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Report to the Chairman, Committee on Science, Space, and Technology, House of Representatives

September 1991

SPACE COMMUNICATIONS

Better Understanding of Scheduling System Limitations Needed

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United States
General Accounting Office
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Information Management and
Technology Division

B-243986

September 17, 1991

The Honorable George E. Brown, Jr.
Chairman, Committee on Science,
Space, and Technology
House of Representatives

Dear Mr. Chairman:

On December 5, 1990, you requested that we review the efficiency and effectiveness of the National Aeronautics and Space Administration's (NASA) system for scheduling usage of the Tracking and Data Relay Satellite System (TDRSS). As NASA's primary resource for providing communications support to low earth orbiting spacecraft, TDRSS is essential for controlling the position and operation of spacecraft and for relaying scientific data to the ground. Spacecraft operators have expressed concerns that NASA's largely manual system to schedule TDRSS use for communications may soon constrain efficient utilization of the TDRSS network. This report discusses the scheduling system and identifies steps NASA could take to better ensure that the system will be able to accommodate increasing numbers of users during the 1990s. Details of our objective, scope, and methodology are provided in appendix I.

Results in Brief

Unlike a telephone system, TDRSS is not immediately available to provide routine communications service whenever controllers and scientists need to communicate with spacecraft. Instead, TDRSS service is typically requested weeks in advance. Because certain TDRSS resources are limited, conflicts between users for the same service at the same time are not uncommon. When such conflicts arise, coordination among many different people and organizations is required to resolve the problem. Among the hundreds of TDRSS events scheduled each week, dozens of conflicts must be manually resolved. A lack of automated tools has made the conflict resolution process more tedious, labor-intensive, and potentially error-prone than necessary.

With only seven spacecraft currently using TDRSS, NASA is meeting users' needs for TDRSS communications. TDRSS users are concerned, however, that the current scheduling system may be reaching its practical limit, a point at which the addition of new users jeopardizes the ability of the system to meet all users' needs. NASA has collected a variety of data on TDRSS activity. However, the agency has only recently begun collecting specific data on the amount of conflict resolution activity that the scheduling system currently supports, and those data are not comprehensive enough to accurately forecast the impact of additional users on the system, especially during periods when the space shuttle is flying. Such a forecast will be critical, considering that plans call for two additional TDRSS-user spacecraft to be launched in 1991, two more in 1992, and still more in the years following. A breakdown or degradation in the scheduling system could result in users being unable to fully complete their missions.

An entirely new scheduling system is being planned but will not be available until 1997 at the earliest. In the meantime, several software enhancements have been identified that may streamline the conflict resolution process and thus help reduce the risk that important and costly spacecraft flights may not be able to fully carry out their missions. NASA has been reluctant to implement these enhancements because of the competing demands of another software project. NASA officials believe that, on the basis of the recently collected scheduling data, they are not taking a serious risk in delaying the enhancements. However, we believe the data are not comprehensive enough to accurately predict the impact of additional TDRSS users on the scheduling process.

Background

NASA has invested approximately $3 billion in TDRSS, which began operating in 1983 and uses the largest and most sophisticated communications spacecraft ever developed. TDRSS provides communications support to spacecraft flying in low earth orbit (altitudes of up to a few hundred miles) by relaying all transmissions through three TDRSS satellites located in geosynchronous[1] orbit to a single ground station in White Sands, New Mexico. Communications support is essential for achieving scientific objectives and for executing critical commands that ensure a safe and successful mission. Through TDRSS, users are able to (1) send commands to operate the spacecraft and maintain its safety and proper functioning, (2) receive data for tracking the exact position of the spacecraft, and (3) receive scientific data collected by the spacecraft's instruments.

The current TDRSS constellation consists of two active and one spare satellite.[2] One active satellite is located in the east, over the Atlantic Ocean

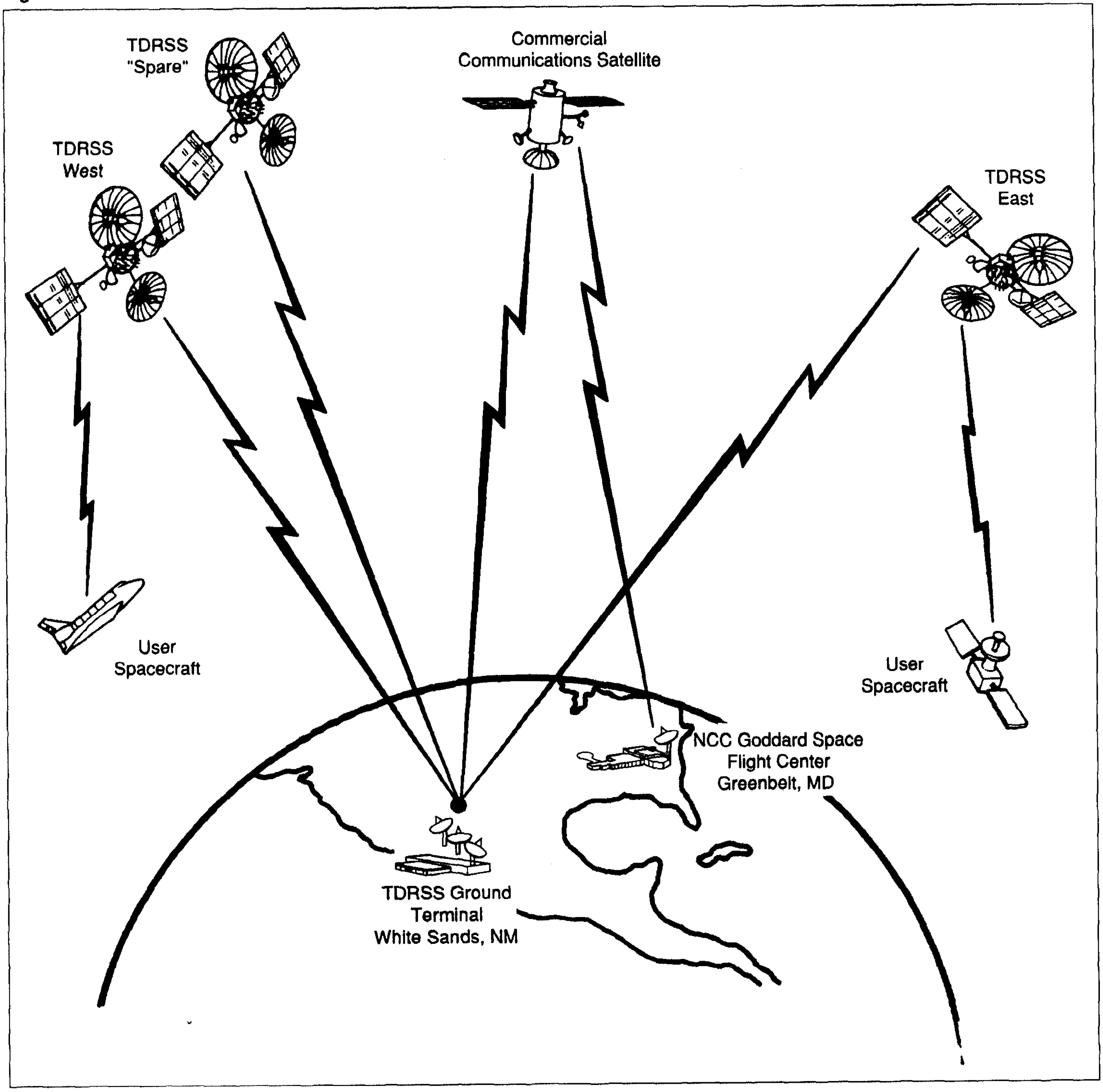
[1] A satellite in geosynchronous orbit remains permanently located over a single spot on the earth, thus facilitating use as a relay station.

