Deep Space Station (DSS 13) Automation Demonstration

D. S. Remer
Communications Systems Research Section
and Harvey Mudd College

G. Lorden
California Institute of Technology

This article summarizes the data base collected during a six month demonstration of an automated Deep Space Station (DSS 13) run unattended and remotely controlled from JPL in Pasadena. During this period, DSS 13 received spacecraft telemetry data from Voyager, Pioneers 10 and 11, and Helios projects. Corrective and preventive maintenance are reported by subsystem including the traditional subsystems and those subsystems added for the automation demonstration.

Operations and maintenance data for a comparable manned Deep Space Station (DSS 11) are also presented for comparison. The data suggests that unattended operations may reduce maintenance manhours in addition to reducing operator manhours. Corrective maintenance for the unmanned station was about one third of the manned station, and preventive maintenance was about one half.

I. Introduction

Since the mid 1960's there has been a strong effort to reduce the crew size of the Deep Space Stations in order to improve the cost effectiveness of DSN use of NASA resources for tracking and data acquisition. This program has been very successful, as summarized in Fig. 1, where we can see an 80 percent reduction in DSS 12 crew size since 1967.

A research task was started several years ago to extend this effort to running an unattended, fully automated Deep Space Station. It was also hoped that automation would improve network productivity by increasing the time available to the end user. Automation would reduce the time required for check out and calibration, and eliminate the time for operator training. Finally, DSN reliability might be enhanced by reducing the human operator interface. To meet these goals, DSS 13 has been automated and was operated in an unattended mode for telemetry reception during the last half of calendar year 1978. Only downlink capability was available during the demonstration, up-link capability is now being implemented, and further demonstrations are planned for 1980. These demonstrations will provide information useful in determining if automation should be implemented throughout the DSN.

The purpose of this article is to summarize the data taken during the six-month automation demonstration in 1978. Several previous articles (Refs. 1-3) have described the initial data during the early part of this demonstration.

The first article (Ref. 1) was prepared prior to the start of the demonstration in order to outline what data should be collected, how the data would be analyzed, and what we could and could not learn from the unattended operations demonstration at DSS 13.

The second article (Ref. 2) presented an initial 9 week data base of life-cycle cost parameters that were collected at a manned station (DSS 11). This work was started prior to the DSS 13 unattended demonstration in order to debug the data collection procedure and to develop a benchmark for comparison with the results from the unattended operations demonstration at DSS 13.

The third article (Ref. 3) presented the initial results for preventive and corrective maintenance based on the first 15 weeks of the unattended operations demonstration at DSS 13. During this period, DSS 13 had been receiving spacecraft telemetry while being remotely controlled from JPL in Pasadena. The overall maintenance manhours for the manned station (DSS 11) were found to be higher than for the unmanned station (DSS 13).

In this article, we will summarize the results of the entire six months of data collected at both DSS 11 and DSS 13 during the first unattended operations demonstration.

II. Description of the Unattended Deep Space Station

DSS 13, a 26-meter antenna station at Goldstone, is being developed as the test bed for the unattended, automated mode of operation. The on-line telemetry data acquisition capability was implemented in mid 1978. Central control and monitor are exercised by an operator at the Network Operation Control Center (NOCC) at JPL in Pasadena via high-speed data lines to Goldstone. The operator enters configuration control and predicts. Monitor data are also available to the operator. The station is powered up and checked out, spacecraft telemetry is acquired and tracked, and the station is shut down, all by remote control from Pasadena without an operator at the station. There is also automatic antenna shutdown capability in case of high winds or certain servo drive failures.

The DSS 13 telemetry stream is sent to DSS 12 (or DSS 11) for bit detection and then to the flight project at JPL via high-speed data lines. Implementation is now underway so that bit detection can be performed at DSS 13.

The unattended operations design at DSS 13 uses microprocessors or minicomputers on each controlled subsystem for configuration control, monitoring, calibration, and checkout. A central station microprocessor is used for supervision of subsystem monitor and control processors.

At present, the antenna, microwave, and receiver subsystems are under centralized control. The 100-kilowatt S-band transmitter and exciter subsystem are being added now. During the past unattended operations demonstration at DSS 13, telemetry data was provided for the Voyager, Pioneers 10 and 11, and Helios projects.

An overview of the station control and system technology is shown in Fig. 2.

III. DSS 11 Data Base

Data were collected at DSS 11 from May 14, 1978 through December 31, 1978. During the nine-week period of May 14, 1978, to July 9, 1978, a preliminary data base was collected on the operation of DSS 11. This initial data base was described in a previous article (Ref. 2) and served three purposes. First, it allowed us to check the data base requirements outlined in an earlier article (Ref. 1) and make necessary adjustments. Second, it served as a way to check out the data collection procedure, and finally, it was a bench mark to compare to subsequent data obtained from both DSS 11 and DSS 13 during the actual automation demonstration. Data base requirements for this initial test period and for the rest of the demonstration were reduced because no additional station data could be collected or special data sheets introduced at DSS 11 over and above what was normally provided at the station.

