JPL's Multi-Mission Operations Strategy for the Next Decade

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Abstract- Since the beginning of the NASA space program, each center has been tasked with the design, development and operations of a set of project resources necessary to accomplish its mission objectives. Those resources during the earlier years of the program could have been described as unbounded in comparison with today's resource restrictions. As NASA's program matured in the 1980's and even more so in the early 1990's, it became evident that with the reductions in project resources significant changes were needed if the Jet Propulsion Laboratory (JPL) were to have any program at all. Therefore, since the mid-1980's JPL has undertaken steps in an effort to remain fiscally responsible while maintaining its role as the "leader in the exploration of the universe".

Five major approaches have been considered for reducing the cost of operations at JPL. These include 1) development of a re-usable ground data system, (2) building to existing ground capabilities, (3) a consolidation of adaptation resources, (4) the development of an integrated flight and ground architecture, and 5) development of a set of standard TMOD Services. These standard services consist of two types of services, Data Services and Mission Services.

The Telecommunications and Mission Operations Directorate (TMOD) at the Jet Propulsion Laboratory (JPL) has been charged with the mission operations support for JPL's science and technology missions. TMOD's Mission Services and Application's Office (MS&A) has the responsibility of providing a major portion of these Mission Services. To make this real, MS&A has developed several of these services and is in the process of developing the remaining set for which it is responsible. "Prototype" operations of several of these services have been demonstrated on existing missions including the Telecom Link Analysis, Spacecraft Time Correlation and Sequence Engineering. Future work will complete the formal development of the MS&A set of services. All of this has occurred prior to the formalization of the TMOD Operations Concept.

This paper will present an overview of the TMOD Standard Services to provide context to the proposed approach for TMOD operations. A presentation of TMOD's Operations Concept extended to the Mission Services level will be provided which in turn will be mapped to the operational needs of Mission Service's. Application of the lessons learned from the "prototype" services will be applied against the classes of missions anticipated in the next decade and the

Operations Concept. Because experience has shown that although similarities exist between missions and even classes of missions, there will exist unique operational requirements driven by different operational needs. This paper will address how MS&A is planning to accommodate these missions operationally. Finally, projected resource savings will be identified, if possible, over conventional mission operations approaches.

The work described in this paper is being carried out at the Jet Propulsion Laboratory/California Institute of Technology under contract to the National Aeronautics and Space Administration.

INTRODUCTION

The new era of space exploration with it's emphasis on multiple missions of reduced size and cost present unique challenges to the space industry in general and to NASA in particular. Today's mission sets such as Discovery, Mars Surveyor Program, New Millennium and X2000, although much different than those of previous eras (e.g. Viking, Voyager, and Galileo), must be developed and operated under the new rules of Faster-Better-Cheaper.

Gone are the days of **long development phases** and **large development costs**. Cost driver's place a premium on development time causing new missions to reduce their development periods from the 3 to 5 years of the past to an 18 months to 2-year period today. Cost to operate these missions has also become a premium, causing new missions to look for ways that the spacecraft can be operated more efficiently. Today's missions look to an operation organization, ignoring the science contingent, of 10 to 20 people rather than the several hundred individuals of the past. Both have been shown to be mission cost drivers. Control of these drivers, reduction in development schedule and reduction in operating staff will facilitate the Faster-Cheaper, but what about the Better? There has been no relief in today's missions to have quality science or for that matter, even less science. Today's missions are expected to provide even larger volumes of data than anything previously (e.g. Magellan returned to the earth more data than had been collected by all the JPL missions combined prior to that time). With few exceptions, little reduction in the science appetite has occurred.

To meet the demands of these new missions and to mitigate risk, NASA's Jet Propulsion Laboratory has taken significant steps over the past decade to position itself for the next century. These steps include:

- Development of a re-usable Multi-mission Ground Data System, thereby reducing the development cost to a project by amortizing the original development costs over multiple missions
- Build upon existing capabilities, thereby minimizing the re-design of capabilities that already exist.
- Consolidation of mission adaptation resources, thereby maximizing the inheritance from mission to mission while minimizing the learning curve for new adaptation personnel.
- Development of a Unified Flight and Ground Architecture Data System architecture to maximize re-use between missions while minimizing new development for future projects.

