TECHNIQUES AND SOFTWARE FOR OPTIMUM AND EFFICIENT MISSION SCIENCE SEQUENCE DEVELOPMENT

David A. Bliss
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California 91109

ABSTRACT

Highly successful mission operations requires efficient and cost-effective science sequence development. Of key importance is the Science Planning and Operations Team's (SPOT's) ability to complete science observation design and integration early in the sequence development process (i.e., before the sequence enters into a formal change control process). Once under formal change control, careful change paper documentation, Flight Team checks, and mission software checks make sequence changes more labor-intensive. This paper discusses team organization, strategies, scheduling, and software employed by the Voyager and Galileo SPOTs to complete science observation design and integration early in the sequence development process.

Key Words: Aerospace, mission operations, science sequencing

1. INTRODUCTION

The schedule for science observation design and integration can vary somewhat from Project to Project. Traditionally, the responsibility for the preliminary phase of mission sequence development belongs to either the mission's Science Planning and Operations Team (SPOT) or to the SPOT in combination with a sequence integration team. During the early sequence development phases, observations are typically designed and integrated to a specified level of detail. During later sequence development phases (i.e., after sequencing changes are under Project Change Control) the final observation design parameters are implemented and detailed mission constraint checking software is run. Experience obtained from both Voyager and Galileo missions suggests that, to maximize science return while minimizing mission operations costs and Flight Team operations impacts, it is best to complete the science observation designs (with the exception of specified parameters such as imaging filters and exposures) and integration while the sequence is still in its preliminary phase. By consulting with the spacecraft engineering team, the SPOT would assign timeline windows and resources for engineering events to be incorporated in detail during final sequence integration. Such early completion of the science observation designs provide the following benefits:

a) Eliminates or greatly reduces the amount of change-paper which must be generated to incorporate changes during final sequence integration.

b) Avoids the extensive inter-team constraint checks and reviews which changes must undergo during final sequence integration.

c) Minimizes sequence reintegrations and software reruns from changes which impact the position and timing of other science and engineering events.

d) Allows the SPOT to focus its attention and efforts on the development of sequences to exploit science opportunities in other mission phases.

By limiting working team size and by utilizing appropriate software tools, the SPOT can achieve early science sequence development.

2. EARLY SCIENCE PLANNING OR SEQUENCE SCOPING PHASE

Before explaining the advantages of early science sequence development, let's first establish an understanding of the overall sequence development process.

2.1 Overview of Sequence Development

The process begins with the identification and selection of the science objectives. Science objectives selection is achieved through a number of meetings with the planetary or science discipline working groups, composed of

investigators from the project experiment teams, sifting through and prioritizing an exhaustive list of possible mission science objectives and resolving inter-experiment conflicts. Following publication of the results of these meetings, the SPOT uses orbit and/or trajectory information from the Navigation Team to compose a science planning guide for the mission. This planning guide establishes prioritized objectives for each mission phase (for Galileo, a mission phase is an orbit composed of several spacecraft command loads) and identifies observation periods which obtain as many science priorities as possible within Project capabilities or spacecraft resources. The science discipline working groups then review and make final planning guide modifications.

After completion of the science planning guide, the formal process of sequence development begins. The first step in sequence development can generically be called Science Scoping (SS). During SS, a science integrator works with instrument experiment representatives (ERs) to assign observation windows and assemble an observation timeline and time ordered listing (TOL) for a specific mission phase. Resources are allocated to each observation and preliminary observation designs are formulated. Timeline windows are identified for spacecraft engineering activities and resources are assigned to these windows.

The second sequence development step can generically be called the Sequence Plan (SP). During SP, the science integrator works with experiment representatives to develop and integrate observations in greater detail. The ERs use mission design software to design observations. Observation parameters which claim spacecraft resources (i.e., the scan platform, telecom, spacecraft power, tape recorder, onboard computer memory, etc.) are input and run through mission guideline and constraints checking software. An updated timeline and time-ordered listing is generated with liens to be resolved in the subsequent Sequence Integration step.