Routine data was collected by DSS 11 operations and then screened by the DSS 13 Station Manager, who then culled out the data requested for analysis. This input data was received in a format similar to those shown in Tables 1 and 2. The resulting DSS 11 data base for the 25 week period of July 16, 1978 to December 31, 1978 is summarized below.

A. Station Operating Hours and Telemetry Hours

The station operating hours (SOH) during the entire demonstration period were 160 hours per week at DSS 11. SOH are defined at those hours when a station is required to be available to conduct DSN activities.

Telemetry reception averaged 88.1 hours per week with a standard deviation of 14.1 hours per week. Telemetry hours varied from a low value of 44.6 hours per week to a high value of 102.9 hours per week. During this 25 week period, the telemetry reception hours averaged 55 percent of the SOH with a range of 28 to 64 percent.

Average Station Operating Hours (SOH)/week	160
Average Telemetry Hours/week	88.1
Telemetry Hours as a percent of SOH	55%

For the purposes of this study we defined "good telemetry" reception hours as the data received when the Telemetry Processor Assembly (TPA) was in lock. A summary of the telemetry hours during this period are shown in Fig. 3.

B. Maintenance, Operations, and Training Manhours

The average manhours per week for operations, training, and maintenance is shown below and the week to week variations are shown in Fig. 4. Note that operation manhours are about half of the total manhours. Also, the maintenance manhours are split almost evenly between corrective maintenance and preventive maintenance, as indicated below.

	Average Manhours Per Week	Percent of Total Manhours
Operation Manhours	373.1	51.7
Training Manhours	156.2	21.7
Corrective Maintenance Manhours	97.7	13.5
Preventive Maintenance Manhours	94.2	13.1
	721.2	100.0

An interesting observation is that there are almost three times as many manhours for operations and training as for maintenance. Since automation essentially eliminates operators and therefore operator training, the potential M&O manpower savings is about 70-75 percent.

Although automation has a large impact on reducing operations manhours, the impact of automation on maintenance manhours was not clear before the demonstration. There is the potential for designing automated systems to improve isolation and diagnosis of failures. On the other hand, there is the need to maintain the additional equipment required for automation. As will be seen later, in addition to operations manpower, maintenance manpower also appears to be reduced for an automated station.

In the listing below, note that the coefficient of variation, which is the standard deviation as a percent of the average, increases from 15.9 percent for telemetry hours to a high of 57.7 percent for corrective maintenance manhours. As expected, both preventive and corrective maintenance manhours are more variable than either operating or training manhours.

	Average Per Week	Standard Deviation	Coefficient of Variation
Telemetry Hours	88.1	14.1	15.9%
Operation Manhours	373.1	69.9	18.7%
Training Manhours	156.2	47.2	30.2%
Preventive Maintenance Manhours	94.2	30.5	32.4%
Corrective Maintenance Manhours	97.7	56.4	57.7%

C. Tracking

The number of tracks per week at DSS 11 varied between 6 and 19 with an average of 13.5. The data lost per week varied from a low of 0.6 hours to a high of 5.4 hours with an average loss of 2.4 hours per week or 11 minutes per track. The variation in number of tracks per week is shown in Fig. 5.

Good telemetry data averaged 88 hours per week, and the lost data of 2.4 hours per week represents about 2.7 percent of the data. This is a low number for data lost because it only accounts for lost data when the TPA was out of lock. Additional losses, such as between Goldstone and NOCC via the high-speed data line, are not included in the above data.

The average weekly precal time per track was 54 minutes with a range of 31 to 108 minutes per track. Since the average length of a telemetry track, excluding precal, was 6.5 hours and the average precal per track was 0.9 hours, the time for precal is about 14 percent of the telemetry time. This is a significant amount of time which can be reduced by automation. The variation in precal time per track is shown in Fig. 6.

D. Cost Parameters

Let's now turn our attention from manhours to costs, specifically telemetry hourly M&O cost and station hourly M&O cost. Actual hourly labor costs that included contractor and JPL burden were used. These hourly costs are a weighted composite of the actual straight time and overtime costs.

The following life cycle cost parameters were calculated to compare the maintenance and operations manpower costs at a station per telemetry hour and per station operating hour (SOH). Note that only manpower costs are included in the analysis.

About 70 percent of the total manpower cost is associated with operations and operations training. Thus, for an automated station, about 70 percent of the manpower costs may be eliminated.

	Average Manpower Cost per Telemetry Hour	Average Manpower Cost per Station Operating Hour
Corrective Maintenance	$ 16.41	$ 8.71
Preventive Maintenance	14.56	8.02
Operations	56.71	31.22
Training	23.74	13.07
Total	$111.42	$61.02

In the next section, we will look at data from DSS 13 during the unattended demonstration.

IV. DSS 13 Maintenance Data Base

The maintenance data base for DSS 13 under remote, automated operation from NOCC during the period from 10/1/78 to 12/3/78 is summarized in Tables 3 and 4. A previous article (Ref. 3) summarizes data during the period from 6/18/78 to 9/24/78. The data are tabulated in weekly increments. Corrective maintenance by subsystem is shown in Table 3 and preventive maintenance in Table 4. A footnote designator "a" next to the DSS 13 subsystem (in Tables 3 and 4) indicates that this equipment was added for this unattended demonstration. The data were supplied by the DSS 13 Station Manager on a data sheet shown in Table 5 of Ref. 2.