- Identification of a set of TMOD Services capable of supporting a variety of missions, while minimizing work force via multiplexing of the mission support personnel and the elimination of operations re-engineering.

By completing these capabilities with their subsequent deployment, positions JPL with the ability to continue its world class exploration of the solar system into the next decade while remaining both fiscally responsive and technologically advanced.

History of Operations at JPL

Mission operations support at JPL has traditionally been a very rigorous and time-consuming process. For many years the large and complex missions flown by the laboratory used processes which required operations development to begin several years prior to the beginning of launch operations and to continue through the remainder of the mission. These teams relied heavily upon manual processes. Each project maintained its' own flight specialists, those who had either been intimately involved with the development or who had developed an integral knowledge of the peculiarities of the spacecraft through test, by a continuation of their funding support through end of mission. These domain specialists became the project specialists upon which the successful execution of the JPL missions depended. With the advent of simultaneous multiple missions, this "projectizing" of the operations teams resulted in a large amount of duplication of effort from one project to the next.

Historically, JPL's Telecommunications and Mission Operations Directorate (TMOD) has provided mainly software tools to the projects, while providing operations support in only a few areas. In the early 1990's, NASA introduced"Faster, Better and Cheaper" with an objective of "blacking the skies with spacecraft" as stated by NASA Administrator Dan Goldin. In 1997, TMOD embarked on an effort to develop a set of Standard TMOD Services capable of providing operations support to all future JPL projects. These standard services when fully deployed would remove the need for a project to spend funds duplicating capabilities already present (e.g. organizational structures, operational interfaces and procedures. The presence of these services and the new operations concept should further enable low-cost mission operations by providing a common integrated operational environment wherein multiple flight projects could share operations personnel. To accomplish this, both common ground data systems and standardized operational processes needed to be established. By utilization of these standard processes, procedures, trained personnel, and common ground systems, a projects ability to support operations would be possible as soon as the project's unique data system adaptation was completed. The modernization of JPL's operations was further enhanced with the completion of the TMOD Operations Concept in 1999. With the completion of this effort, an integrated service system, Deep Space Mission System (DSMS), was established.

Having defined and documented the set of proposed TMOD Services TMOD has now begun to deploy those capabilities. An early form of the service paradigm has been deployed in the real-time operations areas of Mission Control, Data Transport and Data Management. These experiences have only helped to establish the feasibility and benefits of multi-mission support under the new Standard Services concept.

DS1 was the first project to use any of the Tailored Services to support their mission. DS1 contracted to TMOD to provide the three Tailored Services: Telecom Link Analysis Service, Spacecraft Time Reference Service, and Flight Engineering Service. Due to several technology driven re-designs in the project and the lack of an established Flight Engineering Service, TMOD never deployed the Flight Engineering Service for DS1. The successful use of services by DS1 has resulted in their application to the upcoming Genesis and SIRTF missions as well as OPSP, ST3, and Deep Impact.

Current TMOD Services

In 1997, the TMOD identified a set of standard services for use by future JPL missions. These services were categorized as **Standard** or **Tailored** services. The **Standard Services** will allow a customer to meet his operational needs without the expenditure of recurrent engineering costs. **Tailored Services** are of two general classes, the first requires substantial development effort due to the mission-dependent nature of the functions being performed by the service and the second is one requested by customers for functionality different from a corresponding Standard Service. In either case, to fulfill a Tailored service, modification of TMOD capabilities with additional implementation effort will be needed with the cost being born by the customer.

At present, thirteen (13) service families have been defined. Each service family consists of one or more flavors of service. A *service family* is a collection of services with related functionality. An example of a service family is the Flight Engineering Service composed of four related sub-services, including Spacecraft Performance Analysis, Telecom Link Analysis, Spacecraft Time Reference and Flight Control Services. See Table 1 for complete list of services.