[2] A fourth TDRSS satellite was launched in August 1991 and is currently undergoing engineering tests.

off the coast of Brazil; the other satellite is located in the west, over the Pacific Ocean southwest of the Hawaiian Islands. The spare is normally stationed in a central location between the two active satellites, but has been moved temporarily to the western location because of a partial failure in the capabilities of the west satellite. As of April 1991, the two satellites in the western location were both being used actively.

NASA's mission-critical communications services programs, including TDRSS, are the responsibility of the Office of Space Operations. Control of the TDRSS network, including monitoring the performance of the end-to-end system as well as scheduling all usage, is done at Goddard Space Flight Center's Network Control Center (NCC) in Greenbelt, Maryland. NCC is linked to the White Sands ground station through leased commercial satellite communications lines. Figure 1 depicts the TDRSS network.

Figure 1: The TDRSS Network



TDRSS offers two different kinds of communications services. Multiple access service can handle many (up to 19) user spacecraft at once, but only at a relatively low data rate (50 kilobits per second). Single access service allows for much higher data rates (up to 300 megabits per second), but each TDRSS satellite can only accommodate two single-access users at a time. As it turns out, most user spacecraft have been designed to use single-access service to support their scientific missions. Because of the limited availability of single-access service, TDRSS users often end up competing for system time.

TDRSS Scheduling Is a Complex Process

Scheduling TDRSS usage is a complicated process that begins 3 weeks before service is required. Individual spacecraft project users begin by running computer programs that help them generate a tentative schedule of the precise contact times and types of TDRSS service that they expect to need during the target week—3 weeks in the future.

On the Monday 2 weeks before the target week, the forecast scheduling period at NCC begins. At this time, users submit requests for service through special, dedicated computer terminals to the NCC's data system, which maintains the official TDRSS schedule from this point until the communications service is actually provided.[3] Once the user requests are in, TDRSS schedule operators run a program on the NCC system that schedules requests on a simple priority basis, rejecting lower priority requests that are in conflict with higher priority requests. Priority for routine communication services is determined by a ranked list of all user spacecraft, which is established by NASA management. On the basis of data collected between July and December 1990, the system processed approximately 475 requests during each weekly forecast schedule run, of which an average of 74 (about 16 percent) were initially rejected due to conflicts with higher priority users.

TDRSS schedule operators manually resolve all schedule conflicts, usually by telephone. Operators generally have three ways of resolving these conflicts: changing the requested start time; changing the type of service requested, from single access to multiple access or vice versa; or switching the service requested to a different TDRSS satellite or antenna.

[3]The NCC data system, which provides overall control of the TDRSS network as well as scheduling support, is based on a Univac 1100/82 mainframe. This hardware is old and difficult to maintain, and the software, including scheduling functions, is also difficult to maintain or modify. Recognizing these problems, NASA intends to replace the system in 1997.

A week later—1 week before the target week—the active scheduling period begins. At this time the preliminary schedule agreed upon during the forecast period is made final. All requests that have been scheduled during the forecast period are supposed to be firm at this point; they cannot be preempted by other users unless there is a spacecraft emergency or the support is needed by the space shuttle.

NASA officials report that hundreds of revisions are made to the schedule during this period. However, as discussed below, detailed records of this active period revision activity have not been kept in the past. Consequently, it is impossible to determine past trends in the levels of active period scheduling activity. Also, over the eight years since TDRSS became operational in 1983, relatively few spacecraft have been using TDRSS at any given time. As also discussed below, more users are expected in the near future.

Hubble and Shuttle Cause Schedule Disruptions

The two biggest sources of schedule disruption by far are the Hubble Space Telescope and the space shuttle. Because of the complexity of Hubble and its operations (see app. II.), the Hubble project office generally has been unable to develop a precise schedule far enough in advance to request specific contact times during the forecast scheduling period. Instead, Hubble schedulers request blocks of time during the forecast period and then adjust these with specific requests during the active period. Of all the TDRSS events requested by Hubble, half fall outside of Hubble's prescheduled blocks of time. Some of these may conflict with other prescheduled events, requiring manual resolution. NCC officials have negotiated with the Hubble project to try to fully schedule Hubble during the forecast period, when conflict resolution is easier because some automated tools are available. Due to difficulties with its internal scheduling process, Hubble is not yet able to fully schedule during the forecast period.

A space shuttle launch also severely limits the availability of some TDRSS services and delays in shuttle launches can wreak havoc on the TDRSS schedule. When a shuttle launch is planned, a single access link is reserved for its use throughout the flight. As a result, it is much more difficult to schedule single-access service when the shuttle is flying. Further, the shuttle disrupts the TDRSS schedule because of frequent changes to its launch schedule. For example, if a planned launch does not take place, the block of service reserved for its use is usually lost. Worse yet, if the launch date or time is delayed—which is not uncommon—additional time that may have already been scheduled for other users must be cancelled to support the shuttle, and then rescheduled.

Inadequate Automated Tools Make Conflict Resolution More Difficult

NASA believes that resolution of schedule conflicts requires human expertise as well as automated tools. The NCC data system does not, however, provide all the basic automated tools and capabilities that are needed to effectively support its TDRSS scheduling function. Although some automated tools are available during the forecast scheduling period, TDRSS operations officials report that the need for prompt and efficient conflict resolution is more critical during the active period, when tools such as service request editing, screen displays showing alternate times, or full identification of errors, are not available. Instead, active-period scheduling relies heavily on the manual effort of operators, especially to resolve conflicts.