The third sequence development step can generically be called Sequence Integration (SI). During SI, the sequence integration team receives detailed inputs (i.e., scan platform slewing targets, mosaic sizes and scanning rates, instrument configuration details, etc.) from the SPOT and spacecraft engineering teams. The sequence integration team then runs the sequence through engineering activity and observation design parameter checking software and produces an updated timeline and time-ordered listing. Starting with SI, all sequence fixes are under Project Change Control (PCC) and hence must be documented. Minor sequence fixes, such as instrument parameter changes, normally require fairly simple formalized change-paper which are received and acted on only by the sequence team. More involved fixes, such as observation redesigns or timing changes, generally require more extensive change-paper documentation and must receive inter-team review and project approval.

The forth and final sequence development step can be called the Sequence Command Generation (SCG). During the SCG, the sequence is run through spacecraft command and simulation software and spacecraft readable commands are generated. Science changes at SCG are generally allowed only to make a high priority observation work or to preserve an instrument's health. All changes made at SCG require extensive change-paper documentation and must receive inter-team review and project approval.

To enhance sequence development efficiency, this paper proposes and discusses ways to achieve complete science observation development and integration by the end of the Sequence Plan phase (i.e., before sequence changes become subject to PCC).

3. IMPROVED SCIENCE SEQUENCE DEVELOPMENT PROCESS

On the Galileo Project, we have achieved early science observation design and integration by adjusting the Science Scoping and Sequence Plan steps as discussed below.

3.1 Science Scoping

Science Scoping is divided into three stages: development, review, and update. During the development stage, the science planning and operations team develops a formal Science Scoping product for investigator review. The review stage is simply a meeting in which the investigators review the Science Scoping product. The update stage involves incorporating investigator comments into the science scoping product. We have streamlined and modified the development stage (which comprises approximately 75 percent of the Science Scoping step) as described below to achieve an integrated Science Scoping product which is based on and includes detailed observation designs.

To start the Science Scoping development stage, the science integrator holds a kickoff meeting in which he or she proposes the guidelines and schedule for the mission phase sequence development, identifies key information (i.e., telecom and engineering constraints) pertinent to the sequence development, reviews the mission phase science objectives from the science planning guide, and identifies major issues for the sequence development. The ERs, along with the science integrator and technical support personnel, comprise the working team which develop the Science Scoping product.

A key element of the science integrator's schedule is the frequency and duration of the working team integration meetings. During these meetings, the science integrator works with the ERs to formulate observation design strategies and to develop an observation timeline. Given Galileo's eight week Science Scoping duration for each mission phase sequence, we have found that two integration meetings per week, each of approximately two hours duration, is sufficient to resolve integration issues while allowing a maximum amount of time for ERs to design observations.

Since it's important that the integration meeting discussions are focused and efficient, we find that it is best to limit working team size to one experiment representative from each instrument team. Teams whose observations do not require extensive scan platform design work, such as fields and particles teams, may choose to have one ER represent several instrument teams.

In the first integration meeting, the science integrator may allocate spacecraft resources and propose a timeline of observations to accomplish the mission phase's prioritized science objectives. The timeline also includes and assigns resources to windows which will be filled by important engineering activities during the SP and SI steps. Using this timeline as a starting point, the ERs propose modifications based on their instrument team's desires. The science integrator then adjusts the timeline according to the working team's consensus, and the ERs begin designing observations. During subsequent integration meetings, the observation timeline is adjusted based on design results and instrument team comments. Once the working team has developed an optimized timeline (approximately by the end of week 4), the science input portion of the Science Scoping process begins.

To make science sequence inputs, the ERs and SI use a software inputs package generically diagrammed in Figure 1 (Ref. 1,2). This software package creates a database which contains both scheduling and descriptive information for each science observation. The software is menu-driven and user friendly and can interact with mission-build software. The software uses the scheduling information (i.e., observation name, start/stop times, memory usage, scan platform usage, tape recorder usage, required telemetry data rate and format, rider instruments, etc.) to develop timelines and time-ordered listings, to perform resource summaries, and to identify timing conflicts. The software uses the descriptive information (i.e., the observation's science objectives, detail on how the observation is designed, details on how spacecraft memory usage is calculated, details on how tape recorder usage is calculated, etc.) to generate library and archival products. Once completed, the ERs use the software to deliver instrument observation information to a diskette. The technical support personnel then combine the ER's observation information with engineering, telemetry, and station coverage inputs from the SI and/or supporting sequence integration engineer to form a merged database. The software then uses this merged database to generate numerous specialized review products.

