Effects on Station Productivity of the RF and Antenna Automation Plans

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In May 1975, a demonstration of the RF automation plan was held at the Mars Station (DSS 14). This automation design used a central computer to calibrate and configure the RF subsystem automatically. In August 1975, a demonstration was held at the Venus Station (DSS 13) to show the operation of a remote automatic pulsar data acquisition program. This article attempts to identify the effects of implementation of either of these plans at the deep space stations on network operations, especially in the areas of increasing available tracking time and reducing the level of effort required in the maintenance of network equipment. The percentage of station time spent in calibration can be reduced significantly by automatic calibration and configuration. The amount of scheduled maintenance time spent in corrective maintenance can be reduced due to the capability of automated equipment for self-diagnosis. Station downtime during scheduled tracking time will be reduced to the extent that operator errors will be minimized.

I. Introduction

The goal of the first RF automation demonstration performed in May 1975 was to configure and calibrate automatically the DSS 14 RF subsystem, consisting of two Block IV receivers and one exciter, two Block IV subcarrier demodulator assemblies (SDAs), the Microwave Subsystem, the noise-adding radiometer, and the high-power S-band transmitter—and then automatically acquire the carrier and subcarrier. A central computer accepted configuration messages from the demonstration operator and distributed them to the appropriate subassembly controllers. Diagnostic messages from the subassemblies were printed on a teletype for the demonstration operator's use. In areas where hardware redundancy existed, detection of a failed module within a hardware assembly caused a backup assembly to be automatically switched in and the hardware string to be reconfigured to accommodate the new equipment. Several changes are planned for the next demonstration in November 1976, including replacing the PDP-11 minicomputers used in the previous demonstration with Intel 8080 microcomputers, eliminating the polling scheme adopted in the software by developing the new software on an interrupt-driven basis, and using the high-level programming language PL/M instead of RT-11 Basic. The demonstration operator will be provided with more powerful software tools for handling unexpected events.

The plan to automate antenna operation at DSS 14 began with the development and demonstration in August 1975 of the remote automatic pulsar data acquisition program at DSS 13. After initial configuration by station personnel, the operator in this demonstration, who was located at JPL, typed in position information and caused the antenna to be pointed at a pulsar and then begin sidereal rate tracking. At the same time, the data collection hardware was automatically initialized to begin recording pulsar data on magnetic tape. At DSS 13, one XDS 930 and two XDS 910 computers were used in the pulsar observing project. In adapting the antenna pointing portion of the program for use at DSS 14, a Modcomp II/25 will replace the antenna pointing system's XDS 910.

This article is not an analysis of the technology used in either of the two automation projects. Rather it is an attempt to identify the effects of implementing either of these plans at the deep space stations on network operations, especially in the areas of increasing available tracking time and reducing the level of effort required in the maintenance of network equipment.

II. Station Productivity

Evaluation of the effect of automation on network productivity, which can be defined as

$$\text{network productivity} = \frac{\text{delivered tracking hours}}{\text{manhours expended in DSN}}$$

reduces to examining the changes in delivered tracking hours due to implementation of the automation plans when the manpower required for operation of the stations can be expected to remain constant. The antenna automation plan will reduce the workload of the two crew members stationed in the 64-m antennas by introducing hydraulics monitoring hardware inside the antenna. However, since these crew members also perform duties other than monitoring hydraulics systems, the need for operators in the antenna will remain. In connection with increasing available tracking hours at the deep space stations, three areas in particular are interesting to consider; these are the reduction of precal time, the reduction of maintenance time required to repair failed equipment, and the reduction of downtime due to equipment failure or operator error. There is, of course, no guarantee that increasing available tracking hours will necessarily increase actual tracking hours by an equivalent amount; however, radio science can profitably occupy available tracking time not required for spacecraft tracking.

III. Calibration Time

Table 1 depicts the estimated decrease in the total number of hours requried per year in completing countdowns at the deep space stations. These data were collected from the DSN weekly schedules for CY 1974. There are certain exceptions to the claim that a level-two countdown can be completed in 45 min. This is true only if certain other functions which were not under computer control during the first RF automation demonstration and are not planned to be during the second are, in fact, brought under the control of the RF automation central computer. Several operations in the precalibration of the high-power transmitter require manual operation of equipment in the antenna; valve positions for the heat exchangers must be set for the appropriate transmitter, a number of high-current switches must also be configured for the transmitter to be used in the track, and the main motor generator, if not already running, must be started. None of these operations is time-critical, and they could be accomplished at a time prior to the start of the precal procedure in the control room.