For example, if a request submitted during the active period conflicts in any way with a prescheduled request, the new request is rejected in its entirety. To resolve the conflict, NCC operators normally contact the user but have no automated support. First, because the NCC data system does not store the rejected request, the operator cannot retrieve the details of the request and so does not know what specific part is in conflict. As a result, the operator must resort to telephone calls to the user to try to figure out what types of service were being requested and how they might be rescheduled. According to NCC operations officials, several phone calls over the space of a few hours or more may be needed, depending on how rapidly the user's operations center can respond to NCC. Second, NCC operators are constricted by the lack of a screen display showing what alternate times may be available for rescheduling rejected events. Instead, the operators must look through multiple computer screens of tabular data to try to figure out what times are still available. The labor-intensive process of calling users to find out what services they requested, consulting the schedule to determine which particular service is in conflict, and then looking through multiple screens for alternate times could result in mistakes. During discussions with operations officials, they agreed that the greater the number of conflicts to be resolved, the more likely it was that errors would occur.

Once a specific conflict has been resolved, the user must resubmit the entire adjusted request back through the NCC data system. However, the request still might not be acceptable to the system because the system identifies only the first conflict or error that it encounters. If a request includes several types of service, there could be additional conflicts that will only be identified by the system when the request is resubmitted. As a result, the whole resolution process has to be repeated. An NCC official himself sees the entire process as difficult, time-consuming, and potentially error-prone.

Increasing Communications Work Load Will Likely Worsen Scheduling Problems

NASA is generally meeting current user needs for TDRSS service, but the scheduling work load is expected to increase in the near future. Users are concerned that the scheduling system may be inadequate to handle the expected increase in demand for communications services. NASA has not, however, determined exactly what the limits on the current system are; that is, they have not determined the point at which the system can no longer effectively schedule all requests for communications. Such a determination is needed to ensure continued effective TDRSS scheduling in the future.

Current System May Be Reaching Its Limit

The TDRSS users we contacted (5 of the 7 current users) were generally satisfied with the level of TDRSS service they were receiving. They believe that inefficiencies in the scheduling system have not yet had a negative impact on their operations because, aside from the shuttle, the few TDRSS users that are currently in orbit are making relatively light demands on the available TDRSS resources. The users are concerned, however, that, as NASA adds more TDRSS users, the scheduling system may become less effective and may negatively impact their operations.

Experience during recent shuttle launches is one indicator that the system may be nearing its limit. As discussed, a large portion of TDRSS resources are reserved for the space shuttle when it is flying. Since its launch in April 1990, the Hubble Space Telescope has also been a heavy TDRSS user. According to NASA operations officials, Hubble and the shuttle together consume 34 percent of the current practical capacity of TDRSS. Lower priority users have raised concerns that during shuttle flights, they will have difficulty scheduling the remaining TDRSS resources. Activating the spare TDRSS satellite in the western location has helped to temporarily alleviate this problem by providing additional single-access channels. If the spare had not been made available in the western location for use during recent shuttle flights, some users would have been unable to obtain some communications services when needed.

Because significant TDRSS resources are reserved during shuttle flights, efficient scheduling of the remaining resources is much more critical than at other times. Users that have lower priority than the shuttle and

Hubble are the ones most likely to be affected by problems in scheduling TDRSS usage. For example, Cosmic Background Explorer (COBE) officials report that they would have experienced significant problems in obtaining TDRSS service over the three-year lifetime of the mission if they had to rely on the high-rate single-access service that COBE was designed to use. After testing its ground systems, NASA found that its TDRSS low-rate multiple-access service could meet COBE's requirements. Had this option not been available, according to a COBE official, it is doubtful that all mission requirements could have been met.

Additionally, the missions of spacecraft such as Hubble, the Gamma Ray Observatory, and the Extreme Ultraviolet Explorer all include provisions for the observation of "targets of opportunity." Targets of opportunity are celestial occurrences that are unforeseen and may be very short-lived. By their nature they often must be observed quickly, which means they cannot be accommodated under the standard 3-week TDRSS scheduling process. Instead, TDRSS support must be scheduled rapidly during the active scheduling period. Although some targets of opportunity have been successfully supported by TDRSS in the past, users are concerned that targets of opportunity will be missed due to the difficulty of scheduling TDRSS support.

NASA Does Not Know Current System's Limits

NASA officials recognize that they could eventually reach system saturation, the point at which conflict resolution will be exponentially more difficult with each additional spacecraft launched. In its September 1990 long-range plan[4] for communications networks, the Goddard Space Flight Center notes that although the current NCC system has performed adequately under light work loads, the system's limitations will affect performance under the heavier work loads forecast for 1990 and beyond. Yet, NASA does not know exactly how much additional work load the current system can effectively handle.

Until February 1991, NASA kept no formal records of the amount of scheduling activity during the active scheduling period. During a sample 2-week period in February, NASA collected detailed data on the numbers of changes to the active schedule and when they occurred. The data show that, aside from Hubble, an average of only 23 schedule changes were made each day during that period. Tallies of numbers of changes to the active period have also been kept on a weekly basis since February.

[4]Networks Division 1990 Long Range Plan, NASA Goddard Space Flight Center (Greenbelt, MD: 1990), p. 3-5.

On the basis of these data, NASA officials do not believe the scheduling system is close to breaking down.

