N93-24689
158581
P. 6

SYSTEMS ENGINEERING CONSIDERATIONS FOR OPERATIONAL SUPPORT SYSTEMS

by Robert O. Aller

Operations support as considered here is the infrastructure of people, procedures, facilities and systems that provide NASA with the capability to conduct space missions. This infrastructure involves most of the Centers but is concentrated principally at the Johnson Space Center, the Kennedy Space Center, the Goddard Space Flight Center, and the Jet Propulsion Laboratory. It includes mission training and planning, launch and recovery, mission control, tracking, communications, data retrieval and data processing.

Operations support of NASA's space flight systems during the 1960s and the 1970s was associated with operations characterized as Research and Development. Flight programs were a single flight of limited duration or a series of flights to obtain specific data or to demonstrate an operational capability. This required operational support systems to be reactive and responsive to relatively short duration programs.

In the past ten years, this has continued with some notable exceptions. With advances in space and data technologies, the demonstrated capabilities and advantages of space operations and the increased cost and complexity of space systems has led to longer duration and repetitive flight programs. Systems engineering of operational support systems must accommodate this evolution and the increasing operational nature of NASA.

The need for systems engineering is critical to NASA in its preparations for conducting operations in the late 1990s and into the next decade. The planning and implementation of the operational support systems for this era are under way. Proper systems engineering is vital to the development of each new system, as well as to a "total systems engineering" of the functionality and interfaces of the entire operational system. Implementation, integration and transition of these major changes to the Agency's operational capacity require significant management attention. To assure NASA's future in research, development and operations, this system must be implemented successfully and designed to minimize NASA's operational costs.

TOTAL SYSTEMS ENGINEERING

The need for incorporation of systems engineering concepts and discipline is much broader for operations support systems than the hardware and software systems for which it is normally considered. As noted, operations support is an infrastructure of people, procedures, facilities and systems. Although systems engineering is routinely applied to each new system, the major problems often occur between systems and frequently among people, procedures and facilities. A disciplined systems engineering approach formulating each of these elements in the establishment of the "system" cannot be overemphasized. NASA has learned many times that good system contractors do not necessarily nurture good operational personnel and technicians nor do they necessarily develop usable maintenance procedures. Experience has also shown that facilities not adequately analyzed in conjunction with the planned utilization of the facilities require constant modification to meet operational needs. In considering support capability, each of the infrastructure elements requires analysis and carefully managed selection and attention.

An organizational tier of system analysis from the whole to each element can be applied in a macro sense to assure consideration of both technical and nontechnical systems. A macro analysis of the system involves many considerations; two nontechnical areas that have often caused problems are inadequately skilled personnel and underdesigned facilities.

The nature of operations support requires a spectrum of talents and skill levels. Most newly developed systems have not properly analyzed the experience and skill mix needed nor the number of personnel required, which varies from skilled flight controllers to maintenance and repair technicians. Too often a process to analyze the system operation and system maintenance and repair requirements is not properly developed in advance, resulting in an operations team that is undersized and underskilled.

A second issue is simply undersizing facilities. While managers operate on the "nature abhors a vacuum" principle and insist that each square foot of a new facility needs clear functional definition, too often new facilities are found to be inadequately sized even before they are put into operation. This is particularly true with new operational systems. Facilities should be designed to accommodate the unforeseen. Quite often the unforeseen is a result of an incomplete analysis of the operational and system requirements prior to facility design, but also new requirements will emerge. A contributing difficulty is NASA's facility approval process, which is instituted before a reliable utilization analysis is available. It is prudent to provide capacity for some growth to accommodate new requirements.