A. Corrective Maintenance

The corrective maintenance at DSS 13 averaged 24.3 manhours per week during the unattended period of 6/18/78 to 12/31/78. Shown below is the percent of corrective maintenance manhours for each subsystem.

Subsystem	DSS 13 Corrective Maintenance Manhours (%)
Antenna Electronic Systems	50.3
Block III SDA	9.4
Block III Receiver	8.8
Antenna Hydraulic Systems	7.9
Maser Compressor	5.2
Antenna Terminet	5.1
108 KHz Subcarrier Oscillator (microwave link transmission)	4.5
Antenna Clock	2.9
Control Computer (MODCOMP II/25)	2.8
Microwave Link Channel	1.4
Maser Refrigerator	1.3
Other	0.4
	100.0

Note that the antenna electronic systems accounted for half of the total corrective maintenance manhours. The rest of the corrective maintenance is spread over many subsystems. For example, each of the following subsystems accounted for about 5-10 percent of the overall corrective maintenance: the Block III Subcarrier Demodulator Assembly (SDA), the Block III Receiver, the Antenna Hydraulic Systems, the maser compressor, the antenna terminet, and the 108 kHz subcarrier oscillator. Almost half of the subsystems summarized in Table 3 required no corrective maintenance.

B. DSS 13 Preventive Maintenance

The preventive maintenance at DSS 13 averaged 36.7 manhours per week. Shown below is the percent of preventive maintenance manhours for each subsystem during the period of 6/18/78 to 12/31/78.

Subsystem	DSS 13 Preventive Maintenance Manhours (%)
Antenna Hydraulic Systems	49.1
Antenna Electronic Systems	17.8
Maser Compressor	8.0
Control Computer (MODCOMP II/25)	6.8
Block III Receiver	6.0
Block III SDA (Microwave Link Transmission)	4.6
Maser Refrigerator	3.6
108 KHz Subcarrier Oscillator (Microwave Link Transmission)	3.1
Microwave Link Channel	0.6
Station Controller (8080 Based Microcomputer)	0.4
	100.0

The Antenna Hydraulic Systems accounted for almost half of the preventive maintenance manhours. About half of the subsystems received no preventive maintenance during this period, as shown in Table 4.

C. Comparison of Corrective and Preventive Maintenance

The antenna electronic and hydraulic subsystems had vastly different percentages of corrective and preventive maintenance as shown below.

Subsystem	Percent of Total Corrective Maintenance	Percent of Total Preventive Maintenance
Antenna Electronic System	50.3	17.8
Antenna Hydraulic System	7.9	49.1

For example, while the Antenna Electronic System accounted for 50.3 percent of the total corrective maintenance manhours, this system only received 17.8 percent of the total preventive maintenance manhours. On the other hand, the Antenna Hydraulic System received 49.1 percent of the total preventive maintenance manhours and only 7.9 percent of the corrective maintenance manhours. Perhaps there could be a shift in preventive maintenance to reflect corrective maintenance experience in order to optimize the overall maintenance effort.

D. Maintenance for the Traditional Subsystems versus the Subsystems Added for This Demonstration

The subsystems added for this demonstration are shown by the footnote designators "a" in Tables 3 and 4. The percent of preventive maintenance for these subsystems is shown below for the third and fourth calendar quarter of 1978.

	Preventive Maintenance %	
	3Q78	4Q78
Subsystems added for this demonstration	10.6	11.4
Traditional subsystems	89.4	88.6
	100.0	100.0

The subsystems added for this demonstration received only about 11 percent of the total preventive maintenance.

The corrective maintenance for these added subsystems as reported in a previous article (Ref. 3) was 28.9 percent of the total corrective maintenance during the first half of the unattended demonstration. However, there was a very sharp drop to only 6.6 percent of the total corrective maintenance for these subsystems during the second half of the demonstration as shown below.

	Corrective Maintenance %	
	3Q78	4Q78
Subsystems added for this demonstration	28.9	6.6
Traditional subsystems	71.1	93.4
	100.0	100.0

This is a very encouraging result and is evidently due to debugging the new equipment and also to a possible maintenance learning curve.

V. Comparison of Maintenance and Operations Manhours at DSS 11 and DSS 13 for Telemetry Reception

A. Comparison of Maintenance Manhours

The average weekly maintenance manhours for DSS 11 and DSS 13 are shown below for the period of 7/2/78 through 12/31/78.

	Average Weekly Manhours	
	DSS 11	DSS 13
Corrective Maintenance	94.7	24.5
Preventive Maintenance	91.1	35.7
	185.8	60.2

Both the corrective and preventive maintenance manhours at DSS 11 are more than at DSS 13. However, DSS 11 has more equipment than DSS 13. For example, DSS 11 has two receivers, two SDA's, two masers, etc., whereas DSS 13 has only one of each. By doubling the DSS 13 maintenance figures for these subsystems, we arrived at the following comparison.

