TOWARD LOWERING THE COST OF MISSION OPERATIONS

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ABSTRACT

The mission operations system is one of the more significant drivers of the cost of the mission operations and data analysis segment of missions. In large or long-lived projects, the MOS can also be a driver in total mission cost. Larger numbers of missions, together with an increasingly cost-conscious environment, dictate that future missions must more strictly control costs as they perform to their requirements. It is therefore prudent to examine the conduct of past missions for ways to conserve resources.

In this paper we review inputs made to past projects' "lessons-learned" activities, in which personnel from past projects (among other things) identified major cost drivers of MOSs and considered how economies were or might have been realized in both design and performance of their MOS. Common themes among four such reviews are summarized in an attempt to provide suggestions for cost reduction in future missions.

Key Words: MIssion operations, cost efficiency, lessons learned

1. INTRODUCTION

Remote sensing missions, including both missions that explore beyond the terrestrial environment and those which use space as a vantage point from which to study earth, provide us a growing experience base in the design of mission operations systems (MOS). The evolution of MOS designs has certainly been a benefit to the later projects, allowing them to concentrate more on research goals and somewhat less on the questions of how the basic spacecraft and mission will operate. This collective experience allows us to learn from our past successes and failures and gives us the possibility to reduce the operations costs of future missions from the lessons that the past provides.

In an attempt to document that experience base, several recent missions have conducted after-the-fact reviews of their mission operations, commonly known as "Lessons Learned" reviews. The purpose of such reviews has been to review the mission's performance and to record those elements that were either (1) done in a way worth recommending to future missions or (2) done in a less-than-optimum way and worthy of comment to allow future missions to correct the approach. Within the reports from these were many suggestions for improvement of cost efficiency in the mission operations system.

This paper results from an examination of Lessons Learned reviews for topics relating to cost. As such, it is a compilation of suggestions from the project team members who operate at the "worker" level as to how future projects might perform their tasks with higher productivity and lower overall cost. Inputs consisted of published Lessons Learned reports

from the UARS (Ref. 1) and Magellan (Ref. 2) projects, and less formal presentations and reports from Voyager and Galileo. Individual lessons that dealt with operations, ops management, or ops development were entered into a database and rated for their relevance to cost reduction. Suggestions were assigned to one or more of three mission phases: requirements definition; development, test and training; and operations. The database was then sorted for keywords, and common subjects were sorted according to the number of entries. This report is a compilation of the most often-mentioned subjects taken from that database.

Suggestions fell into two categories: those thought to increase mission success or to reduce risk, and those with potential contributions to reduction of cost. A total of 186 individual suggestions were related to cost savings. After sorting, 27 comments were found applicable to the requirements definition phase, 140 to development, test and training, and 90 to operations. In the following sections we summarize the content of the comments made concerning each phase.

2. REQUIREMENTS DEFINITION PHASE LESSONS

For the purposes of this paper we define the requirements definition phase as the period from project inception to the beginning of implementation, including any studies or preliminary definition steps. Chief among cost concerns in this phase were familiarity of both the details and the intent of requirements and continuing interaction with users to ensure that the requirements were well understood.

The most frequently mentioned topics relevant to the requirements definition phase suggested early achievement of a clear high-level understanding of the goals, scope, and risk acceptance criteria envisioned by the project before beginning the process of writing requirements. This conceptual understanding should then be modified considering available resources. All projects in the study mentioned this issue. A similar set of comments suggested earlier involvement by representatives of spacecraft developers, science users, and operations designers in a mission definition document, which was variously referred to as a "Project Plan" or "Operations Concept" (Refs. 3, 4). The UARS document in particular recommended the development of a "realistic and affordable project plan" as a potential cost saver, specifying both local and remote facility designs as cost drivers to be understood early in the definition stage.

Next in number of recommendations in this phase was the subject of software requirements. UARS and Magellan suggested that software documentation such as Software Management and Development Plans and Users Guides be outlined prior to software definition to save redesign during implementation. Voyager suggested that earlier involvement of multimission representatives in requirements writing would save downstream costs. Magellan also cautioned that a cost-related tradeoff exists between the effort spent on completing requirements definition and that required for testing of partial software deliveries.

Recommendations from UARS and Magellan suggested that consideration of computer loading needs (*e. g.*, disk space, CPU speed, and workstation sizing) as a fundamental requirement would have saved later expenditures to re-size processing systems that were specified without proper forethought. UARS also noted that ground data systems should be designed to accommodate expansion.

Magellan and UARS both commented that archiving requirements had not been sufficiently considered in the original levying of requirements, and that excessive resources were required to satisfy the projects' archiving obligations during the operations phase. Both projects benefited from a Data Management Plan which described archiving and dissemination designs, and UARS suggested that such a plan should be kept updated as the mission matures.

An unusual suggestion was made in the Magellan Lessons Learned that projects should as a matter of course perform an exercise following requirements definition wherein all requirements writers would be asked to identify those requirements that would be deleted should the project be required to halve its runout cost (an approximation of the descoping activity that created Magellan from its predecessor, VOIR). Such an exercise, done early in the design might be useful should actual descoping be necessary and, according to its author, could identify requirements that were less than critical.