Another nontechnical factor that is of increasing importance to NASA is life cycle costing (LCC). NASA has not traditionally incorporated LCC as a critical selection, design or engineering process. The elements critical to LCC have all been managed and considered, but an LCC process has not been established within NASA or by NASA's contractors as a routine process. LCC was used as a contract selection factor by NASA for the first time in 1988 with the selection of the second Tracking and Data Relay Satellite System (TDRSS) Ground Terminal. It is rare that a contractor has an established technique to trade and iterate design cost against operations costs. LCC needs to be a driving discipline to assure that the costs of operating the increasingly more sophisticated flight systems can be controlled. The flight systems of today are projected for 15-20 years of operation. This demands that the operational support systems be analyzed and designed to minimize LCC, or the cost of operations will increasingly erode NASA's resources for new development capacity. NASA and its contractors should establish more sophisticated models of development, operations and maintenance costs that will provide more reliable data for conducting operations cost trades against alternative system designs.

SYSTEMS ENGINEERING AND OPERATIONAL SUPPORT SYSTEMS

Systems engineering for operational support systems follows the traditional disciplines applied to the development of major flight systems. Operational support requirements need to be translated into performance parameters and configurations through multiple iterations to optimize system design. The purview of systems engineering includes requirements definitions and verification, system analysis and design, integration planning, requirements control, configuration control and testing.

While similar to the design and development of major flight systems, the emphasis of the systems engineer for operational support systems is generally to provide generic support to an aggregate of flight programs and the increasing necessity to provide systems with extended operational usefulness. This operational longevity can be attained by systems capable of accommodating change while continuing to provide service. The Deep Space Network operated by Jet Propulsion Laboratory and the Goddard Space Flight Network are excellent examples of major systems that have provided space flight program support with tracking and data retrieval service for 30 years, all of the while undergoing changes to provide support for increasingly complex missions.

In addition to providing generic support to many users, a vital characteristic of support systems is operability. The focus in the vehicle development community is principally directed toward designing a system that optimizes performance; the operations community's focus is directed more toward an effective and efficient operation of the system. Operability emphasizes ease of operation, resistance to system problems and failures, maintainability, reparability, simplicity, efficiency, capacity for growth and modification, and accommodation of users.

These two features, multiple program support and system operability, are key to assuring the proper systems engineering of operations support systems. They are historically the most difficult to sustain as cost and schedule pressures frequently tend to compromise the system's range of utility and operability.

REQUIREMENTS, EVALUATION, VERIFICATION AND CONTROL

Operations systems development is generally driven by new, expanded or improved support service required by new flight programs or expanded program objectives. The systems engineer needs to challenge user requirements to assure the "real" needs are not sacrificed at the expense of low priority, highly demanding requirements. Occasionally, requirements are driven by the fact that new technology is available and not that it is essential (or even desirable) for effective operation. The systems engineer must consider the broad base of program users and not provide a narrow focus of support that overly complicates or ignores operations of the aggregate of users.

While sharply defining real needs, it is equally critical to consider the potential to provide for future capacity. In the information age, the computer (including software), communications, and electronics industries have developed new technologies and capabilities often before a flight program's support requirements are established. The incorporation of these new services needs careful examination and scrutiny; when these new services clearly enable future or expanded programs, however, the operational community should provide them to enhance future operations. An example of capability beyond defined need was clearly incorporated in the TDRSS program in 1975. The TDRSS provides capacity and data rates that will meet the requirements of the 1990s and well into the next century. It has also enhanced flight control concepts by greatly increasing the capability to access and control spacecraft. If phasing in of added capabilities can be accommodated, it will permit smoothing of resources and help the budgeting process.

Another important consideration of the systems engineer in the evaluation of support requirements is the impact these services will impose on the user. The goal is always to limit the interface restrictions imposed on the user program. Two of NASA's major operating systems have caused major constraints in their use. The Shuttle Program has imposed major safety and integration complications on deployed payloads and the TDRSS program has imposed scheduling and radio frequency interface constraints that have been restrictive to some users. Some of these constraints with both the Shuttle and the TDRSS were intrinsic to their operational concepts, but some were avoidable, had operability and utilization been more completely evaluated.