	Average Weekly Manhours for "comparable" systems	
	DSS 11	DSS 13
Corrective Maintenance	94.7	30.6
Preventive Maintenance	91.1	43.6
	185.8	74.2[a]

[a](39.9% of 185.8)

This comparison is based on the conservative assumption that if DSS 13 had had two SDA's, for example, then the preventive and corrective maintenance for SDA's would have been doubled at DSS 13. In actual practice, this factor should be somewhere between one and two. However, even with this conservative assumption, the corrective maintenance at DSS 13 only increased by 24.7 percent and the preventive maintenance by 22.2 percent. For comparable systems, we see in the above table that the preventive maintenance manhours at DSS 13 are about 1/2 of DSS 11 and the corrective maintenance manhours at DSS 13 are about 1/3 of DSS 11. A weekly comparison of corrective maintenance at DSS 11 and DSS 13 is shown in Fig. 7 and similar data for preventive maintenance is shown in Fig. 8.

B. Comparison of Operations Manhours

The average manpower used for operations at DSS 11 is 373 manhours per week. On the other hand, DSS 13 was run unattended and remotely from NOCC in Pasadena. If we conservatively assume that this remote operation takes 50 percent of the time of one operator at NOCC, then the DSS 13 operations manpower requirement is 80 manhours per week or about 1/5 of the operations manpower at DSS 11. As a result, it would be reasonable to assume a corresponding 80-percent reduction in operator training for an automated station versus current station operation. Operator training averaged 156 manhours per week at DSS 11.

C. Limitation of Results

The data suggests that unattended operations may reduce maintenance manhours. There are other factors, however, that may substantially affect comparisons between the two stations in total maintenance manhours and the split between preventive and corrective maintenance. DSS 13 has substantially different equipment and a different schedule of operations from DSS 11. In addition, the two stations have different types of personnel, whose methods of operation are not the same. For example, DSS 13 station personnel do almost all the corrective maintenance and preventive maintenance at the station, whereas DSS 11 personnel do hardly any corrective maintenance and about 84 percent of the preventive maintenance, leaving the rest to the Maintenance and Integration team for the DSN Complex. Preventive maintenance manhours are particularly hard to compare because preventive maintenance is a discretionary activity which may be handled differently by an operating station like DSS 11 and a research and development station like DSS 13. Furthermore, system performance verification is more stringent at DSS 11 than at DSS 13. These caveats are quite important when viewing the results.

Acknowledgment

We want to thank Earl Jackson for supplying the DSS 11 and DSS 13 data and for providing insight into station operation.

References

1. Remer, D. S., Eisenberger, I., and Lorden, G., "Economic Evaluation of DSS 13 Unattended Operations Demonstration," in *The Deep Space Network Progress Report 42-45*, Jet Propulsion Laboratory, Pasadena, CA, March and April 1978, pp. 165-171.

2. Remer, D. S. and Lorden, G., "Initial Economic and Operations Data Base for DSS 13 Automation Test," in *The Deep Space Network Progress Report 42-49*, Jet Propulsion Laboratory, Pasadena, CA, November and December 1978, pp. 78-85.

3. Remer, D. S. and Lorden, G. "Preliminary Maintenance Experience for DSS 13 Unattended Operations Demonstration," in *The Deep Space Network Progress Report 42-51*, Jet Propulsion Laboratory, Pasadena, CA, March and April 1979, pp. 150-155.

Table 1. DSS 11 operations data sheet

[a]Week Ending Date	________
[a]Operations Manhours for the Week	________
Preventive Maintenance Manhours	________
[a]Maintenance & Integration Team	________
[a]Station Personnel	________
Total	________
Corrective Maintenance Manhours (Requiring no Station Downtime)	
[a]Maintenance & Integration Team	________
Station Personnel	________
Total	________
Corrective Maintenance Manhours (Requiring Station Downtime)	________
[b]Pre-Calibration Hours for the Week	________
Post Calibration Hours for the Week	________
[a]Training Manhours	________
[a]Downtime hours During Scheduled Operations	________

[a]Represents data usually received
[b]These numbers are calculated from data in Table 2

Table 2. DSS 11 tracking data sheet

[a]Day of the Year (DOY)	________
[a]Spacecraft ID	________
[a]Pre-Cal Start Time	________
Pre-Cal End Time	________
Antenna to Point Time	________
[a]Receiver 1 In-Lock Time	________
Receiver 2 In-Lock Time	________
[a]SSAI In-Lock Time	________
[a]SSA2 In-Lock Time	________
[a]"Good" Telemetry Start Time	________
[a]"Good" Telemetry End Time	________
[a]Data Lost in Minutes	________
Post Cal Start Time	________
Post Cal End Time	________
[b]Tracking for this Pass in Minutes	________
[a]Scheduled Operating Hours for the Week	________
[a]End User Hours for the Week	________
[b]Telemetry Reception Hours for the Week	________

[a]Represents data usually received
[b]These numbers are calculated from the data in this Table

