"COST MODELING FOR LOW-COST PLANETARY MISSIONS"

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ABSTRACT

Flight science missions often generate observational challenges requiring the use of state-of-the-art technologies and designs. The types of flight science instruments, the associated measurements, and observational data products for remote and in-situ sensing missions are often unique. These requirements drive the designs and technologies being used, frequently with significant cost impacts.

Beyond the technology and new engineering challenges to develop a low-cost planetary mission, a key step is to develop a sound business case to secure the budget required for the mission. Credible cost models will play a vital role in performing cost/schedule trade-offs analysis so that senior management can make the appropriate go/no-go decision for the mission. The NASA Jet Propulsion Laboratory (JPL) has been developing life cycle cost models to support the Lab's senior management in achieving this goal.

This presentation will provide attendees an overview of the JPL parametric cost models used to estimate flight science spacecrafts and instruments. This material will emphasize the cost model approaches to estimate low-cost flight hardware, sensors, and instrumentation, and to perform cost-risk assessments. This presentation will also discuss JPL approaches to perform cost modeling and the methodologies and analyses used to capture low-cost vs. key cost drivers. Included will be lessons-learned for current and future flight science mission cost modeling. Further, it will present Cost Estimating Relationship (CER) development and methodologies envisioned for future low-cost planetary mission cost-model development.

1. OVERVIEW

Since the Mariner era, JPL has successful managed, developed, and operated several planetary missions; these missions include both directed (non-competed) and competed missions.

A directed mission is a sole-source mission that does not go through the competition (proposal) process. During the early 1960's, when cost was not a decision factor, directed missions did not have a cost ceiling (or cost cap). Typically, these missions were extremely complex; that is, the spacecraft and instruments were often designed with new engineering and technology. These missions, therefore, normally had a moderate to long development cycle. The missions developed under what was then referred to as the "business as usual" (BAU) environment.

During the early 1990, the federal government advocated it design-to-cost/affordability initiatives. NASA responded by launching a new paradigm to develop low-cost missions: the faster, better, cheaper (FBC) era was born. Most of the missions developed ~ post 1992 were competed through the Announcement of Opportunity (AO) process wherein they were assigned a strict cost cap. The cost cap varied by NASA program office. To fit within the cost cap, the missions were much less complex and more inherited engineering and technology were used. Thus, the FBC missions normally had a much shorter development cycle. Figure 1 and Figure 2 present the development and operations cost history [1] for the JPL planetary missions from 1960 to 2005.