The working team generally has one review before the investigator review meeting. To perform this review, only a time-ordered listing, conflicts report, and certain resource summaries such as the tape recorder map, are needed. The working team resolves as many of the remaining conflicts as possible and documents them as resolved in the conflicts report. The ERs and science integrator then adjust their databases to reflect conflict resolutions and redeliver their diskettes to technical support. Technical support uses the updated database to generate the investigator review product. The investigator review product includes a time ordered listing, a time ordered listing sorted by instrument team, resource summaries which include a tape recorder map, a library describing the science objectives of each observation type, hardcopies of each observation's scheduling and descriptive information, and a timeline.

Following the investigator review, the working team incorporates investigator comments into the science scoping database. Technical Support then produces the final Science

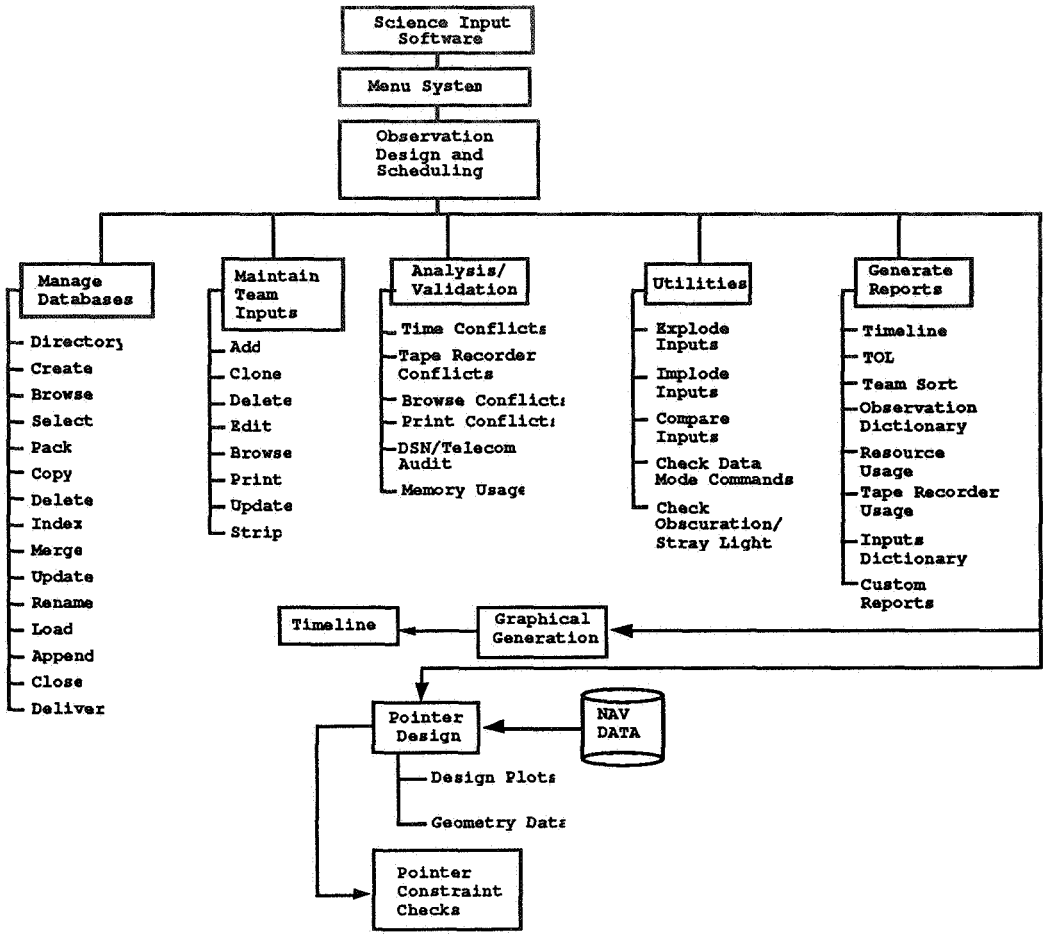

Figure 1. Functional Overview of Science Input Software

Scoping product while the ERs complete their observation designs. The final Science Scoping product is an updated investigator review product which includes a science overview description written by the science integrator. The Science Scoping product is delivered to and forms the baseline to begin the Sequence Plan step. By SP start, the ERs are also ready with completed or nearly completed observation designs.