Table 3. DSS 13 corrective maintenance activities in manhours, 1978

Maintenance	10/1	10/8	10/15	10/22	10/29	11/5	11/12	11/19	11/26	12/3	12/10	12/17	12/24	12/31	Total
26-m Antenna															
Hydraulic Systems	2.0	3.4				3.0			4.0	8.0			0.5		20.5
Electronic Systems	4.0	3.0	2.0	1.0	19.5	37.0	35.5	39	16.0	13.5	39.0	15.0	3.0		227.5
[a]Control Computer (MODCOMP II/25)		11.0													11.0
[a]Clock															
[a]Terminet										4.5	5.5	0.5			10.5
[a]Microprocessor										1.0					1.0
Waveguide Configuration Assembly															
Low Noise Amplifier (Maser)															
Maser Compressor	21.0		1.3		2.0	1.5	0.5	6.5				1.5	0.5		34.8
Refrigerator	1.0			3.0					1.0	3.0	1.5				9.5
Block III Receiver						8.0	16.5	5.0	13.0	3.0	1.0			1.5	48.0
Block III SDA			2.0		0.5	1.5	2.5		1.5	1.0					9.0
[a]108 KHz Subcarrier Oscillator (Microwave Link Transmission)															
[a]Station Controller (8080 Based Microcomputer)							2.0								2.0
Star Switch Controller															
[a]SDA Controller															
[a]Block III Receiver Controller															
[a]Waveguide Configuration Assembly Controller															
High Speed Data Line Data Set															
Microwave Link Channel															
Total	28.0	17.0	5.3	4.0	22.0	51.0	57.0	50.5	35.5	34.0	47.0	17.0	4.0	1.5	373.8

[a]Equipment added for automation demonstration

Table 4. DSS 13 preventive maintenance activities in manhours, 1978

Maintenance	10/1	10/8	10/15	10/22	10/29	11/5	11/12	11/19	11/26	12/3	12/10	12/17	12/24	12/31	Total
26-m Antenna															
Hydraulic Systems	13.0	7.5	26.0	29.0	27.0	30.0	27.0	25.0	25.0	21.0	18.0	5.0	5.0	4.0	262.5
Electronic Systems	6.5	5.3		12.0	8.5	4.5	4.0	5.0		0.5	7.5	14.0	22.5	8.0	98.3
[a]Control Computer (MODCOMP II/25)	26.2		12.3	1.5	4.0	2.0									46.0
[a]Clock															
[a]Terminet															
[a]Microprocessor															
Waveguide Configuration Assembly															
Low Noise Amplifier (Maser)															
Maser Compressor	2.0	7.0	1.0	1.5	1.0				1.0		0.5	1.0	2.5	2.0	19.5
Refrigerator	1.0	3.5		4.0	0.5			2.5	1.0	3.0					15.5
Block III Receiver	1.5	5.0	0.5	0.5	1.0			2.0		0.5			0.5		11.5
Block III SDA	1.0	0.5	1.5	1.0	1.0	1.5	2.0	1.0					0.5	0.5	10.5
[a]108 KHz Subcarrier Oscillator (Microwave Link Transmission)				1.0		2.5									3.5
[a]Station Controller (8080 Based Microcomputer)															
Star Switch Controller															
[a]SDA Controller															
[a]Block III Receiver Controller															
[a]Waveguide Configuration Assembly Controller															
High Speed Data Line Data Set															
Microwave Link Channel					1.5	2.5	0.5								4.5
Total	51.2	28.8	41.3	50.5	44.5	43.0	33.5	35.5	27.0	25.0	26.0	20.0	31.0	14.5	471.8