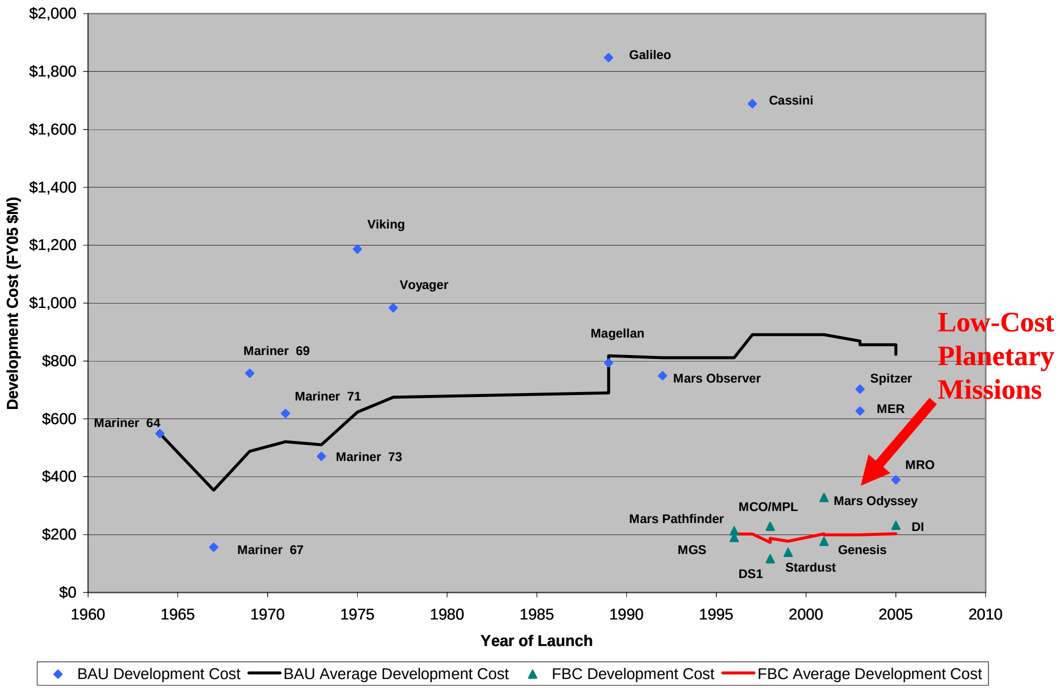
2. JPL LOW COST PLANETARY MISSIONS

Data from Figure 1 and Figure 2 indicates that JPL low-cost planetary missions (LCPM) normally have an average development cost of ~ $200M and an average annual operations cost of ~ $10M. The average development time is ~ three (3) years, while the operations time is ~ five (5) years.

Figure 1 and Figure 2 further indicate that the JPL LCPM are mostly competed missions with a cost under ~ $400M. Examples of competed LCPM are: Mars Pathfinder, Deep Space 1 (DS1), Stardust, Genesis, and Deep Impact (DI). Figure 3 presents the cost caps by NASA program office. It shows that these competed LCPM fall within the $400M cost cap and that a majority of them fall under the Discovery Program.

2.1 LCPM Characteristics

The JPL LCPM have three key characteristics of the FBC missions. First, the mission is normally less complex, with no multiple objectives: i.e., the mission has focused science objectives, resulting in fewer instruments and a smaller science team. Also, the system does not have multiple flight elements and functionalities and does not operate in harsh environments.



Note: Cost excluding launch vehicle; BAU: Business As Usual; FBC: Faster, Better, Cheaper