1. Command Services:
   - **Command Radiation Service**
   - **End-to-End Command Delivery Service****
2. Telemetry Services:
   - **Bit Stream Service**
   - **Frame Service**
   - **Packet Service**
   - **Telemetry Channel Service**
   - **Data Set Service**
3. Mission Data Management Services:
   - **Short-Term Data Retention Service**
   - **Long-Term Data Repository Service**
   - **Archive Product Preparation Service**
4. Tracking & Navigation Services:
   - **Raw Radio Metric Measurements Service***
   - **Validated Radio Metric Data Service**
   - **Orbit Determination Service****
   - **Trajectory Analysis Service****
   - **Maneuver Planning/Design Service****
   - **Navigation Ancillary Data Service**
   - **Ephemerides Service**
   - **Modeling and Calibrations Service**
   - **Gravit Modeling**
   - **Cartography**
5. Experiment Data Product Services:
   - **Level 1 Processing Services**
   - **Higher Level Processing Service**
   - **Photo Product Service**
   - **Science Visualization Service**
6. Flight Engineering Services:
   - **Spacecraft Performance Analysis Service****
   - **Spacecraft Health & Safety Monitoring Service**
   - **Telecommunication Link Analysis Service**
   - **Spacecraft Time Correlation Service**
   - **Instrument Health & Safety Monitoring Service****
7. Sequence Engineering Service**
8. Science Observation Planning Service**
9. Ground Communications & Information Services:
   - **Ground Network Service**
   - **Data Transport Service**
   - **Collaborative Service**
10. Radio Science Services:
    - **Baseband Measurements Service**
    - **Power Spectrum Display Service**
11. VLBI Services:
    - **Narrowband Measurements Service**
    - **Wideband Measurements Service**
12. Radio Astronomy Services:
    - **Radio Astronomy Service within DSN Bands**
    - **Radio Astronomy Service at Special Frequencies**
13. Radar Science Services:
    - **Continuous Save (CW) Service**
    - **Binary Phase Coded (BPC) Service**
    - **Interferometric Observations Service**

Table 1 -- TMOD Standard Services

New TMOD Operations Concept Architecture

Following the development of services, it was necessary to develop an operations concept for the deployment of these services to a flight project as an integrated operational system. In 1999, TMOD developed its Operations Concept (see Reference 1 and/or, SpaceOps2000 paper,"DSMS Operations Concepts" by Gary L. Spradlin), the deployment of which is defined as the Deep Space Mission System (DSMS).

The DSMS as described in the Operations Concept consists of:

- Data system elements (i.e., hardware and software)
- Multi-mission Operational support teams (Services)
- When fully deployed, DSMS will include:
    - Ground-Based Service Elements – Deep Space Network (DSN) and Multi-mission Ground Data System (MGDS or AMMOS as it is called)
    - Flight-Based Service Elements- TMOD capabilities provided on-board the spacecraft, e.g. Space Transponding Modem (STM), Mission Data System(MDS), etc.

