Rapid Turnaround of Costing/Designing of Space Missions Operations

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The Ground Segment Team (GST), at NASA's Jet Propulsion Laboratory in Pasadena, California, provides high-level mission operations concepts and cost estimates for projects that are in the formulation phase. GST has developed a tool to track costs, assumptions, and mission requirements, and to rapidly turnaround estimates for mission operations, ground data systems, and tracking for deep space and near Earth missions. Estimates that would often take several weeks to generate are now generated in minutes through the use of an integrated suite of cost models. The models were developed through interviews with domain experts in areas of Mission Operations, including but not limited to: systems engineering, payload operations, tracking resources, mission planning, navigation, telemetry and command, and ground network infrastructure. Data collected during interviews were converted into parametric cost models and integrated into one tool suite. The tool has been used on a wide range of missions from small Earth orbiters, to flagship missions like Cassini. The tool is an aid to project managers and mission planners as they consider different scenarios during the proposal and early development stages of their missions. The tool is also used for gathering cost related requirements and assumptions and for conducting integrated analysis of multiple missions.

I. Introduction

Every year JPL prepares large numbers of proposals in response to NASA Announcements of Opportunity, NASA directed studies, and in support of outside organizations requesting the use of JPL managed resources. In the past all of these proposals would take weeks for the ground system cost estimates to be completed, and would tie up multiple engineers from different disciplines. To further complicate matters the mission concept would frequently evolve and require significant changes to the estimate during the course of the early design phase. Clearly if JPL wanted to be able to quickly provide quality cost estimates for multiple ongoing proposals, something needed to change.

II. The need for rapid costing of mission operations

A. Turning weeks into minutes

In response to this challenge a more rapid and consistent approach requiring fewer people was developed that would enable the rapid turnaround of grassroots-like estimates and to support rapidly changing mission requirements. The solution was the formation of the Ground Segment Team (GST). The team is responsible for the coordination and cost modeling of the different elements that make up the ground system, also referred to as the Mission Operation System (MOS), at JPL. GST contains a core group of systems engineers along with representatives from subsystems involved in the ground system. They were tasked with implementing an integrated suite of models that would allow proposals and projects to cost their Mission Operations in a short amount of time.

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Cost models existed for some elements and required integration into the suite, and other elements required models to be developed. The model developed and integrated together created a single suite of parametric models that has been used for proposal cost estimation, trade studies, and has served as a common point of reference for internal negotiations on the MOS design and cost. This integrated model concept reduced the number of points of contact in mission operations and allows JPL to run study sessions with only one operator interfacing with the project or proposal representatives.

B. Defining Mission Operations

One of the more difficult aspects of costing mission operations is the proper definition of the scope and functions of the ground system to be used for proposals and projects. Usually project managers, proposal managers, principal investigators, and scientists have a limited or incomplete understanding of mission operations (especially for deep space missions). Deep space missions at JPL are generally characterized with the following attributes: long round-trip light times (minutes to hours), high autonomous operations, stressing spacecraft resource constraints, very tight navigation requirements, infrequent contacts (daily/weekly), low data rates with long communication passes, and use the in-high-demand NASA Deep Space Network. These characteristics have brought about the need for functions either not typically needed or as rigorously handled for many Earth orbiting missions.

An example of the differences between expectations versus reality can be found in two examples. First are the differences associated with operations for a deep space mission versus a simple Earth-orbiting mission. Often when working on deep space missions, we interface with proposal managers and scientists whose understanding of what an MOS architecture and cost should look like, is based on the Earth-orbiting example. However, simple Earth-orbiting missions have little navigation, few maneuvers, simple pointing requirements, and have significantly greater spacecraft resources available. These features result in simpler, streamlined mission operations. This difference often can lead to holes in the costing of the MOS and provide misleading expectations.

The second example stems from a proposal where an engineer estimating the MOS had worked on a similar mission and was trying to determine the number of computer workstations that they would need for the proposed mission. The engineer decided to count the number of workstations they saw in the mission operations room. They came up with a rough number and then brought this information to GST to verify. They were frustrated when GST came up with a number that was three times their estimate. They did not realize the workstations required during ATLO, the workstations required by engineers who were not in the operations room, and workstations that ended up being delivered to scientists for testing instrument sequences.

For purposes of our proposals and projects in general, GST defines mission operations with the following areas:

Telemetry and Command
Ground Network Infrastructure
Spacecraft Operations
Instrument Operations
Mission and Science Planning
Sequencing
Data Management

Each mission will use these areas in various degrees based on the requirements and scope of the mission. Simpler missions such as a single instrument mission conducting a sky survey may not require a separate designation for Instrument Operations but a large deep space mission such as Cassini may require multiple centers and special coordination functions. This definition is important, as it is the basis around which the cost models were designed.