The Y-factor chart cannot at present be generated automatically, and the test signal control panel which serves to route the test signal is still operated from the front panel. In the first RF automation demonstration, the test translator was used in place of the test transmitter, which is not under computer control, to run automatic gain control (AGC) curves. Finally, the carrier suppression calibration requires manual installation and removal of attenuators in the receivers. If, in fact, interface hardware is added to allow computer control of these functions, then implementation of the RF automation plan can be expected to reduce total precal time about 77% over a period of a year. At present, the two crew members charged with monitoring the hydraulics equipment in the antenna perform the manual part of the transmitter precalibration procedure.

A level-one precalibration will be reduced in length only slightly because this procedure requires complete calibration of the Block III as well as the Block IV RF hardware, and there is no capability for computer control now installed in the Block III equipment. A level-two countdown treats only one string as being prime and the other as backup. Under the RF automation scheme, the

Block IV equipment comprises the prime string, and the Block III equipment need only be calibrated to level-three countdown conditions; this requires only a brief check for malfunctions and a three-point AGC curve instead of a full curve, but it must be done manually, since no capability exists for computer control of Block III equipment. The RF subsystem calibration is the major contributor to the length of the station precalibration procedure. The existing antenna precal procedure is still shorter than the 45-min estimate for the automated RF precal; therefore, antenna automation will have no effect on overall precal time.

IV. Station Maintenance Time

A reduction in the number of precal hours required at the stations yields an increase in the number of hours available for other activities. Table 2 and Fig. 1 show the present distribution of station hours per year in the Deep Space Network listed in DSN time utilization reports, as well as the resultant distribution if all available hours gained from the reduction in precal time were devoted to tracking, and the distribution if the additional hours were divided among various activities according to their present fraction of non-precal or maintenance time. These data also take into account the reduction due to the automation plans of the 20.2% of station time scheduled for maintenance; 3.2% of station time is scheduled for minor modification, during which time engineering change orders are implemented that require only 2 to 3 h for completion. Table 3 shows the distribution of maintenance time by activity estimated by maintenance personnel at DSS 14. It indicates that of this combined 23.4% of station time, 30% is spent in corrective maintenance, isolating the faults which have occurred during a track causing a hardware system to fail and necessitating switching to the backup string to minimize data loss. Since no repair of hardware occurs at the station, all of the 30% corrective maintenance time is spent actually isolating the fault to the circuit card or blue board chassis level.

Development of hardware which incorporates efficient fault isolation capabilities would lead to a reduction in corrective maintenance time at the stations. Maintenance time is distributed among the major hardware systems as shown in Table 4; 33% of all maintenance time is spent either on the antenna or receiver systems, with approximately 30% spent on the RF subsystem and 3% on the antenna.[1] The savings in station hours per year if automatic fault location techniques, which could be expected to reduce failure location time by 75%, were incorporated into the RF and antenna hardware only would be about 1200 h or a total of 2% of all station hours.

Another benefit which can be derived from the use of error-finding hardware is the automatic logging of failure information. If the failure of a module not only initiated a fault-locating routine in the controlling hardware but also caused a failure report to be recorded with information concerning the time and location of the fault, as closely as can be automatically determined, histories of particular pieces of hardware concerning failure rates and failure-prone areas could be easily accumulated.

V. Mission Changeover Time

Mission changeover time will not be affected significantly by the RF automation program due to the fact that most of the present 30 to 60 min of changeover time is spent loading programs in the digital and antenna systems, as well as waiting for the antenna to move. The time needed to reconfigure the antenna could not, of course, be reduced below the 15 min required to move the antenna from horizon to horizon.