3.2 Sequence Plan

The Sequence Plan step generally has two input or development stages. The process is approximately ten weeks long with the first input two to three weeks after SP start. At the first input stage, the ERs use the science input and mission design software to input their complete set of observation design parameters.

Once the ERs have delivered their observation design parameter inputs, the Sequence Integration Team combines science and engineering inputs into a complete timeline database. The sequence integration team runs the sequence through mission guidelines and constraints checking software and notes corrections which must be made by the science and engineering teams.

A key change to the Sequence Plan step is that, since the ERs have delivered completed observation designs, the SPOT can perform or work with the Sequence Integration Team to run detailed observation parameter check software and possibly spacecraft simulation software on all their science observations. If software complexity or the absence of initial condition and detailed engineering files do not allow spacecraft simulation software runs to occur at SP, the SPOT can develop specialized

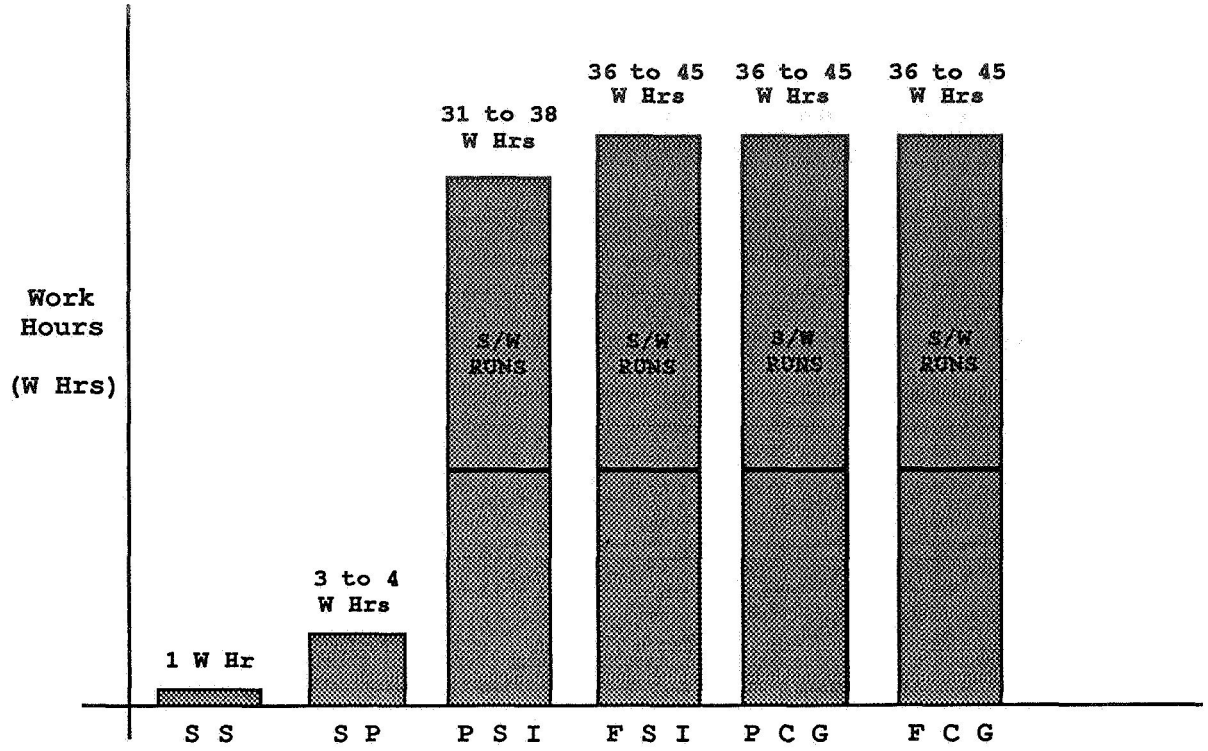

Figure 2. Estimated Work Hours for a Remote Sensing Observation Redesign/Reintegration

software which checks certain key science observation design parameters (i.e., scan platform slew start and end times, scan platform slewing rates when scan platform target motion compensation is active, and any other parameters which could require sequence reintegration if problems were discovered during spacecraft simulation software runs) at the same level of detail as the spacecraft simulation software. Hence, at this point in the SP process, before the sequence is under PCC, it is possible for the SPOT to discover and fix all possible science sequence problems. The fixes would simply be included in the SPOT delivery at the second or final SP input stage (approximately seven weeks into the SP process)