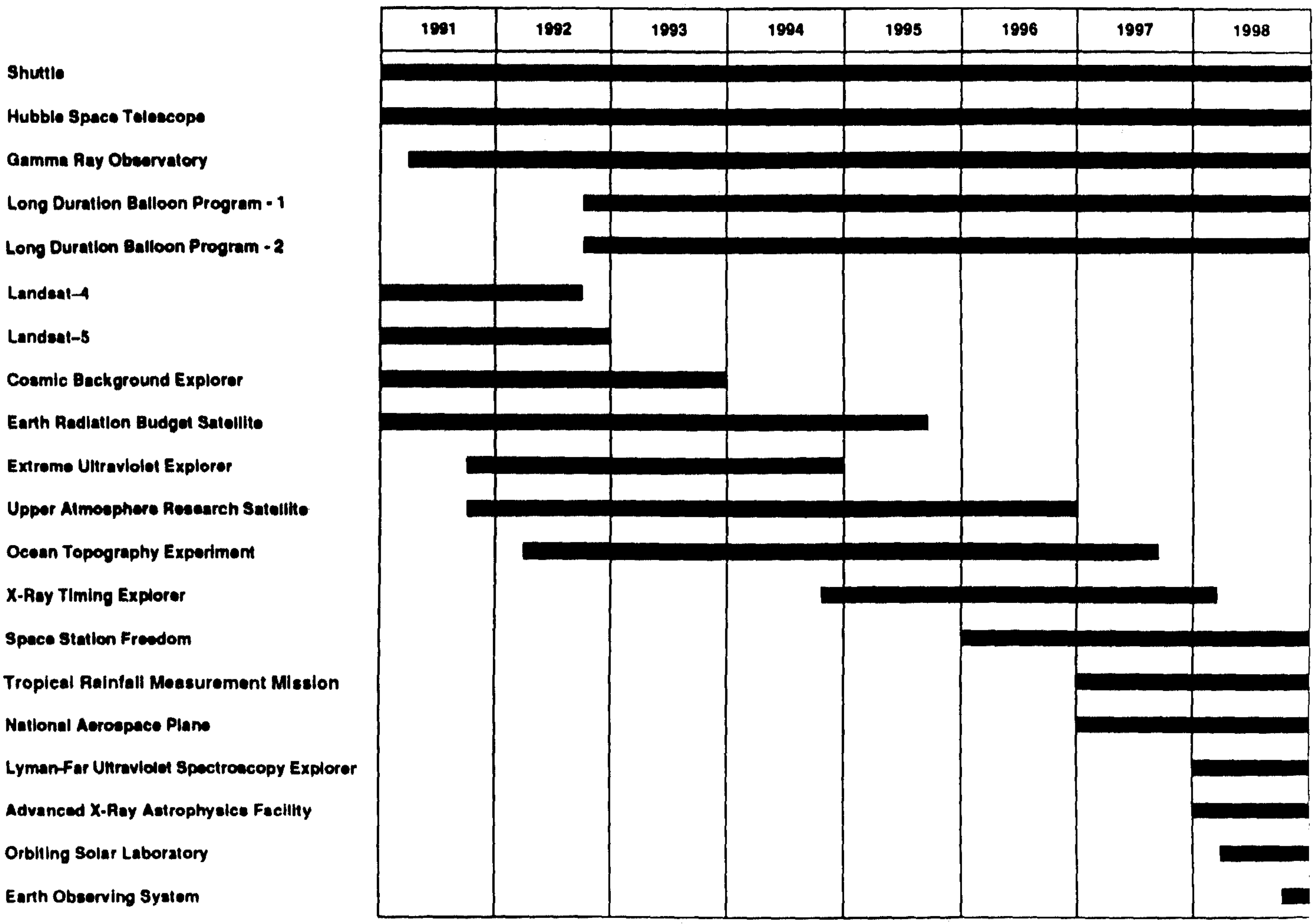
Although it has collected these data, NASA still keeps no records of the time spent by NCC operators in resolving conflicts, nor has it measured how adding new TDRSS users will affect active-period scheduling in the future. As a result, NASA has no precise measure of just where its scheduling process stands and cannot predict what effect the addition of new TDRSS users to the system would have on the effort to resolve schedule conflicts. Data from April 1991 indicate that the addition of one new TDRSS user, the Gamma Ray Observatory, resulted in roughly a 30-percent increase in the number of events scheduled during the active scheduling period (from an average of 961 events to 1263). The April data did not indicate if this increase stressed the scheduling system or how well the system might be able to accommodate increasing numbers of users.

NASA has conducted several studies to assess the overall capacity of the TDRSS network to support planned future missions. NASA's projections show sufficient TDRSS capacity to accommodate missions planned for the near future. However, only one study, conducted in 1987, included a rough estimate of the manual effort required for conflict resolution, and that estimate was based on a simple straight line projection for the impact of future users on the system. Spacecraft operators argue that an exponential curve would be a more appropriate model for TDRSS scheduling. Given the lack of detailed data on the impact of adding new TDRSS users, NASA's simple linear estimate may not adequately account for the expected demands of increasing numbers of users.

TDRSS Scheduling Work Load Will Soon Increase

As more TDRSS user spacecraft are launched, contention for single-access service can be expected to rise. As of April 1991, seven spacecraft, including the space shuttle, were using TDRSS. NASA officials acknowledge that present users are already requesting single-access service at a higher rate than their forecast had predicted. Compounding this, in 1991 alone, three new missions—the Gamma Ray Observatory (launched successfully in April), Extreme Ultraviolet Explorer, and Upper Atmosphere Research Satellite—will each begin competing for single-access service along with Hubble, the shuttle, and other current users. NASA spacecraft operations officials said that demand for single-access service is, in their opinion, approaching the effective limits of system capacity. Figure 2 illustrates the spacecraft that plan to use TDRSS from 1991 through 1998.

Figure 2: Current and Planned TDRSS Users[a]



[a]Includes both single and multiple access service.

Failure to Schedule TDRSS Service Could Have Economic and Scientific Ramifications

The TDRSS system to date has generally been very reliable in providing service when needed. However, any failure of TDRSS to support user missions could have serious economic and scientific ramifications. For example, some complex spacecraft, such as Hubble, require contact through TDRSS to receive command loads from the ground on a regular—usually daily—basis. Although it has not happened yet, if TDRSS were unable to provide the requested contact times, the craft would go into safe-hold mode, a condition that is costly to recover from and which temporarily prevents the craft from performing its mission. According to a Hubble operations official, Hubble would require about a day of effort, which costs about $1 million, to recover from a safe-hold condition. Furthermore, because celestial occurrences are unpredictable, TDRSS scheduling must be flexible enough to support the scientific missions of its user projects. Without the ability to observe rare targets of opportunity, scientists may miss clues to important scientific discoveries.

Spacecraft projects, both current and planned, report that they intend to use a strategy of over-scheduling critical TDRSS contacts to ensure that important commands get transmitted to their spacecraft. If a problem should arise that prevents an earlier contact time from taking place as planned—if it is preempted by a higher priority user, for example—then the commands can be transmitted at a later time, scheduled specifically in anticipation of just such a problem. The Hubble Space Telescope, Gamma Ray Observatory, and Upper Atmosphere Research Satellite all report using this strategy. In over-scheduling contact time, however, the scheduling problem may be compounded because it will reduce the amount of time available to other users.

Improvements to the System Have Been Identified

According to NCC officials, developing an efficient NCC scheduling system to accommodate future growth will require an entirely new system design. NASA's long-range plan for networks states that the inflexibility of the current NCC data system architecture, which includes the scheduling system, is one of the main reasons a new system is needed. NASA recognizes the need for such a system and currently plans to have one developed by 1997.

In the meantime, NASA's TDRSS network operations personnel have identified several software enhancements that could improve current system shortcomings during the active-scheduling period. For example, the computer display that operators use to resolve schedule conflicts could be programmed to show all the details of both requests, with the specific conflicting details highlighted. A simple graphic time-line display could then be used to quickly show the operator what times are still available to reschedule a rejected request. Operators of NASA's older ground station network have such tools available on their scheduling system.

Further, other basic system enhancements have been identified, in addition to the conflict resolution tools, that could help resolve operational problems associated with developing the TDRSS schedule efficiently. For example, some of the supporting data parameters associated with a service request often apply to more than one request, yet the system has no way of retaining that data once a request has been processed or rejected. As a result, each resubmitted request, as well as every new request, must be built entirely anew, instead of referring to data that was already prepared and submitted in other requests.

Recognizing the opportunities for scheduling system improvements, NASA has already developed conflict resolution tools for the forecast period similar to those mentioned above. While adding these and others to the active period would help, NASA currently has no plans to test and implement them. TDRSS scheduling officials say that this software, which represents approximately 11,000 lines of computer code and would cost roughly $600,000 to test and implement, would add to the efficiency and effectiveness of their operations. However, officials have chosen not to implement this upgrade partly because they believe the improvements are not essential to scheduling operations and partly because doing so would take resources away from another major software development effort underway at NCC.