[a]Equipment added for automation demonstration

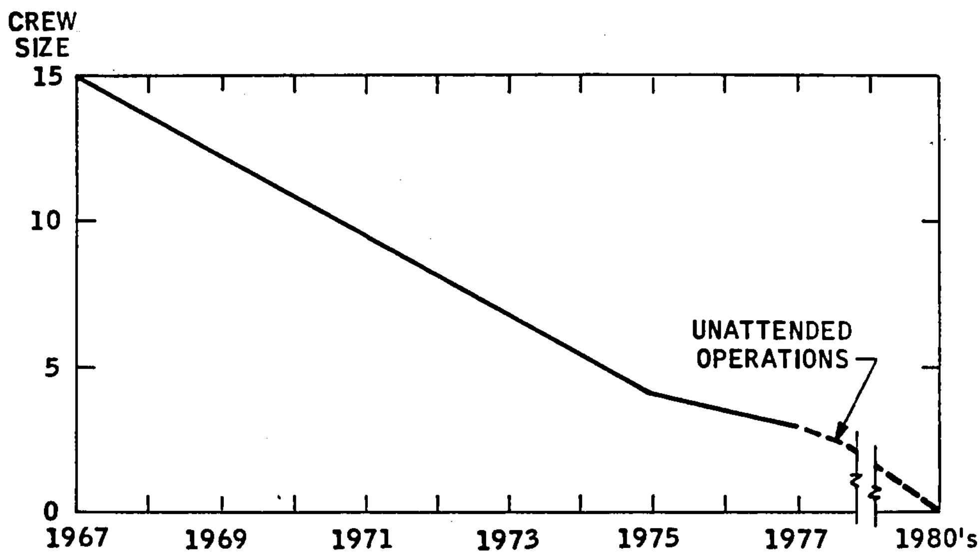

Fig. 1. DSS 12 crew size

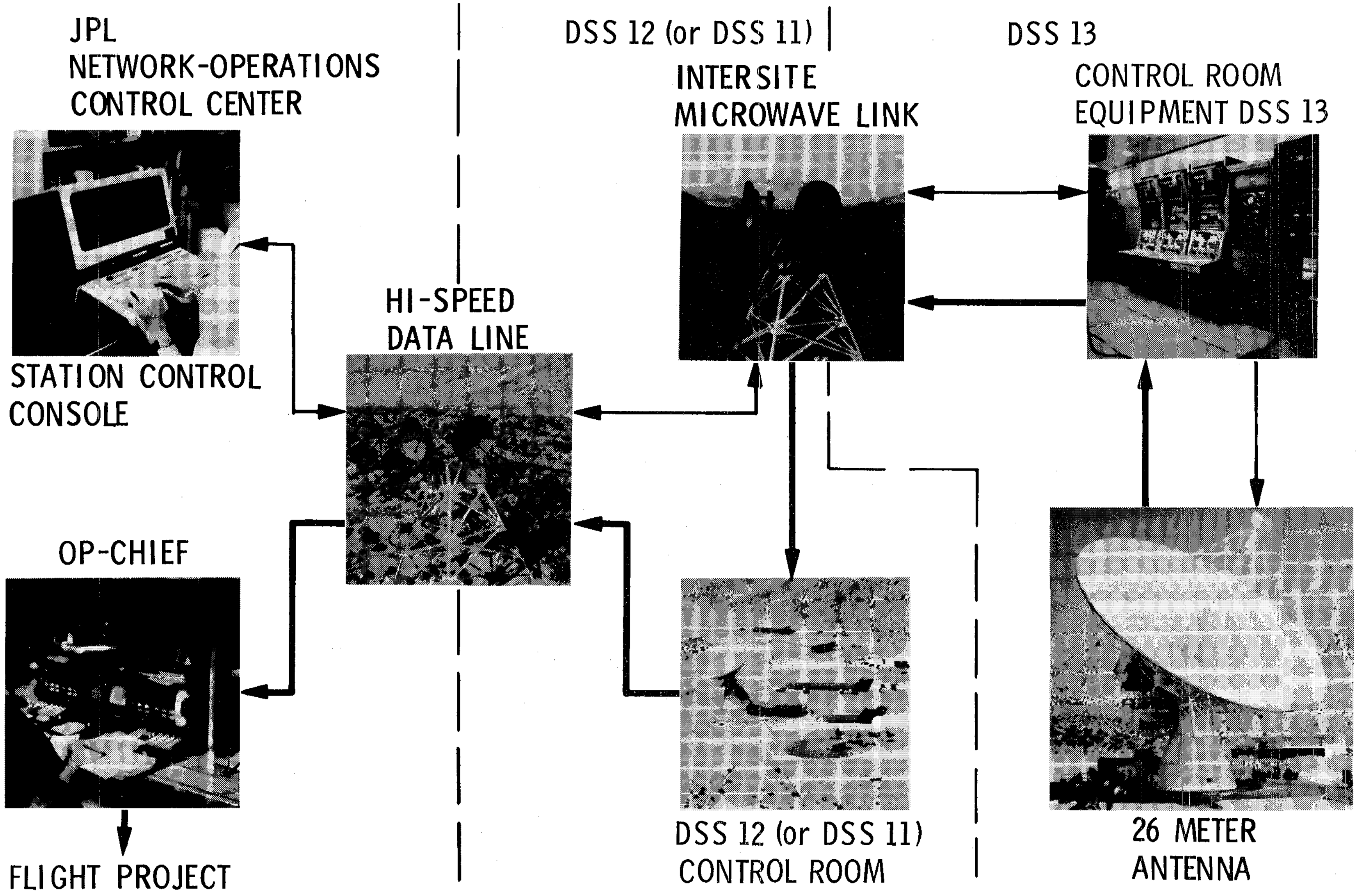

