Proven Innovations & New Initiatives in Ground System Development

Reducing Costs in the Ground System

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The state-of-the-practice for engineering and development of Ground Systems has evolved significantly over the past half decade. Missions that challenge ground system developers with significantly reduced budgets in spite of requirements for greater and previously unimagined functionality are now the norm. Making the right trades early in the mission lifecycle is one of the key factors to minimizing ground system costs. The Mission Operations Strategic Leadership Team at the Jet Propulsion Laboratory has spent the last year collecting and working through successes and failures in ground systems for application to future missions.

I. Introduction

A concerted effort has been made over the past year at the Jet Propulsion Laboratory (JPL) to understand cost drivers for mission operations and to find effective means to lower those costs. The Mission Operations Strategic Leadership Team (MOSSLT) was formed, in part, to investigate and provide leadership to address this challenge. The MOSSLC functions as a strategic planning, advisory, vetting, and advocacy board for mission operations and is comprised of line and program managers from mission operations-contributing and stake-holding organizations who serve as representatives for identifying and addressing issues of strategic importance in the area of mission operations. The effort to address mission operations costs has included reviewing previous studies, collecting lessons learned, examining past trade decisions and their eventual outcomes, and analyzing cost data. Michael K. Jones was the Principal Engineer supporting this task, this paper's author is the MOSSLT lead.

A. Ground System

The Ground System, commonly referred to as the Mission Operations System (MOS) at JPL, plans, controls, monitors, and analyzes the activities of the flight system and payload and delivers mission data collected to the science and other users. The MOS consists of ground-based hardware and software, ground networks, facilities, and trained operations personnel and their plans and procedures. The scope of the MOS is from the ground-based antennas (typically those of NASA's Deep Space Network) through the uplink and downlink operations systems at JPL, contractor, and science-sites. The MOS is typically divided functionally into twelve "elements" comprised of operations teams and their subsystem tools as illustrated in Figure 1.

Typical MOS elements include Mission and Science Planning, Sequencing, Command Processing, Mission Monitoring, Telemetry Data Processing, Tracking Data Processing, Flight System Analysis, Data Management and Archiving, Navigation, and Science Data Processing. Some missions, depending on size and mission needs, combine two or more generic elements into a single element (e.g., planning and sequencing). Typically, element leads are responsible for developing their tools, plans and procedures and for certifying element operations personnel as properly trained and prepared for flight operations. At JPL, reuse of multimission ground software is in the 70% – 95% range.