III. Building the Tool

A. Building the individual models

The first step for building the tool was to work with domain experts of the various elements that make up the MOS at JPL and understand how they did their grassroots cost estimation. The models would be parametrically based as traditionally practiced in systems engineering[1]. The interview process involved asking the domain experts to come up with the complexity factors that they consider when determining cost. Often we would come up with over generalizations for complexity. Such as stating if the mission is like Cassini it will be three Full-Time-Equivalent (FTE) for 12 months and for a mission like Deep Impact it will be one FTE for 8 months. This over generalization was not useful because it did not capture the essential characteristics that affected staffing decisions, what is it about one mission that required different staffing than another mission. Was it just the mission duration, or number of instruments, perhaps the complexity of the instruments, or the amount of conflicts over limited resources, etcetera. In general we found that there were specific factors that could be identified to come up with a scaling factor for sizing the different types of missions. Some of the factors would include: number and type of instruments, number of science partners, data rates, scenarios of day to day operations, and sequence operating length. These factors would be weighted to come up with an overall scale for the subsystem for the mission and would be applied to adjusting the various staffing levels of the subsystems.

To develop the initial suite over twenty engineers were interviewed to cover the subsystems of the MOS. The process of interviewing and developing the individual models took over twelve months with a staff of three. Over fifty models were created ranging from a model that estimated the number of workstations, to a model that estimated the workforce needed for operating an imaging instrument on a Mars orbiter. In certain cases, some models had already been built. One example of this is the cost model for utilizing the Deep Space Network. In such a case, we simply integrated these already-existing models into the tool suite.

B. Integrating into a Single Suite

Integrating the models into a single suite had many benefits. The obvious benefit was creating a single common input questionnaire for all of the models, thus reducing data entry errors in entering the same values across multiple models. This also provided a central set of questions that could be provided to a proposal team that help bound the MOS concept and usually required the proposal team to address issues they would not normally consider until much later in the design. It also provided one central location for the assumptions made that generated cost estimates.

Spacecraft Settings		
Spacecraft Type	Carrier SC Only	
Number of Craft	1	Qty
Number of Rovers	0	Qty
Number of Landers	0	Qty
# of different Telecom Links	2	Qty
Deployable Probe	0	Qty
Average Autonomy	Moderate	
Interactivity of Instruments	Med	
Power	Solar	
Propulsion	Mixed	
Science Interactivity Level	Med	
Spacecraft Stabilization	3-axis	
Conflict Level	Some Conflicts	
SC Systems TestBeds	1	Qty
Sequence Process Duration	1 Month	
Cruise Tracking	3	Passes/Week

Figure 1. *Sample of model inputs*

Another major benefit was that it provided improved visibility of the coupling across different elements that were not always obvious to proposal teams showing how their design decisions rippled across MOS subsystems. A final significant benefit was that it created a single cost of the MOS for the mission quickly and easily.

Microsoft Excel has long been a tool used at JPL for developing cost estimates. A single worksheet is used for entering all of the information for the mission, and then several visual basic scripts are run to produce an output. The outputs of the tool are in workforce estimates with both real year and fiscal year dollars. The tool also outputs a month-by-month estimate of labor over the full lifecycle of the mission as well as a phase-by-phase summary.

Labor Dollars ($K)		Phase A	Phase B	Phase C		Phase D			Phase E	Total
Phase Summary ($M)				Design	Fabrication & Assembly	Subsystem I&T	System I&T	Launch Ops		
	Phase Durations	5	10	11	3	4	11	4	6	54
07	MOS	$ -	$ 0.36	$ 0.97	$ 0.36	$ 0.47	$ 1.91	$ 0.80	$ 0.77	$ 5.63
09	GDS	$ -	$ 0.52	$ 1.83	$ 0.57	$ 0.81	$ 2.49	$ 1.04	$ 0.38	$ 7.63
	Procurements	$ -	$ 0.03	$ 0.31	$ 0.02	$ 0.60	$ 0.24	$ 0.06	$ 0.07	$ 1.33
	DSN	$ -	$ -	$ -	$ -	$ -	$ -	$ 1.07	$ 5.27	$ 6.34
	Travel									$ -
	Phase Totals	$ -	$ 0.91	$ 3.11	$ 0.94	$ 1.87	$ 4.64	$ 2.97	$ 6.50	$ 20.94
		Total	$ 20.94	$ 14.59						

Figure 2. *Sample of a hypothetical model run*

The tool instantly produced several benefits for proposals, project managers, and staff. First, cost estimates are generated faster, which allows for consideration of several design possibilities in one session. Second, since the tool outputs workforce in a month-by-month view, it allows projects to consider different schedules in order to maximize staff effort. For JPL upper management it allowed them to have a common view of the cost estimates across multiple proposals. Perhaps the greatest benefit was that the tool forced proposals to understand how their design decisions were impacting operations earlier in the design and costing process.