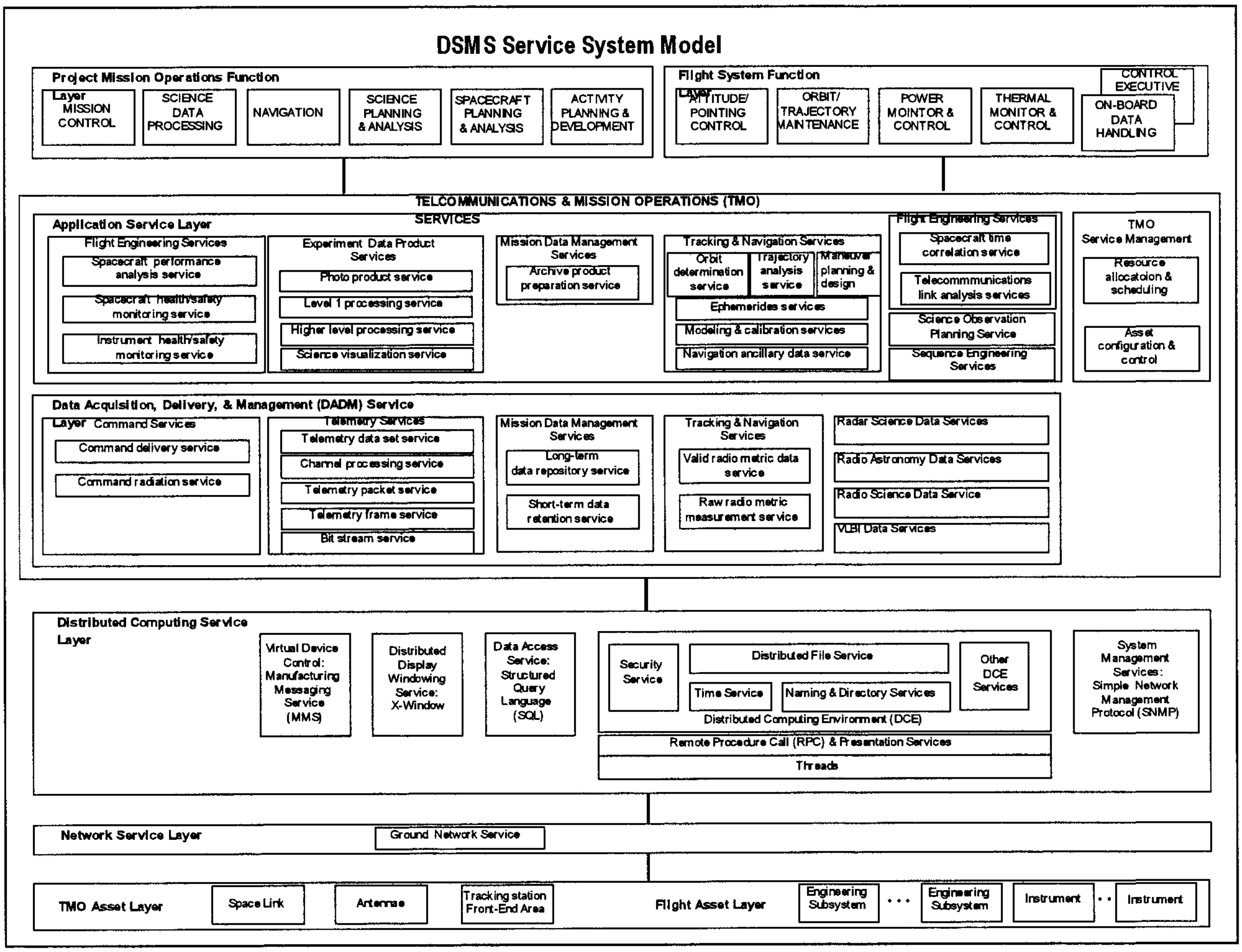


Figure 1 - Service System Model

Figure 1 [1] illustrates a logical layering of the DSMS Services and their relationship to the Project Mission Operations Functions (e.g. the top layer). As illustrated, the DSMS provides the ability of the project to obtain services to support all elements of its operations and to do so as a turn-key /plug & play system.

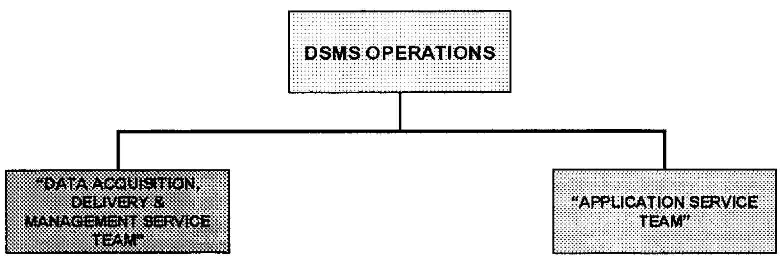
The DSMS is cognizant for all of the physical assets of the ground with future capabilities in the area of flight as noted previously. The Standard Services of Network Services and Distributed Computing Services provides the data processing environment and the digital communications infrastructure needed to make the services function. Due to these services'" infrastructural" nature, no operations organization has been identified for them.

The other services offered by the DSMS to a project are concentrated in the two upper layers, Data Acquisition, Delivery, & Management and Applications layers. The primary difference between these layers is the specialized knowledge and capabilities required to provide it.

It is TMOD's plan to support its customers by utilizing this service-based system. Projects who are willing to use widely accepted standards can utilize existing capabilities for standard functions (telemetry, command, tracking, etc.) for costs far less than that required to develop those capabilities themselves. Additional functionality and increased operational savings can be obtained in the areas of spacecraft analysis and engineering support.