3.3 Cost Comparisons for changes at Science Scoping, Sequence Integration, and Command Generation Phases

Figure 2 displays cost comparisons for fixing a fairly standard integration problem at the different phases of sequence development. The integration problem selected for this comparison involves a remote sensing observation slew overlap which requires either the observation to be shortened and/or redesigned, or for one or several surrounding observations to be moved. In all of these comparisons, assume that an initial product has been produced (i.e., an initial Science Scoping timeline, or an initial Sequence Plan or Preliminary Sequence Integration timeline) and that we are incorporating our changes into that product.

During the Science Scoping phase, the fix involves shortening or moving observation time locations and can be accomplished by merely changing the start/end times in the science input software. This change can easily be performed in thirty minutes. By allowing another thirty minutes to check the change in the mission design software, the total change can be accomplished in approximately one work hour.

During the Sequence Plan phase, the change is more involved since observation design parameters have already been input into the sequence. The individual(s) involved in fixing the problem would probably have to use the mission design software to redesign the

affected observation and to determine if any of the surrounding observations were adversely affected. They would then have to use science input and/or mission build software to change sequenced observation design parameters according to the fixes achieved in the mission design software. This observation redesign effort combined with observation parameter adjustments causes the cost of the fix to rise to three or four work hours.

At the Preliminary Sequence Integration (PSI) stage, all changes of this nature fall under Project Change Control, or PCC. Hence, the change request must be written on standardized mission request paper, by the sequence integration team, reviewed by the appropriate spacecraft engineering team subsystems to insure that spacecraft resources and subsystem health are not adversely affected, and submitted for review to a Project Change Board which includes sequencing and engineering team personnel plus the Mission Director and Office Managers. The observation redesign, paperwork, and requester and team chief checks cost an estimated three to four work hours. The sequence integration team impacts, spacecraft engineering team analyses, and team chief signatures cost an estimated six to eight work hours (Ref 3). The Project Change Board costs an estimated two work hours (twenty minutes for the presenter and each Change Board reviewer). A rerun of the mission's science observation and engineering event constraints checking software (based on the Galileo software model) could cost 20 to 24 work hours. Hence, the net total cost for this change at the Preliminary Sequence Integration could be as high as 31 to 38 work hours (Ref 3,4). The costs at Final Sequence Integration (FSI) and at the Preliminary and final Command Generation (PCG and FCG) levels would be the same as for the Preliminary Sequence Integration, except that now the mission's spacecraft simulation software may also have to be rerun. This rerun would add another five to seven hours to the total cost for a net result of 36 to 45 work hours (Ref 4).

4.0 SUMMARY AND CONCLUDING REMARKS

This paper has shown that there is a tremendous advantage for science to complete its observation design and integration (i.e., to effectively complete its work on the sequence) before the sequence goes under Project Change Control. The number of Project work hours involved in fixing an observation design problem at Science Scoping versus after the sequence is under PCC can be a factor of thirty. By streamlining Science Scoping, limiting working team size, and using effective software tools, the SPOT can complete its observation designs and integration before the sequence undergoes PCC. By reducing, and by hopefully eliminating, the amount of time that science team members (and other Project personnel) are involved in fixing problems after the sequence has undergone PCC, more of the SPOT resources can be focused on exploiting science opportunities in other mission phases.

Since the early completion of the design and integration of science observations yields such potentially high cost savings, this paper would recommend that future Projects, when developing operating and mission software architecture plans, consider making the software sufficiently generic so that the complicated spacecraft constraint checking and modeling software can be run by the SPOT earlier in the sequence development process. If this approach proves infeasible, then it is recommended that future Projects consider developing specialized software packages that the SPOT could run to perform detailed constraint checks on selected observation design parameters at the Sequence Plan level.

The work described in this paper was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

REFERENCES

1. Finnerty, D.F., Martin, J., Doms, P.E., 1987. "Asset: An Application in Mission Automation for Science Planning", JBIS, 40, 461-470.

2. Henderson, V., private communications.

3. Tan, K., private communications.

4. Thomas, R., private communications.