Fig 1. Planetary Mission Development Cost

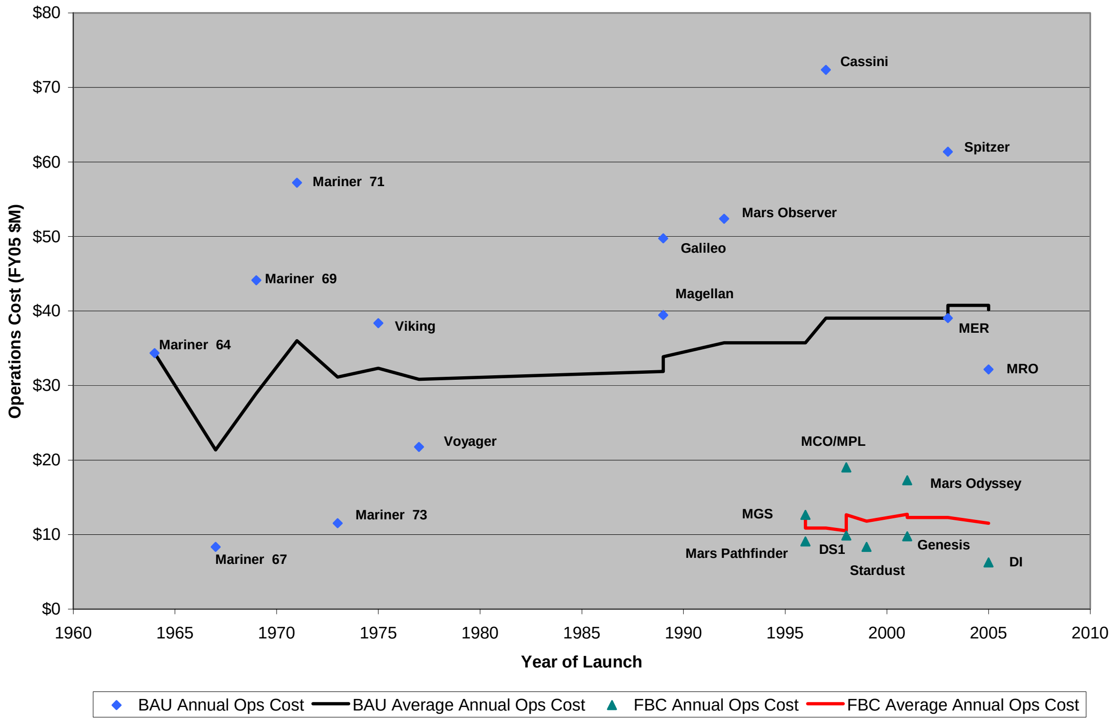


Fig 2. Planetary Mission Operation Cost

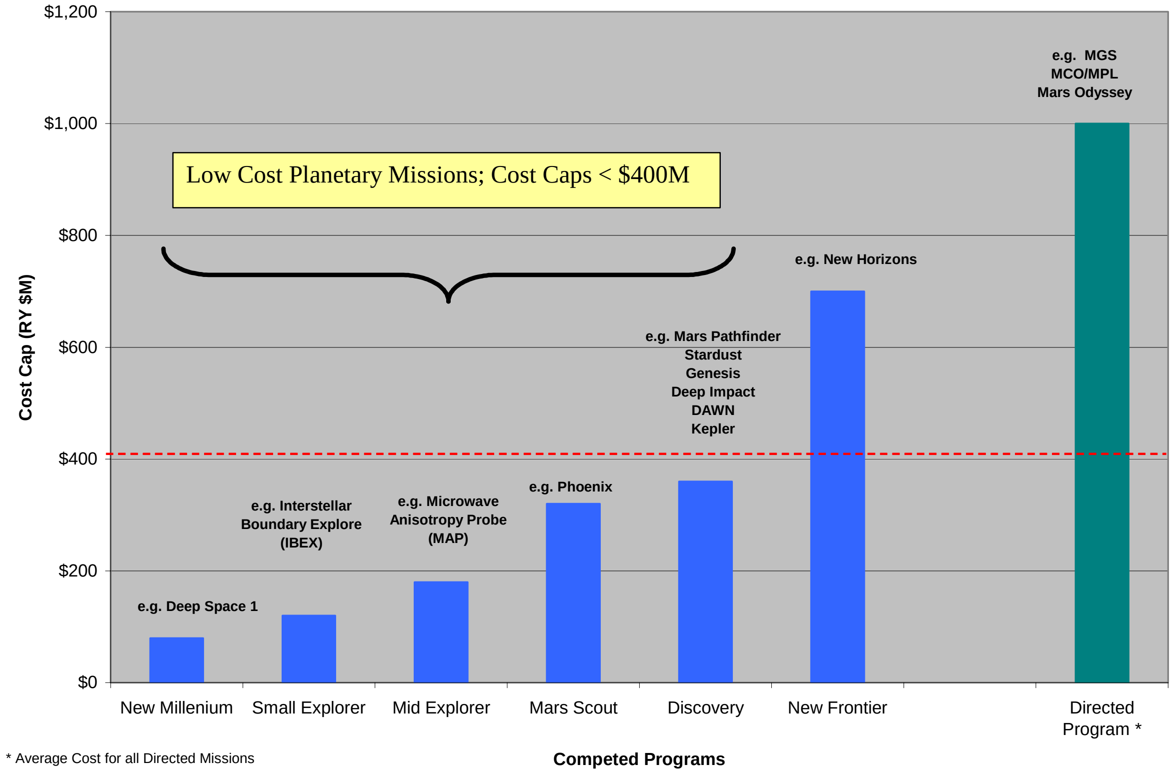


Fig 3. Cost Cap by NASA Program Office

Second, the flight system is designed and developed using inherited engineering and technology; i.e., it minimizes using system design with TRL < 5 and new or unvalidated software inheritance. Essentially, these missions used technology inherited from previous missions and off-the-shelf equipment.

Third, as a result of the #1 and 2 characteristics discussed above, the JPL LCPM missions had greatly reduce the development cycles. With strategic stockpile and common buy for long-lead items, and descope options in place, the JPL LCPM methodology helps ensure a short development cycle.

2.2 Key Factors to Reduce Total Mission Cost

The three key characteristics of the LCPM discussed in Section 2.1 are also the key factors in reducing total mission cost. To reduce total mission costs, the system must not be too complex and must not have new/significant technology development and/or a long development cycle.

In addition, the mission must minimize new system architecture (i.e., level 1 requirements must be defined early in the formulation phase) and must minimize ACS modes and deployments and pointing control reliability requirements using state–of-the-art technology. The mission should take advantage of the design-to-cost concept and information technology during design and development: for example, conduct concurrent engineering; design trades between cost, schedule, performance, and risk; apply a model-driven design process, automated fabrication from models, and continuous integration and testing. The mission should be managed by an experienced team, including the project manager and key project personnel. The mission must also use qualified and experienced prime contractors and limit the numbers of organizational interfaces. Finally, the project office should establish realistic technical and cost margins.

JPL has conducted an internal study [2] to identify cost risk factors that could cause a mission to overrun. The missions selected consist of contracted and in-house missions that are ongoing, recently launched, or approaching launch. The study identified eight (8) cost risk factors and their cost impacts if they are not properly monitored and mitigated. Table 1 presents the historical cost overrun by mission based on the number of cost risk identified.