Specifically, major changes must be made to the NCC data system software to accommodate a new ground terminal at White Sands, New Mexico, that is scheduled to be operational by January 1993, and an upgrade of the old terminal planned for 1994. NASA officials decided that they did not have the resources available to work on both the software upgrade to support the ground terminals and the conflict resolution upgrade, without the risk of being late in supporting the ground terminal development. The upgrade to support the ground terminals is a much larger project. It involves about 90,000 lines of code and is expected to cost $21.5 million between fiscal year 1991 and fiscal year 1994.

Given these other pressing needs, NASA officials decided to accept the risk to scheduling effectiveness of delaying these software enhancements. They believe that the data collected on current scheduling activity implies that the risk is not great.

Conclusions

TDRSS is of major importance to NASA. It has already cost approximately $3 billion, excluding the additional billions of dollars invested in earth-orbiting satellite projects. Beyond cost, however, TDRSS is an essential communications link, enabling operators to control spacecraft so that they can complete their missions and contribute valuable scientific knowledge. Given this, it is critical that NASA fully understand the limits of the system, and take advantage of any opportunities that would minimize the possibility that spacecraft projects will not be able to fully utilize TDRSS to carry out their missions.

On the basis of its past experience and limited data collected over several recent months, NASA believes scheduling system improvements can be deferred until a new system is developed in 1997. We believe, however, on the basis of discussions with TDRSS users and operators, that this level of confidence is unwarranted, especially since no precise assessment of the impact of near-term future TDRSS users has been made. NASA should find out whether the current scheduling system will be able to handle the increasing user demand for TDRSS services between now and the late 1990s, especially at times when the shuttle is flying.

Recommendations

Accordingly, we recommend that the Administrator, NASA, assess the ability of the current scheduling system to accommodate the additional TDRSS users expected in the near future. Basic measurements to support this assessment would likely include the volume of user requests that are received and rejected at all points in the scheduling process, the number of those requests that must be altered and resubmitted, and the time it takes to reach final resolution of conflicts. We recommend that NASA use the results of this assessment to reevaluate its decision not to implement software enhancements that have been identified by scheduling operations personnel as critical to improving productivity.

Agency Comments and Our Evaluation

In commenting on a draft of this report, NASA expressed the view that the analysis supporting our conclusions and recommendations was based upon significant speculation and failed to take into account actual successful NASA experience. NASA believes the report raises an undue level of concern and that its current system will be able to cope with the anticipated addition of new users through 1997. It admits that changes would benefit the system, but believes they are not essential.

We do not agree with NASA's characterization of our supporting analysis. We acknowledge NASA's belief that improvements to its scheduling system are not needed in the near term, but we also point out that NASA's confidence in this matter is not based on any precise assessment of the impact of planned future TDRSS users. Our conclusions are based on the careful review of all data available regarding the scheduling system's performance, as well as discussions with the system's managers about the kinds of data that could be collected to measure such performance. Our assessment of the potential impact of a scheduling system failure—the inability to handle increasing user demand for TDRSS services—is based on detailed discussions with TDRSS users as well as scheduling system officials. Our recommendation to assess the scheduling system's ability to handle the expected work load follows logically from our conclusions.

We believe that the level of concern expressed in this report is justified. Our review included discussions with officials from four of the five major satellite missions scheduled to launch before 1997 that plan to use TDRSS; all were concerned about scheduling TDRSS support. Officials involved in the day-to-day operation of the scheduling system also expressed concerns. We believe the report accurately reflects the level of worry expressed to us by these individuals, all closely involved in TDRSS scheduling activities.

We recognize that the scheduling system has proven satisfactory under the work loads it has experienced to date. Yet we remain concerned that an increasing work load could well reduce the system's effectiveness. The report also acknowledges the tradeoff NASA made in deciding not to implement the identified scheduling system enhancements. While recognizing the need for tradeoff decisions, we believe that NASA does not yet have sufficient data to support its conclusion that improvements to the system are not essential to assuring continued reliable support. NASA has recently begun collecting some data that could be used to help prepare an assessment of the scheduling system's capability to support planned upcoming TDRSS users. If a thorough assessment confirmed this position, we would not take issue with NASA's decision to delay the system enhancements.

NASA's detailed comments on the report, along with our response, are contained in appendix III.

As arranged with your office, unless you publicly announce the contents of this report earlier, we plan no further distribution of it until 30 days from the date of this letter. We will then give copies to appropriate congressional committees; the Administrator, NASA; and other interested parties. Copies will also be made available to others upon request.

This work was performed under the direction of Samuel W. Bowlin, Director, Defense and Security Information Systems, who can be reached at (202) 275-4649. Other major contributors are listed in appendix IV.

Sincerely yours,

Ralph V. Carlone
Assistant Comptroller General

Contents

Abbreviations

GAO	General Accounting Office
IMTEC	Information Management and Technology Division
NASA	National Aeronautics and Space Administration
NCC	Network Control Center
TDRSS	Tracking and Data Relay Satellite System

Objective, Scope, and Methodology

In December 1990, the House Committee on Science, Space, and Technology asked us to review the efficiency and effectiveness of TDRSS scheduling. To do this we obtained available quantitative data on the current level of scheduling activity at NCC and determined that an accurate quantitative measure of scheduling efficiency and effectiveness was not available. Lacking such a measure, we interviewed schedule operators and NASA operations officials to obtain their views on scheduling efficiency and effectiveness. We also reviewed technical documentation on plans and other proposals for enhancements to or replacements of the current NCC system.

We also interviewed the principal current users of the TDRSS system, as well as representatives from missions planned to be launched in the near future to obtain their assessments of the efficiency and effectiveness of TDRSS scheduling. Current users interviewed included officials of the Cosmic Background Explorer, Hubble Space Telescope, Landsat 4 and 5, and the Gamma Ray Observatory. Near-term future users interviewed included officials of the Upper Atmosphere Research Satellite, Extreme Ultraviolet Explorer, and X-ray Timing Explorer.

We obtained agency comments on a draft of this report from officials at NASA headquarters and the Goddard Space Flight Center. These comments have been incorporated into the report where appropriate. We performed our work from September 1990 to June 1991, in accordance with generally accepted government auditing standards.

Hubble Space Telescope Scheduling

Along with the space shuttle, Hubble is one of the heaviest users of TDRSS. Scheduling TDRSS support for Hubble is a long, complex, and inflexible process that is carried out in an iterative fashion, beginning with planning the scientific objectives, then factoring in limitations imposed by the spacecraft itself and the constraints of TDRSS support. All of this activity must be carried out prior to combining Hubble's requirements with those of other TDRSS users, as discussed in this report.

