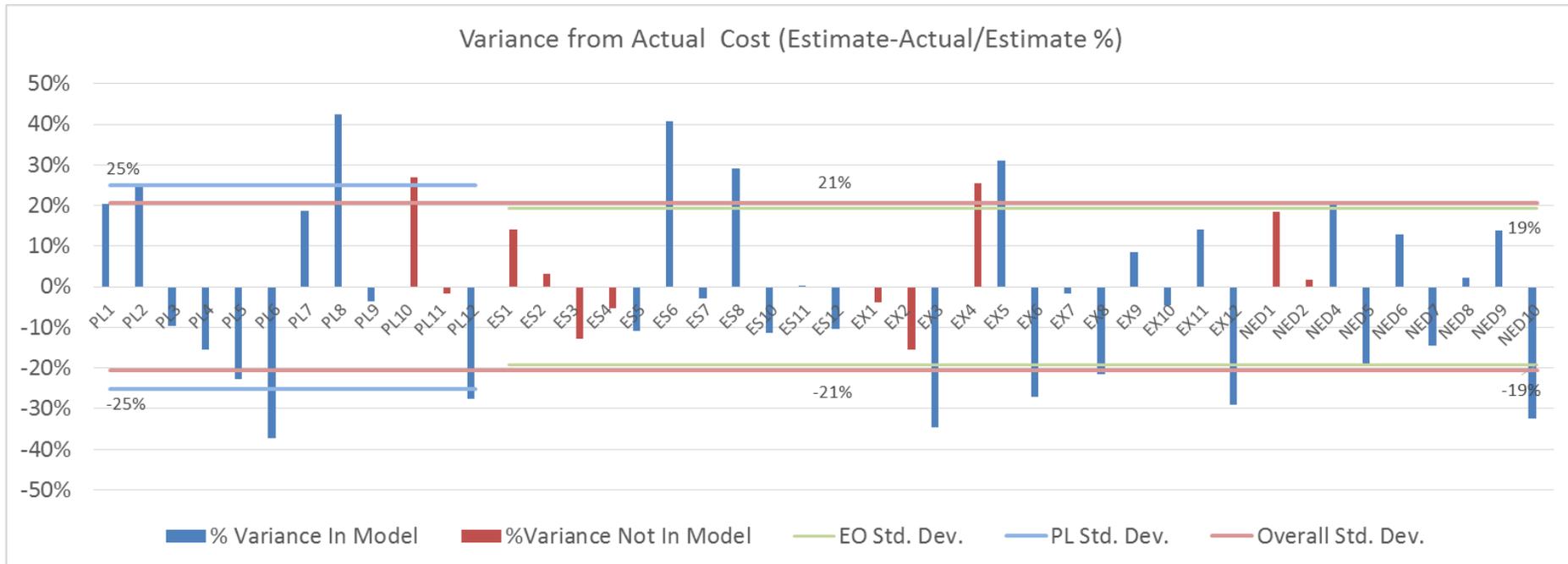
*Y = Average Monthly cost for phase (FY13)

Overview

- Introduction
- Development Approach and Database
- Mission Phases
- Model Development
-  • Validation
- Excel Tool Overview
- Summary

Model Performance

- The model was compared against actual mission costs to gauge performance
 - *Both missions inside and outside of model development were included since data is limited*
 - *Standard Deviation for all missions was found to be 21%*
 - Planetary: 25%
 - Earth/Near Earth: 19%



Overview

- Introduction
- Development Approach and Database
- Mission Phases
- Model Development
- Validation
-  • Excel Tool Overview
- Summary

Mission Operations Cost Estimation Tool (MOCET)

- The MOCET workbook is
 - *A tool for building missions as collection of CERs*
 - *Implemented entirely in Excel, no additional software or tools are required*
 - *Runs on Windows now, and a Mac version is in progress*
- MOCET workbook features include
 - *Fast and scalable, handling missions with many phases*
 - *Graphs, including all generated graph data*
 - *Support for inflation and real-year costing*
 - *Integrated documentation included in the workbook*
- MOCET has 7 main worksheets

Mission Operation Models

Graphs

Graph Data

Mission Class Guide

Phase Definitions

Planetary CERs

Earth & Near Earth CERs

- **Mission Operation Models:** *Main worksheet to enter data*
- **Graphs:** *Displays results in graph format*
- **Graph Data:** *Summary of model results used to generate graphs*
- **Mission Class Guide:** *Details for users to help with mission classification*
- **Phase Definitions:** *Details regarding each phase of operations*
- **Planetary CERs:** *Describes functional relationships used in tool for Planetary missions*
- **Earth & Near Earth CERs:** *Describes functional relationships used in tool for Earth Science, Explorer, & Near Earth Discovery Helio-Astro missions*