Projects were unanimous in their belief that clear, concise requirements are a cost saver. Requirements must be written "clearly, completely and testably," and they must be "fully understood, identified and validated." More system engineering effort was recommended in the early phases of project definition. UARS and Magellan felt that system engineers needed authority over definition documentation, and that more science involvement would have avoided misstatement of resource requirements. These two projects also commented on the costs of technology development, and stated that proven system elements should be inherited, subject to several development caveats regarding inheritance of documentation and test data. Care was also advised to ensure that revision of inherited software or hardware did not outweigh the original cost savings.

3. DEVELOPMENT PHASE LESSONS

We define the development phase as the time period beginning with production of a set of complete or nearly-complete requirements. In this phase the requirements are implemented by, for example, writing software, building flight hardware, or writing procedures and plans. Included in this phase are software and hardware test and integration and personnel training. The largest number of comments in the database concerned this phase.

Magellan, UARS and Voyager suggested that tests of various subsystems could be combined to save resources. UARS further suggested that coordination and more documentation of test requirements across support groups was indicated. Magellan and UARS both felt that earlier testing with dataflow, either real or simulated, would have saved overall costs. Training costs could be saved according to UARS and Magellan if simulators used for test and training could serve double duty as simulators for sequence validation during operations, and as substitutes for subsystems not yet ready in system-level tests.

Development-phase efficiency could also be improved with a clearer overall concept document, according to most projects. Specifically, Voyager referred to earlier involvement of multimission, project-specific operations and science personnel, and asked for more internal reviews. Magellan mentioned simultaneous design of mission, spacecraft and mission operations system, and UARS suggested that development of ground data systems should consider flight operations design.

Establishment and control of interfaces have been considered key to the effective MOS design (Ref. 4). Early identification of, characterization of, and agreement to interfaces was mentioned by three projects in this study. Identification of single points of contact for each interface was thought valuable by Voyager. Formal Software Interface Specification documents (SISs) were thought worthwhile by Magellan despite the unexpected effort required. Voyager also suggested that all parties be required to sign interface agreements. Magellan also indicated that many paper interfaces could be replaced by an electronic mail system.

The subject of change control was popular at Lessons Learned reviews. A tighter link between the entity that approves changes and the one that commits resources was mentioned by both Galileo and Magellan as a way of avoiding wasted time and thus funds. Galileo and UARS suggested that all requested changes to requirements be thoroughly evaluated by system engineers to avoid forgotten impacts. The Galileo project, which was forced to undergo several major design changes prior to its launch, indicated that changes must be documented and widely distributed when redesign occurs, and that the rationale for changes should be archived as well.

Another popular subject was that of the formal review process used by most NASA missions. Reviews were seen as necessary and beneficial by all projects, although the comment was made that the resources necessary for reviews need to be better anticipated. Independent design and analysis reviews were thought to be effective, as were design and interface "walkthroughs," and informal discussions prior to formal reviews Involvement of flight controllers in sequence design reviews was thought by Voyager personnel to be an aid to avoidance of costly command errors.

Contingency plans are usually developed prior to beginning operations. The projects reviewed here produced varied opinions as to the tradeoff between development of a few contingency plans to a very high level (*e. g.*, to the level of a command load that could be immediately uplinked) and development of a large number of contingency plans to a relatively low level. It was clear, however, that the level of plan development was considered to be a cost issue, and that the time spent in contingency work should be carefully balanced against acceptable level of risk.

4. OPERATIONS PHASE LESSONS

The operations phase includes all portions of the mission dedicated to actual acquisition of science data. Matters concerning science and science interfaces were most numerous among operations phase comments.

Both UARS and Magellan used a working-group approach for both data product and uplink interfaces with science teams and believed that approach saved time. Magellan believed that timely release of science data, both digital and photoproduct, to be effective, with a minimal required validation period. Magellan also suggested that science investigators' involvement in operations and data production was beneficial in reducing data production costs. Extensive use of students and post-graduates in operations was seen as a cost saver both at the operations center and investigators' home institutions.

Voyager, UARS and Magellan projects attempted some form of distributed operations to avoid the expense of transporting large numbers of investigators and/or contractor support personnel to the operations center. With few exceptions, the

response to such "remote" operations was positive. Voyager investigators were pleased with remote data access, but suggested that the access should be simpler and easier. Magellan urged future projects to emphasize better teleconferencing systems, more voice nets, and more regular status reports to ease the problems encountered with their remotely-located spacecraft team. UARS similarly commented that good communications and frequent meetings are beneficial. However, all three projects noted that physical separation of groups within a center was detrimental.

5. MANAGEMENT AND CONTRACTUAL LESSONS

Several comments in the Lessons Learned reviews pertained not to a particular phase of a mission but to contractual and management issues. Both Magellan and UARS felt that contracts written with award fees were more productive per dollar spent. Magellan added that to maintain productivity award fees should be constructed so that some incentive always remains for the contractor. Both projects also noted that time could be saved by working problems at the lowest possible management level.

6. CONCLUSIONS

Personnel involved in Lessons Learned activities were quite concerned about issues relating to productivity and cost-consciousness, and made many specific suggestions to future projects as to how resources could be saved or better directed. Surprising numbers of topics were found to be common among the four projects reviewed here.

According to our characterization scheme, the greatest number of comments received related to (1) software requirements placement and related development efficiencies, and (2) the achievement of a better conceptual understanding of the mission before or early in the requirements definition phase. Issues regarding interfaces were second in number. Also receiving relatively large number of suggestions were distribution of facilities, importance of reviews and keeping a strong and responsible system engineering function.

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