The DSMS Operations Concept has organized the operations into two super-teams (See Figure 2) that map into functions provided by that service. These teams, The Data Acquisition, Delivery and Management (DADM) team and the Application (AS) team. The DADM has been charged with providing a set of fundamental services needed for any Deep Space mission without consideration to the mission objectives. The AS team has been charged with providing the class of service requiring mission specific specialized knowledge and capabilities either to augment the mission set or to provide a non-projectized replacement mission flight support capability.

Figure 2 - The Two Super Teams1



- Multi mission/multi service
- Works on the DADM services layer
- Not focused on data content
- Always required by the customer & comes with the service subscription
- Bridges gaps, makes interconnects work between services & service elements

- Multi mission/single service
- Works on application services layer
- Focused on data content
- Negotiable support level
- Provides knowledge/skill-based support of specific functions needed by the customer
- Viewed by the customer as within the project rather than part of the DSMS, customer experiences the joy of ownership without the cost

[1] TMOD Operations Concept Document, Draft 6, 7 Feb. 2000, DSN No. 827-001
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Role of DADM Service Team

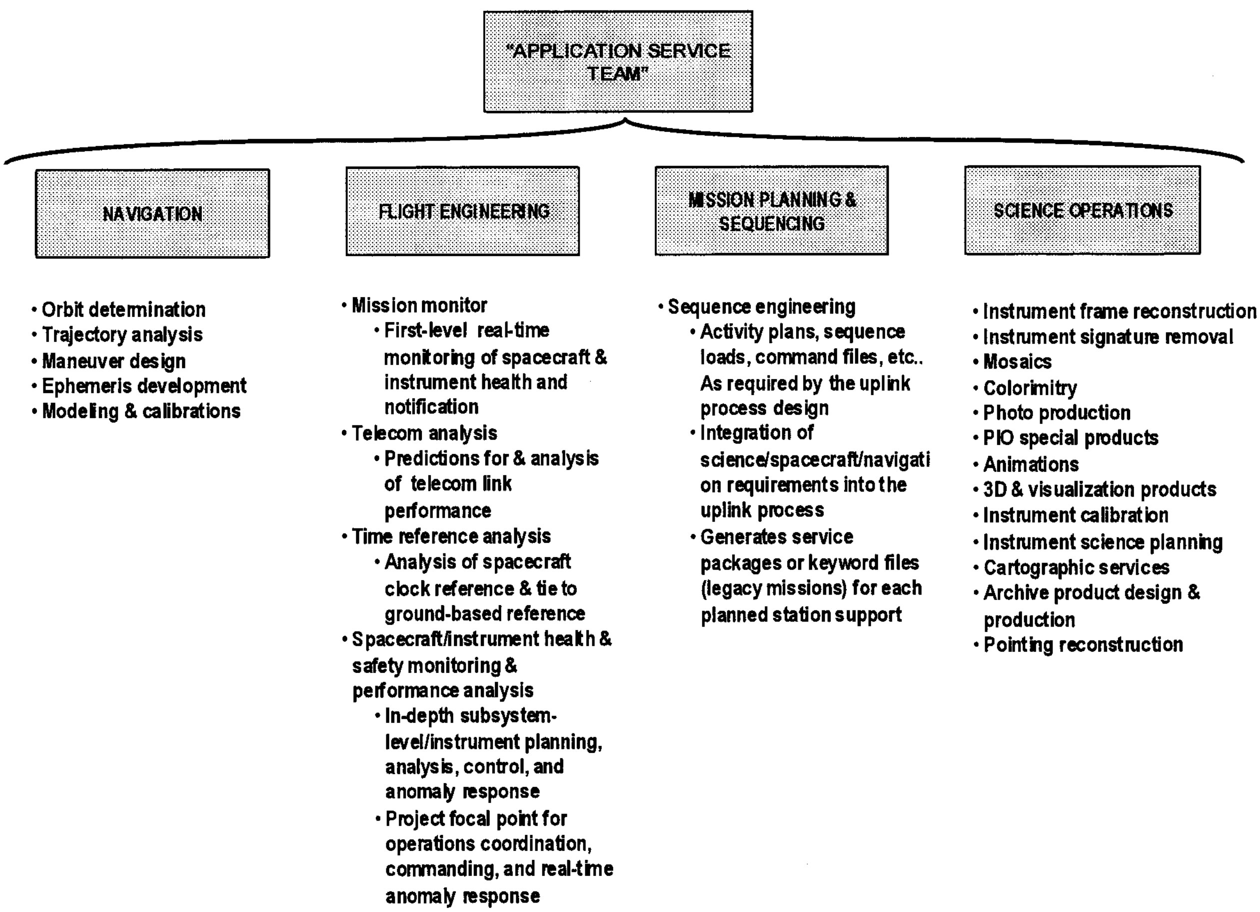
Because the objective of this paper is to address the Mission Services contained in the Application Service Team, suffice it to say, the **Data Acquisition, Delivery & Management (DADM) Service Team** is responsible for supporting the basic multi-mission services and the successful flow of data through the DSMS. For a detailed discussion, see Reference 1. Although the grouping within the DADM Service team is by specialty, that specialty is not a technical discipline, but rather, a type of function performed to support the service requests of the customer.