To manage a successful low-cost planetary mission, the project management must control the cost risk factors as identified in the study.

Table 1. Key Cost Risk Drivers

Cost Risk Factors	Msn 1	Msn 2	Msn 3
Complex Mission			Yes
New/Significant Technology Development	Yes		
New S/W Development			Yes
Low Technical Margin			
New System Architecture		Yes	Yes
Inexperience Contractor/Capabilities Match		Yes	Yes
Inadequate Programmatic Cost and Schedule Margin	Yes		
Inexperience Mgmt Team		Yes	Yes
Cost Overrun	15%	35%	50%

3. COST MODELING FOR LCPM

Increasingly, JPL must operate in a competitive environment, wherein project cost is a significant factor for NASA decision makers. Accurate, timely, and defensible cost estimates are needed in JPL's planning of science roadmaps and acquisitions of new work.

3.1 JPL Formal Cost Estimation Process

JPL has a formal cost estimation process (see Figure 4.) requiring the use of a standardized Work Breakdown Structure (WBS), extensive reviews by the project team, including NASA/industrial partners, and the development of multiple estimates by independent sources outside of the project.

The engineering cost estimate is performed by the implementing organization (i.e., the project/proposal team, including industry partners) using the grassroots cost estimating methodology that begins with the project cost guidelines, the JPL Standard WBS, and the WBS dictionary to capture all activities and products of the mission technical baseline. Each WBS element is assigned to a WBS element manager in the respective technical area; the WBS element manager must develop the schedule and determine staffing requirements and other possible costs based on metrics and recent program histories.

Project management cost estimation is a top-level cost estimate performed by the management responsible for the work and/or by the Costing Office. This estimate is usually based on analogy and/or parametric cost estimation methods.

Internal reviews (S/C and instrument peer reviews) are conducted at JPL and each partner organization before their estimates were submitted to the project office.

A project team conducts cost reconciliation between the engineering cost estimate and the project management cost estimate to ensure that they are current, accurate, and complete before they are submitted for program-level reviews.

Program reviews include two Technical, Management; and Cost (TMC) reviews that not only challenge the cost estimates directly, but also the bases of estimate and technical inputs — including cost risk — that drive the cost estimate.