VI. Station Downtime

Scheduled track time and delivered track hours differ by the amount of time that data flow is interrupted due to equipment failure or operator error. Table 5 shows the number of hours per year lost in the DSN during tracking time as recorded in discrepancy reports. The reductions in downtime credited to the two automation plans are derived from an estimation of the reduction in the number of operator errors producing data loss, the improvement in hardware assembly replacement and reconfiguration time with automatic failure backup, and the capability to constantly monitor conditions in the subsystem which are not now detectable to the operator. In addition, in the antenna automation scheme, a change in the procedure for reloading programs makes it possible to correct errors faster and thus save downtime.

Implementation of both RF and antenna automation plans would yield approximately a 20% decrease in the downtime recorded for 1 year of operation at all nine stations, the RF automation contributing about 18% and the antenna automation about 2% of the reduction. As can be seen in Table 6, the lost time listed in discrepancy reports as being associated with the antenna or the antenna pointing system would be reduced by 30% by the

[1] I. Eisenberger, *Estimated Manpower Costs for Operating and Maintaining Three Major Subsystems at DSS-11, DSS-12 and DSS-14*, IOM 331-75-30, Jet Propulsion Laboratory, Pasadena, Calif., April 15, 1975, p. 2.

antenna automation plan as designed at present. The time lost over all deep space stations due to failures or errors in the RF subsystem alone would be reduced by about 50%.

In almost all cases, as soon as a fault is detected in the primary data string, the station switches to the backup string to minimize lost data time. The exceptions to this rule, where there is no backup, are in the microwave hardware (excluding the masers), the antenna servo system, the high-power transmitter, and the Block IV exciter. In the last case, only the ranging capability is lost, since the Block III exciter would still be able to support command capability and a two-way doppler link. The 20-kW transmitter can often be used to replace the failed 400-kW transmitter. In all systems where redundancy does exist, therefore, no reduction in downtime is likely due to added fault location capability. The length of time necessary to accomplish the switch to the backup string depends on how thoroughly the second string was calibrated during the countdown procedure and whether equipment merely needs initializing or programs must be loaded to continue the track. Reductions in the time required to locate the fault in a failed assembly after the track is completed are probable, however, if additional fault diagnosis is possible with the automation hardware. In systems such as the antenna controller, where no backup equipment exists, controlling hardware can also be programmed to monitor changes in a system's condition and diagnose a problem with a list of most-probable causes. This would serve to narrow down the list of possibilities the station personnel would have to investigate in order to locate the problem.

Generating a complete automatic gain control curve, -176 to -90 dB at 5-dB intervals, requires about 40 min to set up the test transmitter and run the calibration. Accuracy is limited due to the instability of the readout near threshold. The AGC calibration is run again after the track, and the expected value during track is found by interpolation. The RF automation plan will reduce setup and run time for the AGC calibration to 15 min; variations in amplifier gain will be calculated frequently from measurements of system noise temperature change during the track to minimize errors induced by an incorrect AGC curve estimate. Errors concerning the AGC curve account for a number of data losses, each of which entails the loss of a significant portion of a spacecraft track. For example, a discrepancy report shows 495 min of outage when the station reported not having time to run an AGC curve.

Operator errors take many forms, some of which go unexplained in the discrepancy reports. Operator errors will not be eliminated by RF and antenna automation, since there will still be operators at the station; however, as the number of repetitive tasks are reduced, so are the opportunities for operator error. In some systems, operator errors can cause the loss of a whole track, as in the case where the wrong AGC curve was loaded in the Digital Instrumentation Subsystem. However, in the antenna or RF systems, they more often take the form of incorrect predict data being entered, causing an inability to lock onto the spacecraft signal. A discrepancy report shows 32 min of outage due to an incorrect receiver bandwidth setting. An automatic failure backup capability will reduce the amount of time now required to detect a failed module within a hardware assembly and reconfigure the subsystem to include a backup assembly. If the number of scheduled hours of track remains at the present value, the implementation of the antenna and RF automation plans would cause an increase of 0.4% (from 98.2 to 98.6%) in the percentage of scheduled tracking hours in which data are actually delivered.