Developing the Initial Science Plan

The Space Telescope Science Institute in Baltimore, Maryland is responsible for preparing the official requests for Hubble to perform scientific observations. These requests also state overall TDRSS communication requirements needed to support each observation.

The Space Telescope Science Institute requires that scientists make precise, highly detailed requests for observations. These requests specify exact timing requirements relative to the spacecraft's orbit. In preparing their requests, the scientists do not have the option to state their requirements generically, that is, to specify ranges of values instead of precise parameters, which would then allow the schedulers more latitude in fitting the planned observations into the rest of the schedule. The Institute takes the scientists' proposals and generates the Institute's official proposed schedule of science activities, called the Science Mission Specification. The specification is usually prepared for a 7-day period and takes from 5 to 10 hours of computer time at the Institute to generate. Although two more stages of schedule refinement are necessary at this point, the Institute's specification requests services in very specific terms, leaving little room for adjustment later in the scheduling process.

Developing the Detailed TDRSS Service Request

The Institute's specification is forwarded to the Space Telescope Operations Control Center at Goddard Space Flight Center, which is responsible for operating Hubble and maintaining its health and safety. The computer system at Goddard incorporates health and safety contacts into the request, validates the planned scientific observations, and provides additional detailed TDRSS support requirements for those observations. It takes 6 to 12 hours to run the Institute's specification through this system and generate a complete, detailed schedule request to be submitted to NCC. The output is analyzed at Goddard, and if any changes in planned observations are necessary, those changes are worked out with personnel from the Institute. If a major change is required, a new specification will have to be generated at the Institute and run through the Goddard system again.

Spacecraft Design Limitations

Both of the Hubble scheduling phases need to take into account limitations imposed by the Hubble spacecraft itself. Hubble is in low earth orbit, which means that the Earth is frequently an obstruction to viewing the sky. Hubble's field of view is comparable to that available from a point one inch away from the surface of a 25-foot diameter beach ball. Furthermore, even if Hubble's desired target is in its view, its large solar panels may be blocking the view of its antenna to the nearest TDRSS satellite. The telescope must also avoid pointing toward the sun, which would destroy its sensitive instruments. The spacecraft can only change its orbital position very slowly—about as fast as a minute hand on a wristwatch—so the extent to which the spacecraft needs to be moved and the time to accomplish that need to be taken into consideration.

In addition to viewing constraints, the basic operations of the spacecraft make considerable demands on TDRSS. The two on-board computers each need to be loaded with software commands twice a day. These software loads are so critical that they are each triple-scheduled to ensure that they get done. Thus 12 TDRSS events per day are planned just to keep the on-board computers running.

About twice a day events are scheduled that require Hubble to be pointed precisely at some point in the sky. Hubble uses a complex system of sensors that search for various guide stars that enable it to precisely locate a small area of the sky. However, this process is tedious and time-consuming, and usually requires the project scientists to examine feedback from the telescope in real time and issue commands to fine tune the pointing of the spacecraft. Some 20 minutes of uninterrupted TDRSS support may be needed for this effort, and must be factored into the planned TDRSS request.

Further constraints also exist, all of which must be considered when planning TDRSS contacts. The number of constraints is so extensive that technicians cannot manually take them all into account when planning a schedule; extensive computer validation is necessary.

Comments From the National Aeronautics and Space Administration

Note: GAO comments supplementing those in the report text appear at the end of this appendix.

NASA

National Aeronautics and
Space Administration

Washington, D.C.
20546

Office of the Administrator

July 30, 1991

Mr. Ralph V. Carlone
Assistant Comptroller General
Information Management and
Technology Division
United States General Accounting Office
441 G Street, NW
Washington, DC 20548

Dear Mr. Carlone:

This is the National Aeronautics and Space Administration's (NASA) response to the General Accounting Office (GAO) Draft Report entitled "Space Communications: Scheduling System Improvements Could Enhance Future Spacecraft Operations," IMTEC-91-48.

The basic conclusion of the draft report questions NASA's assessment and decision to defer implementation of TDRSS scheduling system improvements until 1997 leading to the further conclusion that the "system may be unable to handle the increasing user demand for TDRSS services between now and the mid-1990s, especially at times when the shuttle is flying." The draft report recommends that the NASA Administrator assess this situation and, on the basis of such assessment, decide whether NASA may want to reconsider its decision.

Please be advised that, in NASA's view, the analysis supporting the conclusions and recommendations in the draft report is based upon significant speculation and fails to adequately take into account actual successful NASA experience. NASA firmly believes that the TDRSS scheduling system, which includes an appropriate balance of people, hardware, and software, has consistently met the needs of users, and that the current system will be able to cope with the anticipated addition of new users through 1997.

We do not believe the currently-projected workload will cause a "collapse" of the system as intimated in the draft. While admitting that improvements would benefit the system, they are not mandatory to assure continued reliable support. NASA's decision not to implement scheduling system enhancements until 1997 was based on a carefully considered trade-off between the cost and risk of modifying very complex scheduling software, and the priority of developing software to assure that the overall network control system could properly interface with the planned second ground terminal.

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We believe that the overall content of your report evidences an undue level of concern. We have collected significant information on TDRSS operations for years, which we believe adequately supports our decision to postpone enhancements until a new system is implemented. We recognize, however, that the draft report suggests that collection of specific types of information could provide additional insights that we believe would support our position not to make scheduling system modifications at this time. In support of this, and as noted in your report, we have already begun collecting some of this data.

Enclosed for your consideration are several observations and suggestions which, if implemented, would result in a more balanced report. Thank you for the opportunity to comment on the draft report.

Sincerely,

John E. O'Brien
Assistant Deputy Administrator

Enclosure

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
OBSERVATIONS AND SUGGESTIONS WITH REGARD TO
THE GAO DRAFT REPORT IMTEC-91-48
"SPACE COMMUNICATIONS: SCHEDULING SYSTEM IMPROVEMENTS
COULD ENHANCE FUTURE SPACECRAFT OPERATIONS"

See comment 1.

1. GAO Statement: "... A lack of automated tools has made the conflict resolution process more tedious, labor-intensive, and potentially error-prone than necessary."

   NASA Comment: We believe this statement is judgmental. Our previous experience at scheduling the ground network taught us that human knowledge, intelligence and judgment are mandatory to effective scheduling of a spacecraft support network. NASA never intended that the scheduling system be entirely automated. In support of this human-in-the-loop process, we currently have several tools in daily use, four during the forecast period and two during the active period.

   We disagree with the use of the term "labor-intensive." The scheduling system is staffed with three forecasters on Day shift Monday through Friday, two active schedulers on the Day and Evening shift Monday through Friday, and one active scheduler on Midnight and Weekend shifts. During a Shuttle flight, the active position is augmented to two per shift around the clock.

   We also disagree with the use of the term "error-prone." The best human or computerized system, regardless of purpose, can be considered to be error-prone to some degree. Our actual experienced scheduling error rate is quite low. In the year from July 1, 1990 through June 30, 1991, there were only three Network Control Center (NCC) scheduling errors, impacting four user events out of more than 44,000 events supported.