Role of AS Team

As noted in the figure, the **Application Service (AS) Team** is focused on performing functions which require unique skills and tools to accomplish. The AS provides a full spectrum of selectable capabilities and skills within a given core competency area. The AS service team is composed of four sub-teams as shown in Figure 2: the Navigation Team, the Flight Engineering Team, the Mission Planning & Sequencing Team, and the Science Operations Team. These teams provide specialized engineering support at a level that is negotiated.

A key difference between the DADM teams and the AS teams is that the DADM personnel are largely transparent to the customer, however, the Application Service teams are very visible to the customer.

Figure 3 - Composition of the Application Service Team[2]



[2] ibid

New Mission Types

TMOD has been tasked with developing a set of service operations capabilities capable of supporting all flight missions planned for the next decade. A vast variation of mission types and complexities has been identified for flight during the next decade. Not only are the target bodies discriminators, but the data system has also become a discriminator for a new class of missions wherein common software will be used for both the flight and ground data systems.

TMOD's Mission Service & Applications (MS&A) Office, which is responsible for two of the four AS Team sub-elements, undertook a short study to examine the mission types and to determine the feasibility of their support. The study resulted in the identification of several "sub-classes" or "unique deployments" of the MS&A Services. MS&A has initiated a development of those sub-services based upon that study.

In the case of tailored Sequence Engineering Services (referred above as the Mission Planning and Sequencing Team above), four classes have been identified. Those classes are defined as the Shared Operations Class, the Mission Data System (MDS) Class, the Observatory Class and the Mobile Vehicle/Sample Return Class. A detailed description of each has been provided by Robert Brooks in Reference 3.

In the case of Flight Engineering Service (FES) the study examined the elements from which FES is derived, specifically, the Spacecraft Performance Analysis, the Telecom Link Analysis, and the Spacecraft Time Reference. As a result of that study, both the Spacecraft Performance Analysis and Spacecraft Time Reference determined that a single service should be adequate for all of the identified mission types. However, in the case of the Telecom Link Analysis Service,
Four sub-classes were identified. They were: point to point link, concurrent link, concatenated link and constellation link design capabilities. Although it remains unclear as to whether these are more tool/modeling oriented, as of this date, they are being approached as different classes of service implementation.

Neither Navigation nor Science Operation Services, which are outside of the MS&A Office, were reviewed in this exercise. However, as with the FES, tool differences seem to be the dividing factor between the several mission classes rather than differences in mission operations.

Projected Operations Savings

Sequence Engineering Service:

Significant savings have already been realized from the application of the service paradigm. The most significant to date, is that experienced by the MSOP project. Although not a TMOD service, its approach is common to that of the TMOD Services and is therefore considered representative of the results anticipated when TMOD Services are fully implemented. In the MSOP effort, a project funded "sequencing" effort was established to support its first customer, the MGS mission. As additional missions were added to the Mars Surveyor Program, e.g. Mars '98 Orbiter and Landers, the basic service was augmented by additional staffing rather than replicating a full stand alone capability as would have been the case in the recent past. The savings experienced have been manifest not only in lower dollar costs associated with providing these capabilities, but in the ability to more fully utilize domain expertise for tasks which by themselves may have required less than a full time commitment. Use of these same approaches for MS&A's Sequence Engineering Service will provide similar results. For MSOP sequencing, a baseline staffing of six FTE's was established, four providing sequencing task support and two responsible for maintaining the DSN schedules for the supported missions. With the addition of 2 individuals to this team, the MSOP has been able to expand its mission set from the support of the three Mars Mission, MGS, Mars'98 Orbiter and Lander, to include the Stardust and Genesis missions.