Both automation plans will result in a change in equipment at the station. The RF automation plan will add interface hardware plus six microcomputers with 40K of memory each, all of which, with the exception of a teletype, a cathode ray tube, and a transmitter microcomputer controller which will be located in the antenna, will fit into existing equipment racks in the control room. Except for the standard microcomputer controllers, all of the equipment will be built at JPL. The Intel 8080 microcomputers appear to have a very low failure rate; in the 13 months since the microcomputers have been delivered, the manufacturer has recorded failures in only 1% of the existing units. The antenna automation plan will replace the XDS 910 in the antenna pointing system with a Modcomp II/25.

Failures in the controlled hardware in the RF automation plan should be detected and compensated for by the controlling microcomputer. Failures in the controlling hardware itself present a different problem. If the central computer fails, then, of course, each individual hardware assembly could be calibrated as is now done. However, when a level-two countdown is scheduled and only 45 min are allowed, approximately 4 h of track time will be lost due to the extended precal procedure. If, in fact, any of the individual standard controllers fails, the associated hardware assembly will have to be manually calibrated, and any functions that the manually run hardware performs in conjunction with other hardware assemblies will have to be performed in a manual mode. It seems likely, then, that the failure of any of the six standard controllers could cause a significant delay in completing a countdown. In such a case, fault location capability in the standard controllers would be very valuable. A failure in the controlling computers in the antenna automation scheme is likely to cause loss of the ability to point the antenna and then track unless the problem can be solved by reloading the XDS 910 or 930 programs. Otherwise, it will be impossible to operate the antenna until the malfunctioning hardware is repaired.

VII. Conclusion

Implementation of the RF and antenna automation plans will probably not affect the number of operators required at the stations. Since no backup equipment exists in the antenna pointing system, the use of self-diagnostic techniques in the design of automated equipment can reduce the amount of downtime due to failures in the antenna controller. Calibration time will probably not be affected by antenna automation, but the RF automation scheme will cause a significant decrease. The capacity for automatic failure backup in the RF automation plan will permit a decrease in the amount of downtime during scheduled tracking time spent switching to a backup string and recalibrating. While the use of self-diagnostic hardware will save downtime only in isolated parts of the RF subsystem, scheduled maintenance time will be reduced by automatic error-locating techniques. An overall increase of approximately 25% in available tracking time as well as a reduction in the number of station personnel required at the 64-m stations can be expected if both the RF and antenna automation plans are implemented.

Table 1. Distribution of countdowns performed in DSN, CY 1974[a]

	Level 1 countdown	Level 2 countdown	Level 3 countdown	All countdowns
Number per year	106	750	2322	3178
Percent of all countdowns	3.3	23.6	73.1	100
Present average duration, h	9.52	4.80	1.87	2.81
Estimated average duration, h	8.5	0.75	0.25	0.64
Total time/year at present, h	1009.1	3600.0	4342.1	8951.2
Estimated total time/year, h	901.0	562.5	580.5	2044.0

[a]From data collected over a 26-week period.

Table 2. Station utilization for all stations in DSN, CY 1975[a]

	Hours spent/year at all stations and percent of total station hours		Estimated hours/year and percent of total if all additional hours spent tracking		Estimated hours/year and percent of total if additional time allocated proportionally among all activities	
	h	%	h	%	h	%
Track time	19580.3	28.7	24513.6	35.9	21558.8	31.6
Precal	4843.9	7.1	1106.1	1.6	1124.0	1.6
Postcal	886.9	1.3	886.9	1.3	922.7	1.4
Radio science	750.5	1.1	750.5	1.1	818.7	1.2
Training	2319.6	3.4	2319.6	3.4	2592.5	3.8
Maintenance	13781.2	20.2	12585.7	18.5	12485.0	18.3
Project-related support	6208.4	9.1	6208.4	9.1	6822.4	10.0
DSN operational prep	1842.0	2.7	1842.0	2.7	2046.7	3.0
DSN development	272.9	0.4	272.9	0.4	272.9	0.4
Minor modifications	2183.2	3.2	2183.2	3.2	2456.1	3.6
Reconfiguration and implementation	5867.3	8.6	5867.3	8.6	6481.3	9.5
Other	9687.8	14.2	9687.8	14.2	10642.9	15.6
Total			68224.0			

[a]From data collected over a 23-week period.