See comment 2.

2. GAO Statement: "... A breakdown or degradation in the scheduling system could result in users being unable to complete their missions."

   NASA Comment: We believe this statement, although within the realm of possibility, is highly speculative. We periodically experience perturbations when a Shuttle mission must be rescheduled quickly. We recently experienced a TDRS anomaly which deprived us of all TDRS-East services for 12 hours. The scheduling system was resilient enough to accommodate these scheduling activity "spikes." The scheduling system benefits from the inclusion of trained personnel who can adapt to changing conditions and workload variations. Compensatory adjustments can be made thus precluding any breakdown or degradation of the system.

Enclosure

See comment 3.

3. GAO Statement: "The two biggest sources of schedule disruption by far are the Hubble Space Telescope and the space shuttle."

   NASA Comment: We suggest that schedule "disruption" be changed to schedule "revision" to more accurately describe the scheduling process, which is iterative.

See comment 4.

4. GAO Statement: "A space shuttle launch also severely limits the availability of some TDRSS services..."

   NASA Comment: The availability of TDRSS services is a resource capacity issue. We suggest that where appropriate the GAO differentiate between TDRSS resource capacity and the scheduling system.

See comment 5.

5. GAO Statement: "... The NCC data system does not, however, provide all the basic automated tools and capabilities that are needed to support its TDRSS scheduling function."

   NASA Comment: This statement is misleading. We are successfully scheduling the TDRSS today. As stated previously, we do have several tools currently in use. We believe additional tools could facilitate the function but are not mandatory.

See comment 6.

6. GAO Statement: "... NASA officials report that the need for prompt and efficient conflict resolution is more critical during the active period, when no tools are available."

   NASA Comment: We believe that conflict resolution during the active period is equally critical, not more critical. We suggest the above statement be changed to "conflict resolution is more difficult during the active period because fewer tools are available."

See comment 7.

7. GAO Statement: "... According to NCC operations officials, several phone calls over the space of a few hours or more may be needed, ..."

   NASA Comment: The resolution of conflicts requires interaction between the Payload Operations Control Center (POCC) and the NCC. In addition, the POCC requires time to evaluate the impact of conflict-driven changes on its experiment plans. Multiple automated tools will not eliminate the need for this interaction. The NCC scheduling operator is not at liberty to unilaterally reschedule a user event.

See comment 8.

8. GAO Statement: "... Users are concerned that targets of opportunity will be missed due to the difficulty in scheduling TDRSS support."

   NASA Comment: Targets of opportunity are usually short lead-time events and are normally handled by real-time scheduling. We are capable of scheduling an event up to 10 minutes before start time. We are aware that the Gamma Ray Observatory (GRO) expressed a concern, but it was expressed in early November 1990, 5 months prior to launch. On June 7, we responded to GRO's first scientific target of opportunity request to support data acquisition from X-class solar flares. We have also satisfied Hubble Space Telescope's (HST) requests for targets of opportunity in addition to extensive Landsat requirements, handled on a target of opportunity basis, during the past year.

See comment 9.

9. GAO Statement: "... Spacecraft operators argue that an exponential curve would be a more appropriate model for TDRSS scheduling."

   NASA Comment: We believe the straight line model we have been using has been accurate for our projections. The straight line model works because our resources are not saturated. If GAO desires, we can arrange a session to explain the mathematics associated with linear and exponential projections.

See comment 10.

10. GAO Statement: "... NASA spacecraft operations officials said that demand for single-access service is, in their opinion, approaching the effective limits of system capacity."

    NASA Comment: Again, this is a resource capacity issue, not a scheduling issue. As workload increases, capacity limits are reassessed, and resources are augmented, as needed.

See comment 11.

11. GAO Statement: "... If TDRSS is unable to provide the requested contact times, the craft goes into a safe-hold mode, ..."

    NASA Comment: We do not understand the implication of this statement. HST has gone into several safe-holds during its 15 months in orbit. None was caused by failure of the Space Network to provide TDRSS services or by the scheduling process. Safe-hold mode is a pre-programmed reaction, initiated by the spacecraft, and designed to protect it from potential damage brought about by one of several factors such as gyro failure, out of limit torques or command loads not being executed in a timely manner. All spacecraft have a safehold mode of operation. Communications between the spacecraft and ground are maintained even during the safe-hold mode of operations. The safe-hold mode is not related to TDRSS scheduling. Moreover, the scheduling system, which includes the human element, recognizes that spacecraft health and safety hold a higher priority than science and engineering and are treated accordingly in conflict resolution.

See comment 12.

12. GAO Statement: "... NASA ... take advantage of opportunities that would minimize the possibility that spacecraft projects will not be able to fully utilize TDRSS to carry out their missions."

NASA Comment: Encouraging the use of the multiple-access (MA) capability by the Cosmic Background Explorer (COBE) in addition to its use of single-access service and movement of the spare TDRS to the West position to supplement damaged capability on TDRS-West are two major examples of how NASA already takes advantage of opportunities to assure service to users. Again this is a resource capacity issue, not a scheduling issue.

See comment 13.

13. GAO Statement: "... we ... determined that an accurate quantitative measure of scheduling efficiency and effectiveness was not available."

NASA Comment: We do not understand how GAO reached this determination. We suggest that a demonstrated measure of scheduling efficiency is the balanced use of personnel, hardware and software to perform the task in a responsive manner. The measure of effectiveness has been demonstrated by support proficiency in meeting or exceeding the users documented requirements.

GAO Comments

1. NASA takes exception to the assertion that "... A lack of automated tools has made the conflict resolution process more tedious, labor-intensive, and potentially error-prone than necessary." NASA states that it never intended to entirely automate the scheduling system because human knowledge, intelligence, and judgment are prerequisite to effective scheduling. NASA also disagrees that the system is labor-intensive because its scheduling staff is small. Finally, it disagrees with the term "error-prone" because its error rate at NCC has been low to date.

We agree that the scheduling process could not be totally automated and do not suggest that it should be. However, we believe it is important to distinguish between functions requiring human judgment and tasks that can be automated. Access to information about services requested and times available does not require human judgment; the use of it does. Having to access it manually is a tedious and labor-intensive process. Automated tools could make this information more readily available to the scheduler.

NASA mentions that several "tools" are already in daily use, including two in the active scheduling period. However, the items NASA refers to are not genuine scheduling tools of the type we discuss in the report. In earlier, informal comments on a draft of the report, NASA identified these two active period "tools." One is simply the basic system function of accepting or rejecting requests, which, as discussed in the report, is limited and requires manual effort that could be automated. NASA officials involved in day-to-day TDRSS scheduling told us that the other active period tool, a capability to specify ranges of times instead of specific times, is not used at all by the spacecraft projects. None of the tools specified by NASA officials as needed to improve active period scheduling is currently available.