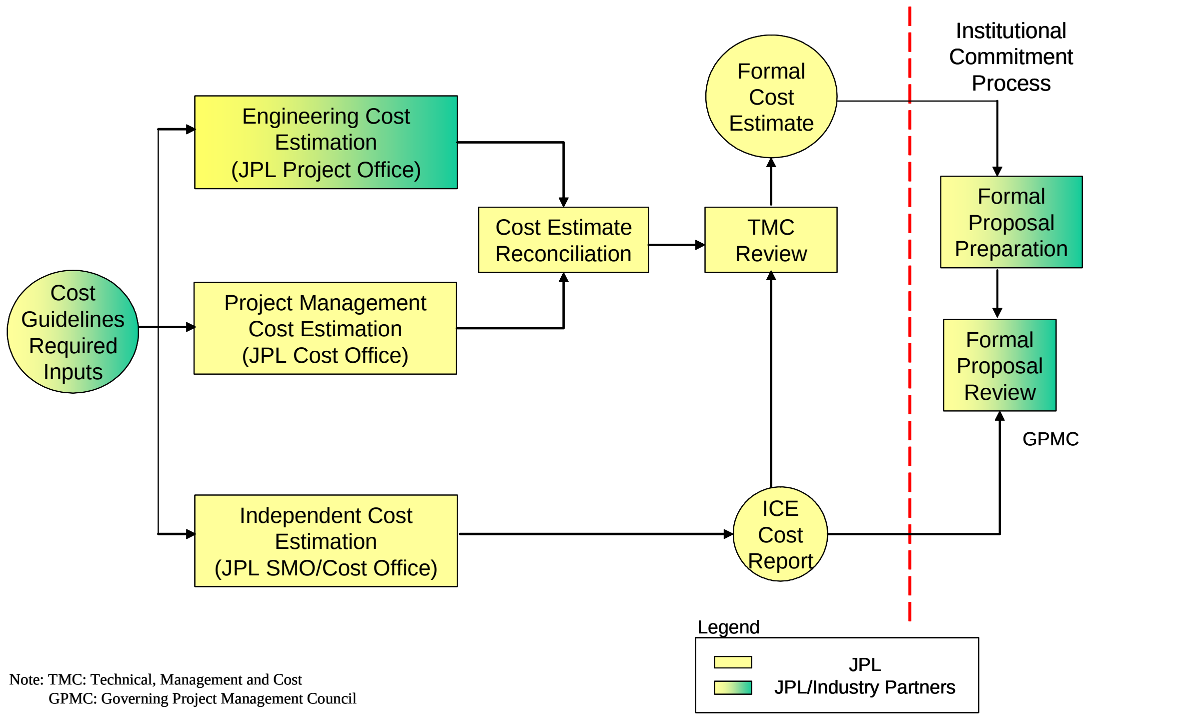


Fig 4. JPL Formal Cost Estimation Process

In addition to the organizational and project reviews, the cost estimates are further compared and reconciled with independent cost estimates (ICE) generated by sources outside a project. Once all parties have approved the cost estimates, the resulting grassroots estimate is submitted for final institutional commitment.

3.2 Cost Estimating Methods and Tools

Cost estimates are also key inputs during trade studies to determine the most cost-effective mission architectures and system designs. State-of-best-practice (and continuously improving) cost modeling methods and tools are thus essential for NASA's strategic goals, engineering excellence, and other customer requirements.

Under the JPL Formal Cost Estimation Process, the engineering cost estimate is developed using the grassroots methodology. However, the project management estimate and the independent cost estimate are used as crosschecks to ensure that the engineering cost estimate is reasonable and realistic. Therefore, these two cost estimates are normally developed using parametric and/or analogy methodologies. Depending on the cost estimating methods, different cost tools can be used to develop the cost estimate. Table 2 provides a matrix of cost estimating methods vs. the cost tools that may be used for that methodology.

Table 2. Cost Estimating Methods and Tools

Methods/Tools	Cost Models	Cost Databases	Concurrent Engineering
Parametric	Yes	-----	Yes
Analogy	-----	Yes	Yes
Grassroots	-----	Yes	Yes

Typical cost tools used by JPL include the following:

Cost Models:

- PMCM (Planetary Mission Cost Model)
- NICM (NASA Instrument Cost Model)
- PRICE (Parametric Review of Information for Costing and Evaluation)
- SEER (Systems Evaluation and Estimation of Resources)

Cost Databases:

- System Cost Database
- Subsystem Technical Cost Database
- Proposal Cost Analysis Tool (PCAT)

Concurrent Engineering:

- Team X (Advance Product Design Team)
- Team P (Instrument Design Team)
- Team G (Ground System Design Team)

As indicated in Table 2, cost models primarily apply to parametric cost estimation; Cost databases can be used to develop analogy and grassroots estimates; concurrent engineering can be applied to all three methods because the teams normally use a combination of cost tools to develop their estimates.

3.3 Cost Modeling Approaches

Cost modeling is a systematic approach to analysing a program or a project that is supportive and quantifiable. Cost modeling plays a vital role in developing the project management and the independent cost estimates under the JPL Formal Cost Estimation Process. It performs an unbiased check and balance of the project engineering (grassroots) cost estimate and provides confidence to the senior management to make the appropriate go/no-go decision for the mission. Thus, the selection of the appropriate cost model to use for a particular project is an important consideration in the cost estimating process.

Cost modeling primarily uses parametric cost estimating methodologies. Parametric cost modeling estimates cost based on historical data and mathematical expressions relating cost as the dependent variable to selected, independent, cost-driving variables through regression analysis. The implicit assumption of this approach is that the same forces that affected cost in the past will affect cost in the future. The underlying "math engine" of a cost model is the cost estimating relationship (CER).

CER relates cost as a function of technical parameters (cost drivers) such as weight characteristics and design complexity. The following CER functions are examples extracted from the JPL Planetary Mission Cost Model (PMCM) and the NASA Instrument Cost Model (NICM).

PMCM CER functions to estimate spacecraft cost:

- ACS = f (pointing knowledge, mass, # of h/w types, heritage of design)
- C&DH = f (mass, processor speed, heritage of h/w types, S/W design)
- Power = f (power source type, solar array type, beginning of life power, battery size)
- Propulsion = f (propulsion type, specific impulse, mass)
- Structure = f (mass, # of types of mechanism, # of mechanism)
- Telecom = f (power, s/c antenna diameter, downlink data rate, bands, mass, redundancy)

NICM CER functions to estimate payload cost:

- Optics = f (mass, schedule, wavelength, electronic # of bands, TRL, max power)
- μwave = f (mass, schedule, power, TRL)

- Fields = f (mass, power, design life)
- Particle = f (mass, power, data rate)

System level cost elements — for example project management, system engineering, integration & test, and product assurance — use a more simplistic form of a CER: These elements are normally estimated as a percentage of the spacecraft and payload hardware costs.