MOCET Screen Shots

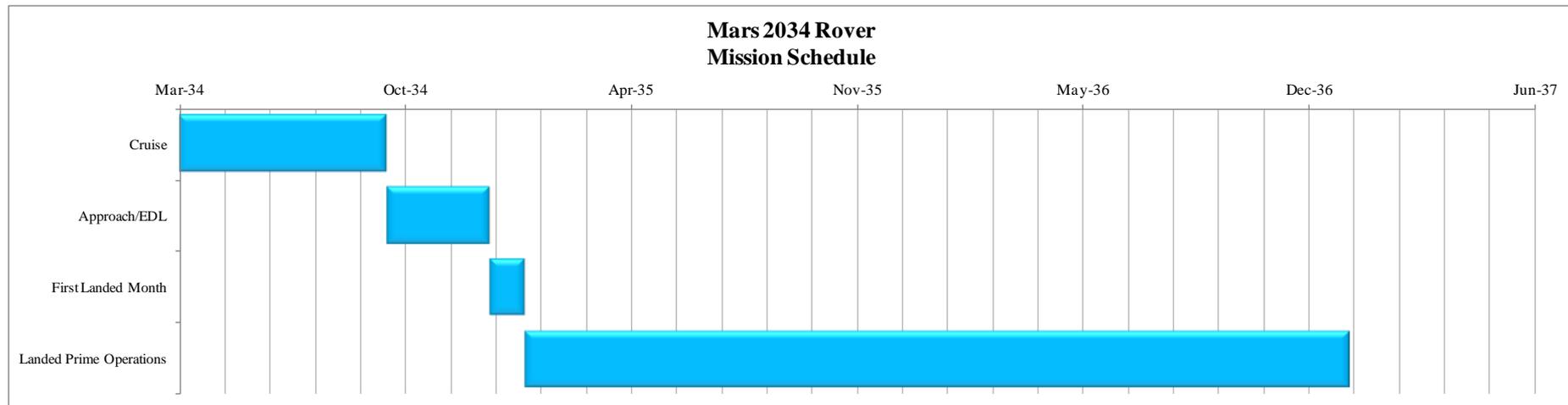
1 of 2



NASA Mission Operations Cost Estimation Tool

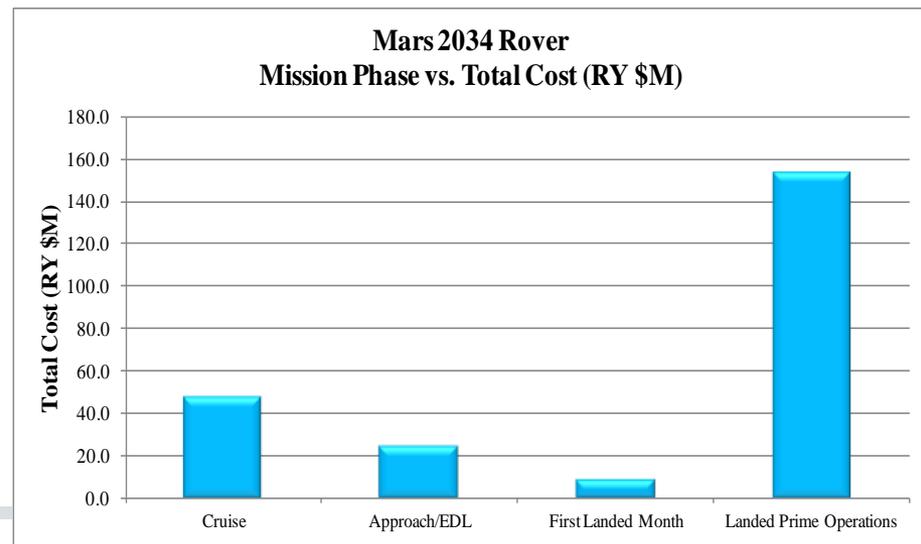
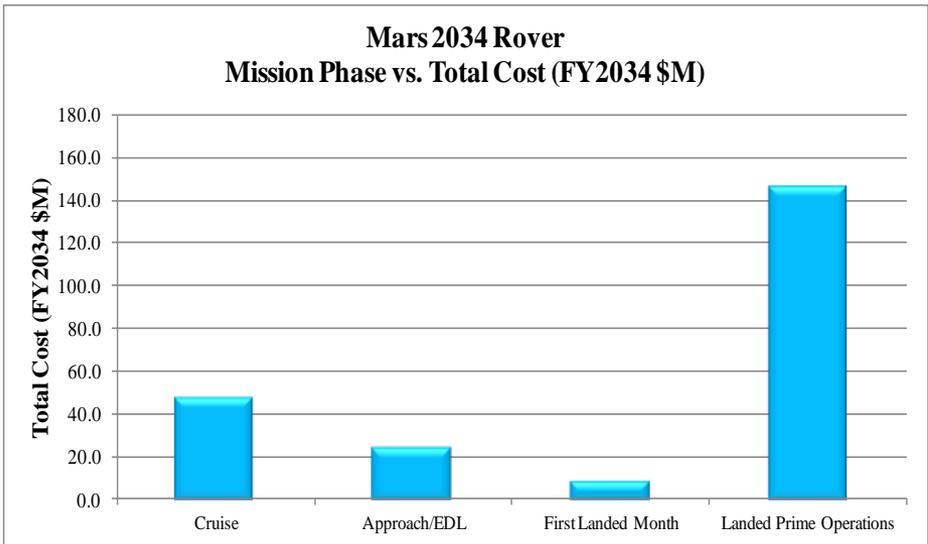
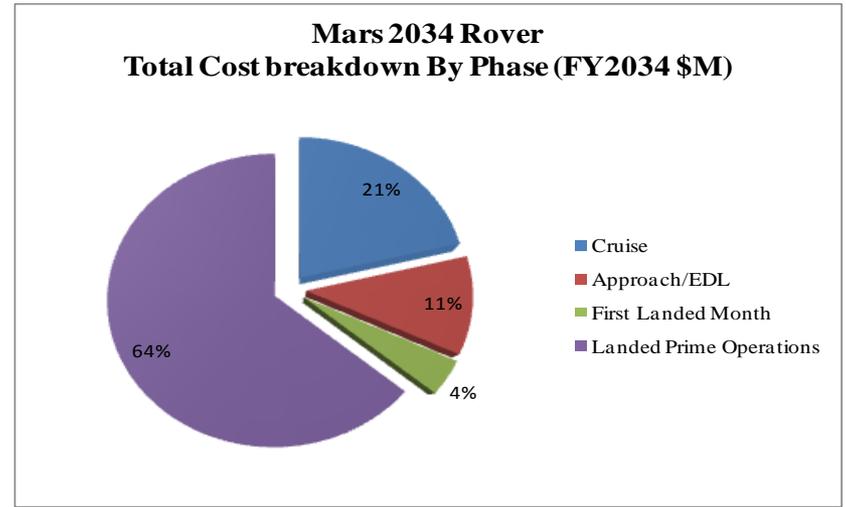
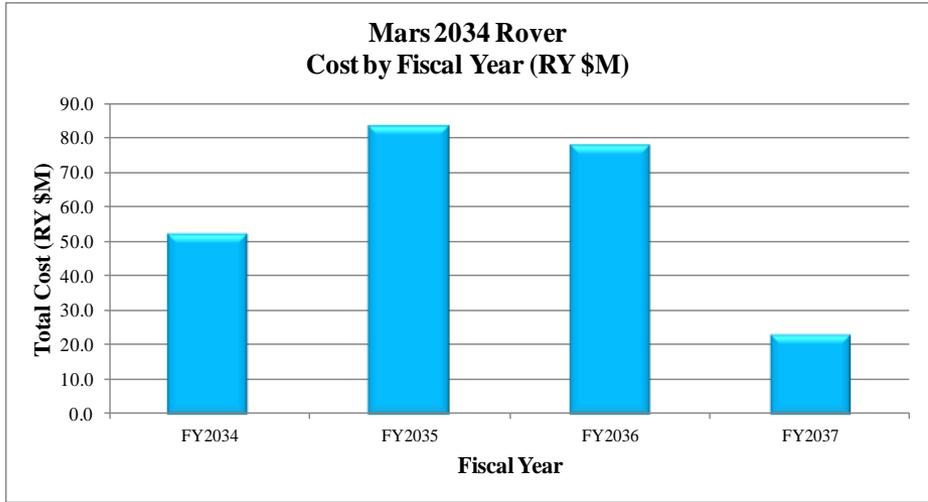
Mission Type	Planetary			Legend:	Apply
Mission Name	Mars 2034 Rover			Input	
Mission Class	Large (New Frontiers, Directed Survey)	Inflate Costs To:	FY2034	Calculated/Read-Only	
Num Instruments	5			Invalid/Incomplete	
				N/A	

Phase Description	Phase Start	Duration (months)	Estimating Phase	Parameter 1	Value 1	Parameter 2	Value 2	Cost/Mo (FY34 \$M)	Total Cost (FY34 \$M)	Total Cost (RY \$M)	Notes
Cruise	03-16-2034	6.0	Cruise	Checkout?	Yes	Quiescent Period?	No	7.98	48.28	48.28	
Approach/EDL	09-16-2034	3.0	Approach/EDL	Cruise Avg Cost	Cruise			8.30	24.83	25.08	
First Landed Month	12-16-2034	1.0	First Landed Mo	Cruise Avg Cost	Cruise			8.95	9.12	9.35	
Landed Prime Operations	01-16-2035	24.0	Prime Landed Ops	Cruise Avg Cost	Cruise			6.07	145.75	153.16	
End of Mission	01-16-2037							Total	\$ 227.98	\$ 235.87	



MOCET Screen Shots

2 of 2



Overview

- Introduction
- Development Approach and Database
- Mission Phases
- Model Development
- Validation
- Excel Tool Overview
-  • Summary

Summary

- A new mission operations cost model was developed from actual costs of historical missions
- The model is constructed by breaking the mission operations into the various phases
- The model also has objective inputs and is suitable for even inexperienced users
- Initial validation results for prime phases mission show positive results
- The model may be used by evaluators for future proposal evaluations
- The model will be released publicly via the Model Portal on ONCE website for proposers to use to develop and/or validate their mission operations estimates