Table 3. Scheduled maintenance: Estimated distribution by activity

Scheduled activity	Percent of maintenance time allocated
Preventive	20
Corrective	30
ECO implementation	50

Table 4. Scheduled maintenance: Distribution by hardware system, CY 74

Hardware system	Percent of maintenance time spent
TCD	60
RCV	30
ANT	3

Table 5. Downtime in hours/year at all stations

	No automation	RF automation only	Antenna automation only	RF and antenna automation
Hours/year	343.8	280.9	336.9	274.0
Percent of present downtime/year	100	81.7	98.0	79.7
Percent of scheduled track time during which data are delivered, assuming 19580.3 h scheduled	98.2	98.6	98.3	98.6

Table 6. Summary of discrepancy reports written 1/1/74 to 7/13/75

Sub-system	Number of DRs written	Uncorrectable		Correctable			Total minutes of outage		Percent difference
		Number	Minutes of outage	Number	Minutes of outage	Estimated minutes of outage with automation	Present	Estimated with automation	
SDA	3	1	1	2	300	75	301	76	
TXR	90	62	2620	28	557	140	3177	2760	
UWV	17	6	419	11	1900	85	2319	504	
R/E	55	23	1330	32	3473	190	4803	1520	(RF) −54
ANT	88	51	1012	37	1148	505	2160	1517	(Ant) −30
Whole station							31,425	25,043	−20

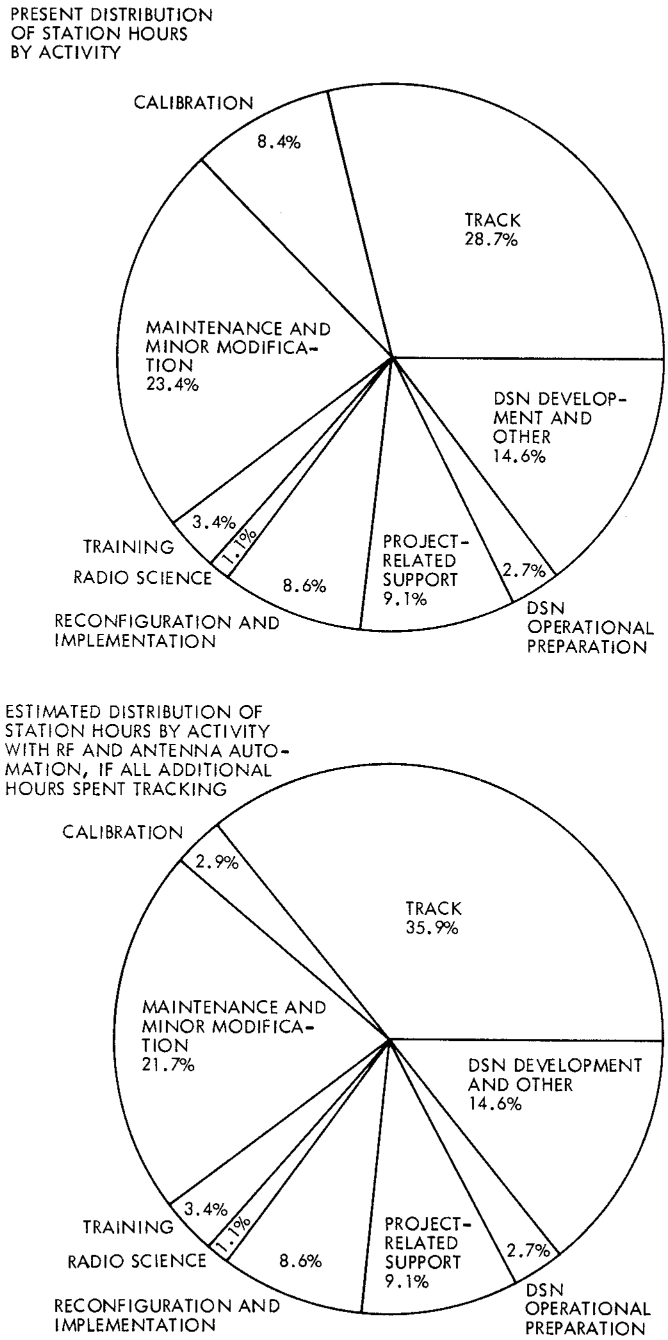

Fig. 1. Station utilization