When developing systems such as the Shuttle and the TDRSS that represent a major departure in operating concepts and expansion of the operational envelope, the systems engineer needs to broaden analysis to the entire mission or spectrum of missions to better define and limit the major complications to system operations and utilization.

NASA's experience with both of these programs has clearly indicated much more effort is required to operationally understand the implications of their use. This experience should be understood and applied in the development of the Space Station, the Earth Observation System, and their associated support systems in consideration of their broad utilization objectives.

Requirements verification and control is generally practiced with all new developments, but control can be difficult to sustain throughout an extended development of an operational support system and its operational life. Unfortunately, the nature of flight programs is to evolve operational support requirements and occasionally to transfer capabilities planned for the flight system as requirements to the ground support systems. Careful monitoring and control of these requirements is essential, particularly in the development of software support systems. Requirement changes will constantly occur, however, and an efficient process to identify, approve and control requirements is vital. Clear and precise interface definition is necessary to enable this control. A detailed knowledge of the flight programs that intend to use the support system, as well as an understanding of other related support systems (operational support systems rarely provide the total functional support services), is required for effective requirements control by the systems engineer. Interface definition and control are essential to maintaining requirements control.

SYSTEM ARCHITECTURE AND SOFTWARE DESIGN

For those operational systems that contain standard computers and specialized software, which are a majority of the ground systems, a special subset of systems engineering must be performed to obtain the optimum hardware and software combination. The selection of the wrong hardware may result in software needs that are difficult and expensive to develop. Similarly, less expensive hardware solutions may be possible when the full range of software abilities is considered. (The designer must always bear in mind, however, the probable need for system expansion, which may make the selection of a more complex hardware element the prudent choice since software modifications are generally less costly than computer replacement.) This analysis of system architecture may involve the estimation of size, complexity and structure of the software needed for a series of mainframe computers.

Management and the systems engineer must realize the definition, design and implementation of major software packages require the same systems management disciplines and controls as do hardware components. Because software code can be easily erased or changed, it does not follow that changes should be considered any more lightly than they are for hardware. The flexibility associated with software is its greatest asset, but if not well managed and controlled, it becomes its greatest problem. Although software design has made astonishing progress over the years, software development remains a significant problem to most major systems. The inability of management to accurately predict software costs, delivery schedules and performance has consistently been a severe problem in the development of major operational systems.

LONG-RANGE REQUIREMENTS

An area often inadequately considered in the design of a support system is its capacity for future modification and upgrade as new technology becomes available and as requirements change over time. Many systems must continue to provide services while undergoing these modifications. Proper consideration for redundancy and capacity can greatly alleviate future expense and complications. Making assumptions regarding future support requirements can lead to a system design that reasonably accommodates alternative future growth requirements. Designs that fail to gracefully accommodate change are limited and will lead to a dead end.

While the Deep Space Network and the Goddard Space Flight Network have effectively accommodated change, the initial design of the TDRSS ground station failed to properly consider the long-term need to modernize and upgrade. This required extensive redesign and change at significant cost. A focus on the current needs may result in limited system utility, and pressures to implement the least cost system may constrain future expansion and ultimately, be the least cost effective.

The development of new features or major changes to operating systems is frequently implemented with new contractors. Generally, if NASA and the systems engineer did not specifically assure that the original contractor provided adequate hooks, the new contractor's implementation will be difficult and costly. The term "transition phase" is applied by NASA to the period when an online system is undergoing change while continuing to provide support services. This is a delicate and challenging problem to the systems engineer and critical in the selection of an appropriate design. It is important that transition be planned in conjunction with the design process and not after the design is established.