Early costing exercises for the Observatory and MDS class missions indicate that many of the proven sequencing procedures used on MSOP will be directly applicable to these other mission types. SIRTF, and to some extent SIM, are being used as the model for the Observatory class missions. Europa Orbiter is the only example to date of an MDS mission available thus far. Especially for the MDS type of mission, there is still much development of the tool set to be completed prior to an accurate estimation of the benefits obtainable from the service paradigm. MS&A is working very closely with MDS personnel to make certain that MDS development is in alignment with MS&A's planned sequencing strategies.

Finally, the mobile vehicle/sample return class of missions will present JPL its greatest challenge to develop a sequencing and commanding strategy because of JPL's limited experience with this class of mission. However, the experiences being gained from the Mars' Pathfinder and Mars'01 mission will be of great value in developing a responsive, reliable and high quality sequence service. With mobile vehicles on the target body surface, the sequencing approach will need to take on a higher level than has been the experience in the past, e.g. commanding of the rover by goals rather than commands, to allow the mobile vehicle to proceed without continual interaction from the ground. This development although in its early stages, is expected to be ready for use in 2002 when the Mars-03 project begins its spacecraft Assembly, Test and Launch Operations period of development.

Flight Engineering Services:

As with the Sequence Engineering Service, significant savings are expected in the Flight Engineering Service domain as well. To date, this experience has been centered in the deployment of the FES sub-services, specifically in the areas of Telecom Link Analysis and Spacecraft Time Reference. Although no deployment has occurred in the FES sub-service Flight Control, similar functionality has been provided via Multi-Mission Control in the past.

Now what of this experience base? DS1 was the first mission to utilize TMOD's Telecom Link Analysis service. In their support, TMOD developed and deployed a Telecom Link Analysis Service including workforce although provided by TMOD performed as an integral part of the DS1 project. The experience on DS1 has been quite successful, although its cost savings have not been as great as would have been expected, mainly because the telecom staff performed several non-telecom functions due to workforce shortages on the project.

Missions have also been benefactors in the area of Spacecraft Time Reference, wherein a single individual working within TMOD has been able to support a multiplicity of missions, including Galileo, DS1 and Cassini simultaneously without adverse impact upon the individual mission's needs.

Under the area of Spacecraft Performance Analysis Service , the MSOP project has demonstrated the viability of a multi-mission spacecraft performance analysis service with their MSOP Spacecraft Team. The MSOP spacecraft team was originally established with a staff of 12 engineers and analysts. With the addition of a new mission or a particularly complex operational condition, e.g. aero-braking, a staffing augmentation of six FTEs were added to the basic team. This eliminated the need to re-invent the operational environment necessary to support each spacecraft operations individually. As a result, rather than having 3 or 4 spacecraft teams of 20 people, the MSOP has been able to deploy a single team consisting of 30 people to support all of their operational missions. That contingent has been expanded to support the additional non-Mars missions of Stardust and Genesis. Again, although this is not a deployment of a TMOD service, its approach is common to that of the TMOD Services and is therefore considered representative of the results anticipated when services are fully implemented.

A recent case study relative to the support of the future Discovery Mission, Deep Impact, identified a savings of 13 (of the 26 in a standalone implementation) FTE's by using TMOD services over the cost of replicating all of the necessary infrastructure in order to provide a project unique solution. This study only examined the MS&A Services. Commensurate savings would be anticipated with other mission application.

By carefully system engineering the MS&A services, large savings will be realized in the flying of a multitude of planetary and science missions. This will, in turn, make space much more accessible and to a broader science community.

Acknowledgements

A gratefully acknowledgement is made to personnel of both Federal Data Corporation and the Jet Propulsion Laboratory for the work described in this paper. This work is being performed at the Jet Propulsion Laboratory, California Institute of Technology, which is under contract with the National Aeronautics and Space Administration.

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