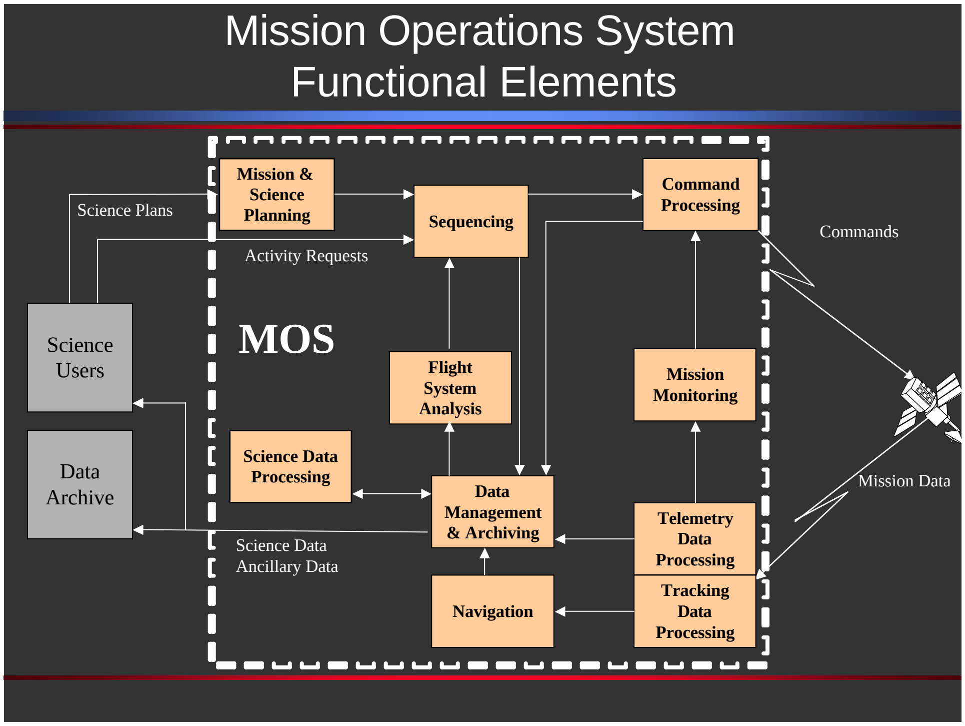

Figure 1. Mission Operations System Functional Elements

II. Mission Operations Cost Drivers

Studies and cost analyses have made clear that highest leverage operations cost drivers are outside of the Mission Operations Systems, either in the design of the mission, project risk posture, spacecraft design, or science objectives, which lend themselves to trade studies early in the lifecycle of the mission. The major driver is the actual design of the mission including mission objectives, mission duration, science goals that drive the duration, complexity and intensity of science operations. Flight system design is the second largest major driver including spacecraft complexity and operability and number, complexity, and competing observation and pointing requirements among instruments. The most human-intensive elements in the MOs, which are generally the most costly, include the spacecraft, navigation, and depending on mission type, sequencing elements. Table 1 lists the significant cost drivers on the MOS.

Mission Operations Cost Drivers

Flight System operability
- Number of commandable states
- Onboard tables requiring frequent update
- Number of telemetry channels
- Number of data rates
- Articulating devices
- Size of onboard data storage
- Onboard memory management
- Telecom link margin
- Thermal margin
- Power margin

Science and Engineering Activities
- Number of science and engineering activities
- Response time to late change or tweak request
- Timing accuracy
- Number of instrument pointing activities
- Real-time vs. sequenced activities
- Real-time vs. playback data

Number of instruments
- Independent fields of view
- Constraints on pointing of instruments
- Pointing accuracy

Antenna tracking requirements
- Antenna racking costs
- Antenna conflict resolution with other Projects

Time to uplink sequence or real-time commands
Number of spacecraft
Duration of operations phase
Duration of science gathering phase
Number and experience of operations partners
Complexity and intensity of science operations
Density of events in the mission timeline
Propulsive maneuver frequency, criticality, and accuracy
Number of objects that require ephemeris
Number of and complexity of flight rules
Time to downlink stored data
Geographical distribution of ops personnel
Number of science teams
Flight system robustness to faults
Sequence development and execution time
Number of consumables and margin constraints

Table 1. Mission Operations Cost Drivers

III. Targeted Trade Studies – A Potential Solution

Addressing MOS costs early in the lifecycle of the mission is key to reducing overall operations costs including both operations development and operations execution costs. Table 2 lists some of the key trades that should be considered during formulation and early development phases.

Trade	Considerations
Spaceflight resource margins vs. operations complexity	More spaceflight resource margin reduces operations complexity (increases operations flexibility), but it also increases spaceflight development cost and complexity (e.g., mass)
Spaceflight operability vs. operations complexity and cost	Operations complexity for each engineering subsystem. More complex engineering subsystems increase MOS complexity and cost
Multimission capability vs. Project-dedicated capability	Multimission capability can reduce MOS development cost, but it also can reduce operations flexibility
Sequencing and real-time commanding vs. stored components	Sequencing and real-time commanding increase flexibility, but also increase ops complexity and cost
Spaceflight autonomy vs. operations complexity	S/C autonomy can reduce ops cost and complexity, but also can reduce flexibility. Increases spaceflight development cost and complexity
Communication data rates vs. ops support	Higher data rates (for a given amount of data) require less DSN support, but can increase S/C development cost
Sequencing memory onboard the spaceflight system vs. operational flexibility	Higher volume of sequencing memory onboard increases ops flexibility, but also increases S/C development complexity and cost
MOS automation vs. development cost	MOS automation reduces ops cost, but increases development cost
Centralized vs. distributed ops	Centralized ops reduces complexity (interfaces), but can increase cost (staffing)

Table 3. Mission Operations Trades and Considerations

It is estimated that the above trades hold the possibility to reduce the operations workforce by up to 50% for the spacecraft and other flight teams. Quantitative data for specific cost savings is however difficult to derive for any one of the above trades. Projects, of course, may decide that the advantage of reducing operations costs is outweighed by other trade decision criteria such as increased science return, programmatic constraints, or funding profile. What's most important is that this be an intentional trade performed early in the mission lifecycle.

Conclusion

Acknowledgement

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