Fig. 2. Station control and system technology overview

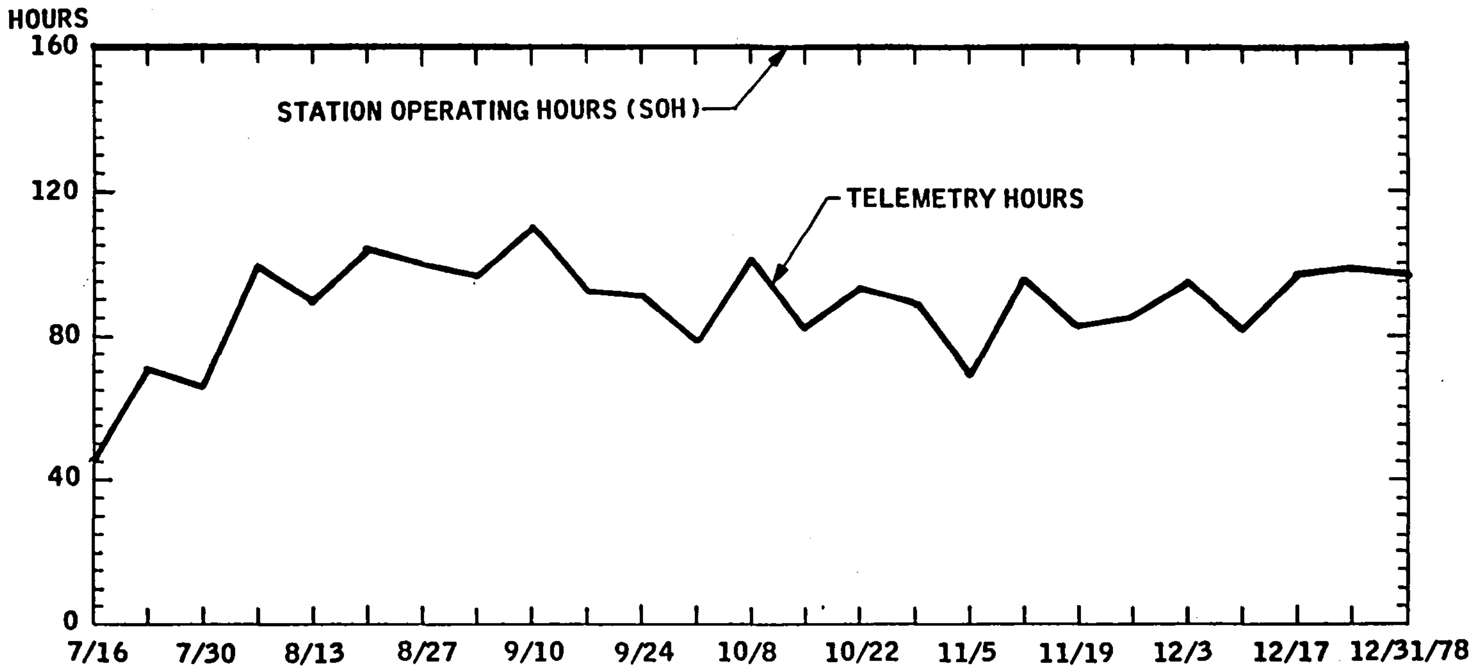

Fig. 3. DSS 11 station operating and telemetry hours (weekly averages)