In considering long-range requirements for operational systems, the type of system, the importance of support, and accessibility are major factors. These factors were central to NASA's decision and ability to sustain the Deep Space Network (DSN) and the Goddard Space Tracking Network over their extended lifetimes while undergoing numerous modifications and changes. The continuous availability of these sites has been possible because of the redundancy within each ground station, a configuration of multiple sites (redundancy among the ground stations), and their accessibility. The recent major rebuilding of the 240-ft. DSN antenna reflectors prior to the Uranus Encounter was feasible because each antenna was sequentially modified, and alternate antenna systems were available at each DSN location to provide continuous tracking support. Redundancy within the system—provided because of the critical nature of tracking and communications support—and ground station accessibility have been critical to NASA's ability to continuously operate these networks while modernizing their capabilities.

When considering system changes, space-based operational support systems present a different challenge. Two major factors influence the consideration to change—accessibility and cost. Cost is directly related to the lack of direct access. Accessibility is difficult at best and impractical for most. The Hubble Space Telescope is accessible at great expense by using the Shuttle but the TDRSS satellites are presently inaccessible. The systems engineering of space-born support systems must consider the criticality of the service to be provided, the longevity of the service (providing adequate redundancy and projected service requirements), and the lack of ready access to the system. Satellites can of course be replaced by an upgraded satellite; systems that use multiple satellites at multiple locations, however, such as TDRSS, require identical satellite configurations to provide orbital coverage as an effective operational system. Spacecraft replacements are normally planned to sustain the system through its projected life with no ground interface and no service changes to the system.

When new services become necessary, they are expensive and require an extended period to implement. A space-based system that consists of several satellites, such as TDRSS, requires a change to the services of each satellite in orbit to provide an effective orbital service to the user. This is consistent with the practice of upgrading all ground station locations to the same service configuration; the accessibility makes the upgrade of space systems more costly and requires a much longer time.

NASA is now planning to modify the TDRSS with a higher data rate KA band service. The system and budget planning for this upgrade was begun in earnest in about 1985, and it is anticipated the satellite fleet will not be in orbit until early in the next century, a 15- to 20-year period. The TDRSS will have been operating for 20 years or more by that time. A similar projection will mean the replacement system, Advanced TDRSS, will likely be operating to the year 2020 and perhaps beyond. It is clear this system will be as challenging as the original, with new problems replacing those resolved with TDRSS. The transition of replacing the TDRSS systems presents a significant new challenge not faced with initiating the original service. Providing systems engineering for the Advanced TDRSS to remain viable 20 to 30 years in the future will tax any manager. Systems can no longer be replaced frequently or modified to meet individual program desires. Careful and complete system analysis and forward-thinking engineering are essential to the establishment of durable, effective support systems.

ASSURING OPERABILITY

To succeed in developing a support system that meets the goals of operability—ease of operation, failure resistance, maintainability, efficiency, expandability and accommodation to users—requires continuous effort and emphasis by the systems engineer. An oversight and regular review from the operator's viewpoint will contribute to success. Both the government and the contractors should provide an operational position within their program management structure that is responsible for maximizing the system's operability. Developments that continuously focus on the ultimate operation are consistently superior in performance and in total costs.

The need for NASA to be alert to systems engineering is more prevalent now than ever before in NASA's history. The implementation of new operating systems is planned throughout the 1990s to prepare the agency for managing the operations of complex, long duration and extremely high data rate programs. The quantity of data the agency will be processing and managing in the later part of the decade was unimaginable in the 1960s and the 1970s. This data will be generated by programs that will be launched in a period when NASA will already be operating and supporting a complex array of flight vehicles. New ground systems, with evolving capabilities and changing interfaces, will come into operation almost continuously throughout this period. The complex nature of interaction among these systems demands a visibility and overarching control that can only be accomplished through a systems engineering network. Management and coordination of the individual systems is required to assure total system functionality, interface definition, requirements control and the optimization of each system.

NASA has done an excellent job for the past 30 years in providing an operations infrastructure that has met the demands of exploring space. The next 30 years of space operations are equally exciting but represent a far greater challenge. The quality of the systems engineering of the operations support team is critical to both the success of the nation's civil space flight programs and to sustaining a viable operational role within NASA.