C. Difficulty of Validating the Models

The models developed were based upon a grassroots cost estimation process and needed to be validated by the domain experts in the context of real missions and against historical data. The models in the costing suite were validated in three ways. The first was to generate cost estimates for several mission scenarios, break the results out for the individual element models and have the domain experts validate the results. The second and more difficult validation was to compare the results of the tool against historical missions. The goal of the outputs was to have the cost be between -10% and +30% of the actual cost. The difficulty in validating the models lay in several areas. First was adapting the historical data into a form that had sufficient resolution to compare costs. This was complicated by the fact that historical costs were coarse, combined elements within the MOS, and often included non-MOS activities. Then we had to take into account changing business practices, and new functions that were added since the original mission flew. Finally, NASA and JPL has shifted to more conservative staffing levels since NASA's "faster, better, cheaper" paradigm of the nineties. The team was able to choose three missions to validate, Mars Exploration Rover, Deep Impact, & Genesis. Finally, the models were also compared against grassroots estimates of the recent proposals.

IV. Tool as a Part of the Costing Process

A. Part of the process

It is an important aspect to recognize that the tool would not be successful if it did not have approval from key stakeholders and if it did not have a strong process around the costing of missions operations. One of the keys to the process was the formation of a team to facilitate the process. That team is JPL's Ground Segment Team (GST). The team is made up of a small core of systems engineers who are familiar with Mission Operations as well as a larger group of domain experts. The core team is the primary contact for the proposals and projects.

B. Interview –> Kick-off –> Sign-off

The first step of the costing process is scheduling an initial interview for the proposal. At this meeting the core team runs through the questions in the model and delivers an initial cost estimate. Often the tool will force them to answer key questions that have not come up in their design discussions such as the data rates of individual instruments, the schedule for ATLO, or the duration of primary versus secondary science. This phase is where the time savings has taken place and where a lot of work has been saved. Instead of the proposal having to interface with twenty engineers in order to come up with the first estimate they work with a GST engineer to come up with an estimate before moving on to a larger group. Often a lot of the questions that would be raised by the larger group would be answered in this first step.

Once the requirements have been defined and the tool generates the initial cost estimate, the second step of the process starts with GST bringing in the domain experts to walkthrough the mission and the cost estimate. The domain experts each have the estimate for their particular area in front of them at the meeting and they are able to see the answers to the questions from the tool. The domain experts then ask questions that were not covered under the tool, as well as offering suggestions to help reduce cost or improve design. The experts then send the core team the updates and they put them together before sending the final results to the proposal team. There may be follow up questions or concerns but often most of the work has been done.

The end result of the tool and process combination is significant savings in time and effort for MOS cost estimation. The domain experts who used to be tied up with individual proposals for days can now handle multiple proposals over a few hours. GST coordinates the meetings, distributes the data and results, and handles early estimates. The core GST is dedicated to the costing process, focused solely on handling multiple projects and proposals at once. For example, during the NASA Discovery and Scout competitions in 2006, the GST was able to handle over twenty proposals from JPL and across NASA during a four-month window.

V. Future – Design

The original suite is focused on handling the MOS for deep space mission. This has worked so well that GST has moved into developing models for Earth orbiting missions. The building of a model for Earth orbiting mission has its own unique challenges. There are more possibilities for ground communications, more possibilities for using "off the shelf" systems, as well as multiple possibilities for operations centers. Initial models have been created which uses a complete JPL solution, but the team is looking into building models that can use industry systems as well.

GST is also starting to develop design tools that will work in conjunction with the cost estimating tools and other tools to create documents that can be used in proposals. Initial work has been used in integrating designs from Microsoft Visio and inputs from the cost tool in Excel.

Another area in the cost modeling on which the team is working is creating a better platform for the tool suite. While Excel has been excellent multi-platform tool for initially building the suite, it does have its limitations and Microsoft has ended its support of Visual Basic for the Apple Macintosh platform. Thus GST is building a web based platform that integrates the cost models and also allows for better documentation of comment, tracks the history of the changes to the inputs and negotiations as the proposal process moves along, and the easy comparison across proposals and missions. Initial prototypes have been created and have been met with success[2]

VI. Conclusion

The creation of GST and the associated suite of cost estimation tools has saved significant labor, improved general responsiveness to changes, and provided a more consistent handling of the MOS in proposals. The use of GST and models has not impacted proposal creativity and does enable more structured negotiations across the entire MOS to find mission specific savings.

Appendix

A. Key Terms and Definitions

GST – Ground Segment Team
NASA – National Aeronautics and Space Administration
MOS- Mission Operations System
GDS - Ground Data System
ATLO – Assembly, Test, Launch and Operations
FTE - Full Time Equivalent

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