While we commend NASA for the low error rate it has experienced to date in scheduling TDRSS usage, our point is that the error rate could increase as scheduling activity intensifies with additional users. The implementation of automated tools to assist schedulers, while not guaranteeing against errors, could reduce this potential risk.

2. NASA characterizes our suggestion that the scheduling system could break down as a possibility, but highly speculative, and cites current examples of its handling of anomalies as evidence of the resilience of the system. It states that its trained personnel have the ability to compensate for changing conditions and work load variations.

We believe our concern about the potential for the scheduling system to break down is valid, based on analyses of available data and extensive discussions with NASA officials and TDRSS users. As stated in the report, NASA has not assessed the impact of additional users on the scheduling system. We believe current performance is not an adequate measure of how the system will perform when new TDRSS users are added.

3. NASA suggests that "revision" be used to describe the impact of Hubble and the space shuttle on the schedule rather than "disruption" because the scheduling process is iterative.

A "revision" to the scheduler can be a "disruption" to the user, and we believe that the use of the latter term is appropriate. When a planned shuttle launch is deferred and rescheduled—as frequently happens—other planned TDRSS usage during that period often must be cancelled to make way for the launch. Those other users must then rearrange their own schedules to try to accommodate their cancelled activities at other times. TDRSS users whom we interviewed made it clear that these changes to the TDRSS schedule were indeed disruptive. The more launch delays and consequent schedule iterations, the greater the disruption.

4. NASA suggests that we differentiate between issues related to TDRSS resource capacity and those relating to the scheduling system.

These two issues cannot be neatly separated from one another and dealt with independently. It is precisely at the point when resources begin to become scarce that the efficiency and effectiveness of the system in scheduling the remaining resources becomes critical. It is the reason why we discuss the context of scarce resources when introducing our concerns about the scheduling system.

5. NASA says our statement that the NCC data system does not provide all the automated tools and capabilities needed to support TDRSS scheduling is misleading. NASA mentions that it currently has scheduling tools in use and that additional tools would help but are not mandatory.

We disagree. As discussed earlier, NASA has not implemented any of the tools identified as critical to improving scheduling system performance. Further, when analyzing the current capabilities of the scheduling system for its long-range plan, NASA officials came to the same conclusion stated in our report. We agree with NASA officials' assessment that automated tools would help to resolve operational problems in the scheduling system.

6. NASA disagrees with the opinion that prompt and efficient conflict resolution is more critical during the active period than during the forecast period.

As noted in the report, TDRSS operations officials themselves expressed the opinion that conflict resolution is more critical during the active period. Because less time is available to resolve conflicts, schedulers must react more quickly and efficiently during the active period. Automated conflict-resolution tools could make a critical difference during this period.

7. NASA remarks that automated tools will not eliminate the need for telephone calls between NCC's scheduling operator and the user's control center, and time for the user's control center to evaluate schedule changes.

We agree that conflict resolution requires interaction between NCC and users' control centers; we do not suggest that all interaction could be eliminated through automation. However, automated tools could reduce the amount of interaction by giving the NCC scheduler quicker access to information that otherwise is only available through a telephone call.

8. In reference to users' concerns about accommodating targets of opportunity, NASA mentions that it has satisfied these types of requests for the Gamma Ray Observatory, Hubble Space Telescope, and Landsat.

We recognize that NASA has handled certain requests for targets of opportunity service for these missions. However, we believe that current performance is not a measure of how well the scheduling system will do in the future, especially when additional users such as the Extreme Ultraviolet Explorer and X-ray Timing Explorer, are launched. Officials from these projects said their target of opportunity requirements would be extensive.

9. NASA comments that a straight-line model, rather than an exponential curve, has been accurate for projecting how its system would handle the work load it has had to deal with. The straight-line model works, NASA says, because its resources have not been saturated.

We agree that a straight-line model has successfully predicted the level of scheduling activity at NCC until now, and that the reason the straight-line model has worked is, indeed, because the scheduling system has not yet been pushed to its limit (saturated). However, as the report makes clear, our concern is with the impact of additional users, not current or past operations. As we have discussed with NASA officials and they agree, once the scheduling system begins to reach its limit, the difficulty in satisfying each new request for services must be modelled exponentially rather than linearly. The point we make in this section of the report is that as the scheduling system nears its limit, scheduling TDRSS services is likely to become dramatically more difficult, rather than just incrementally harder.

10. NASA remarks that the comments of its spacecraft operations officials regarding the demand for single-access TDRSS service approaching the effective limits of system capacity is a resource capacity issue, not a scheduling issue.

We agree with NASA that the matter of reaching the limits of TDRSS single-access capacity is about the capacity of TDRSS itself, not the scheduling system. However, as discussed in comment 4 above, we believe that the efficiency and effectiveness of scheduling becomes critical when TDRSS resources start to become scarce. Thus, a fair representation of potential TDRSS scheduling problems demands consideration of the system's capacity limitations.

11. NASA notes that past instances in which the Hubble Space Telescope has gone into safe-hold mode were not caused by a failure of the TDRSS scheduling process. NASA notes that spacecraft health and safety hold a high priority when resolving schedule conflicts.

We are aware that past instances in which the Hubble Space Telescope went into safe-hold mode were not caused by a failure of the scheduling process, and we do not dispute NASA's general description of the purpose and nature of safe holds. However, our statement describes the potential effects on a spacecraft of the failure to provide normal communications service to it. Hubble officials confirmed that Hubble will automatically go into safe-hold mode if it does not receive its daily uploads of operational instructions, which are transmitted through TDRSS. We have clarified our statement to ensure that the reader understands we are referring to potential future events.

12. NASA comments that it is already taking advantage of some opportunities to assure service to users by encouraging COBE to use multiple-access service and by activating the spare TDRSS satellite.

We believe that these examples demonstrate the importance of maximizing the efficiency and effectiveness of the entire TDRSS system. While NASA has alleviated some potential TDRSS system shortfalls by taking these actions, such actions do not address the potential for failure within the scheduling system. Enhancing the scheduling system could further minimize the possibility that spacecraft projects will not be able to fully utilize TDRSS to carry out their missions.

13. NASA remarks that it does not understand how we determined that an accurate quantitative measure of scheduling efficiency and effectiveness was not available. NASA suggests that a balanced, responsive use of personnel, hardware, and software is a demonstrated measure of scheduling efficiency, and that support proficiency in meeting or exceeding TDRSS users' documented requirements is a measure of scheduling effectiveness.

Our conclusion is based on discussions with TDRSS operations and program management officials, who told us that no comprehensive data have been collected that measure the number of conflicts that occur and the time required to resolve these conflicts. Without such data, scheduling efficiency and effectiveness cannot be measured quantitatively. Further, the success of the system under light loads is not a measure that can be meaningfully applied to the increasing work loads projected for the future.

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