In addition to the JPL cost models, proven/popular cost models outside the lab are also used as a sanity check of the project grassroots cost estimate. Table 3 and Table 4 present key mission and instrument cost models that were widely accepted by NASA and the aerospace industry. Please note that not all of the cost models are applicable to estimating planetary missions.

Table 3. Project Mission Cost Models

	Sponsor/Developer/ Applications		Cost Estimating Level	Users
PMCM	JPL	Planetary Mission	System/ Subsystem	JPL
Team X	JPL	Planetary Mission	System/ Subsystem	JPL
NAF-COM	NASA/ Air Force/ SAIC	Planetary/ Earth Orbiting Mission	System/ Subsystem	NASA/ Air Force/ Industry
SEER	Galorath, Inc	Planetary/ Earth Orbiting Mission	System/ Subsystem/ Any lower level	NASA/ Air Force/ Industry
PRICE	Price Systems, Inc	Planetary/ Earth Orbiting Mission	System/ Subsystem/ Any lower level	NASA/ Air Force/ Industry
USCM 8	Tecolote Research, Inc	Earth Orbiting Mission	System/ Subsystem	NASA/ Air Force/ Industry
SSCM	The Aerospace Corporation	Earth Orbiting Mission	System/ Subsystem	NASA/ Air Force/ Industry

PMCM: Planetary Mission Cost Model
Team X: Advanced Product Design Team Cost Model
NAFCOM: NASA/Air Force Cost Model
SEER: Systems Evaluation and Estimation of Resources
PRICE: Parametric Review of Information for Costing and Evaluation
USCM 8: Unmanned Spacecraft Cost Model, 8th Edition
SSCM: Small Satellite Cost Model

4. CONCLUSIONS

JPL has the expertise and experience in developing low cost planetary missions (LCPM). Based on JPL historical data, LCPM are mostly competed missions with a strict cost cap However, the FBC era also produced a few LCPM directed missions. In this presentation, we have described the characteristics of the low-cost planetary mission and provided key factors to reduce total mission cost. To succeed, a project must closely monitor and mitigate these cost drivers so as to avoid cost overruns.

Cost modeling is vital to developing a credible cost estimate. JPL has successfully implemented the formal cost estimation process to support senior management in making key decision on project selection. Proven cost estimating methods and tools are in-place, so quick turnaround design cost trades can be performed to develop the best business case analysis for the Lab. Finally, cost modeling can be more efficient with the support from system engineers to capture the cost modeling drivers.

Table 4. Instrument Cost Models

	Sponsor/Developer/ Applications		Cost Estimating Level	Users
Tech/ Science	JPL	Planetary/ Earth Orbiting Mission	System/ Subsystem/ Any lower level	JPL
Team X	JPL	Planetary/ Earth Orbiting Mission	System/ Subsystem/ Any lower level	JPL
SICM	Goddard Space Flight Center	Planetary/ Earth Orbiting Mission	System/	NASA/ Industry
MICM	Goddard Space Flight Center	Planetary/ Earth Orbiting Mission	System/	NASA/ Industry
NAF-COM	NASA/ Air Force/ SAIC	Planetary/ Earth Orbiting Mission	System/	NASA/ Industry
PSCM	Air Force/ Tecolote Research, Inc	Earth Orbiting Mission	Subsystem	Air Force/ Industry
NICM	NASA/JPL	Planetary/ Earth Orbiting Mission	System/ Subsystem	Air Force/ Industry

Tech/Science: Technology/Science Instrument Cost Model
Team X: Team X Instrument Cost Model
SCIM: Scientific Instrument Cost Model
MICM: Multi-variable Instrument Cost Model
NAFCOM: NASA/Air Force Cost Model
PSCM: Passive Sensor Cost Model
NICM: NASA Instrument Cost Model

References

1. Rosenberg L.R., *Parametric Cost Modeling of Unmanned Deep Space Missions in the New DNP Environment*, 31st ADODCAS, Williamsburg, VA, USA, 1998.

2. Habib-Agahi H., and Lum K., *Mission Cost Risk and Reserves Study*, JPL, Pasadena, CA, USA, 2003.