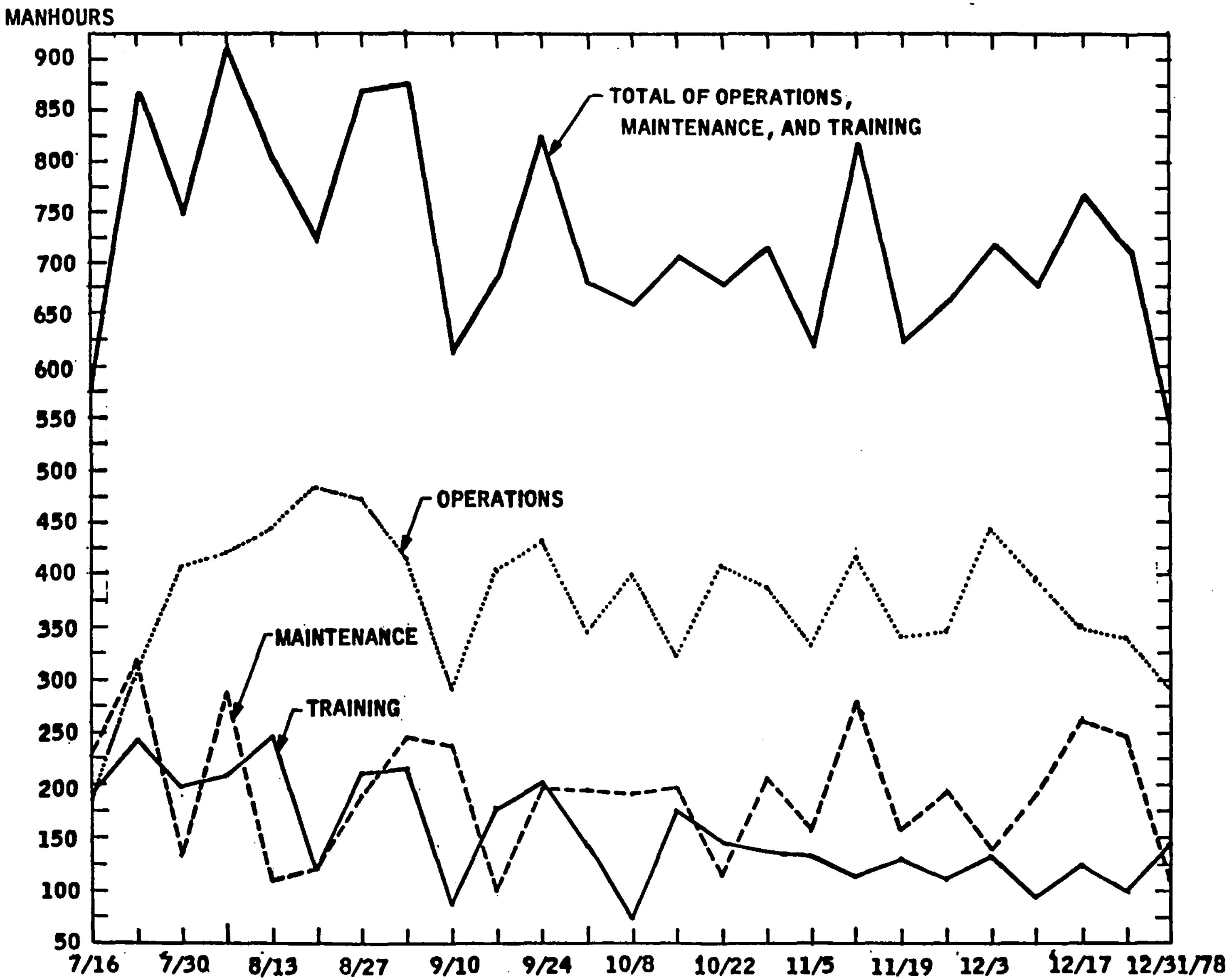

Fig. 4. DSS 11 manhour allocation between operations and maintenance (weekly averages)

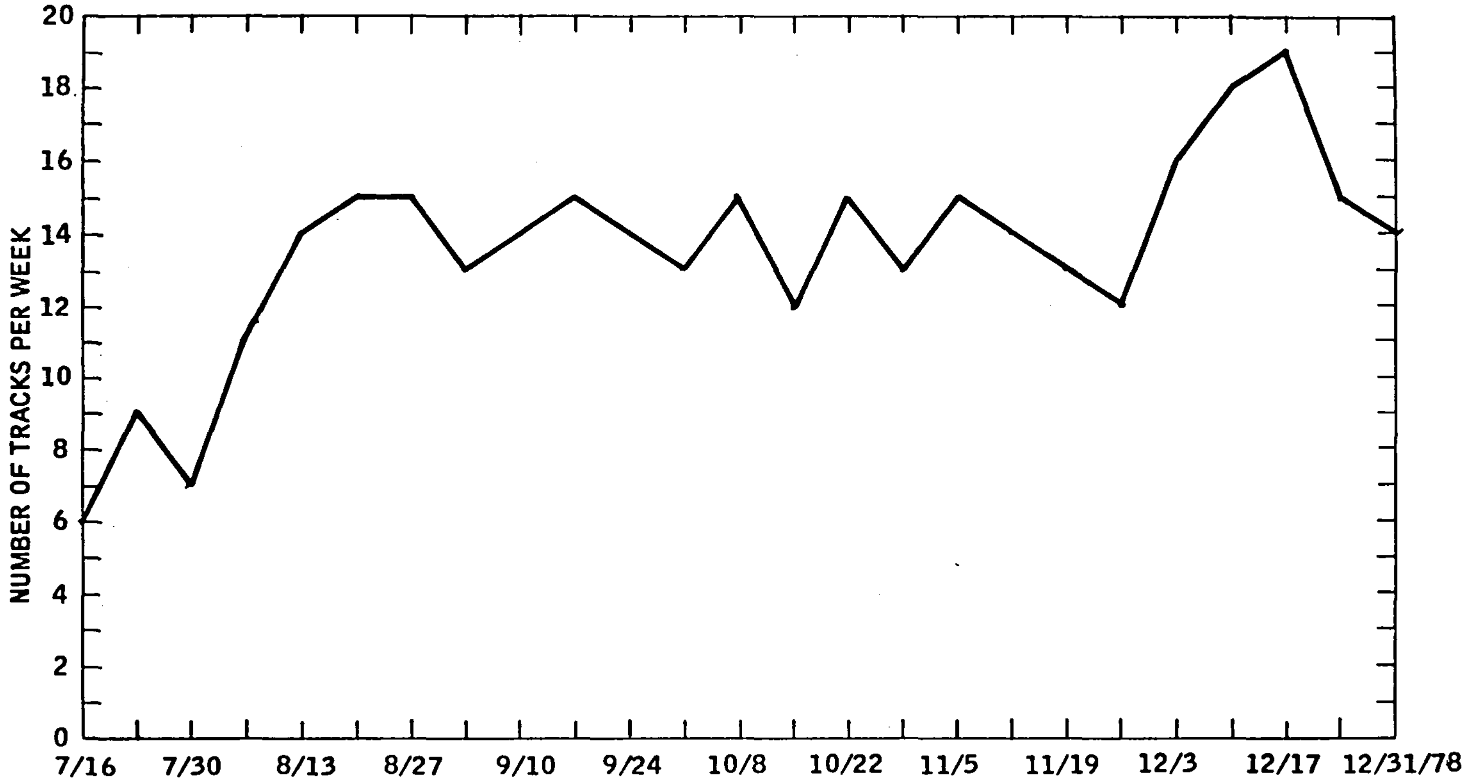

Fig. 5. DSS 11 tracks per week

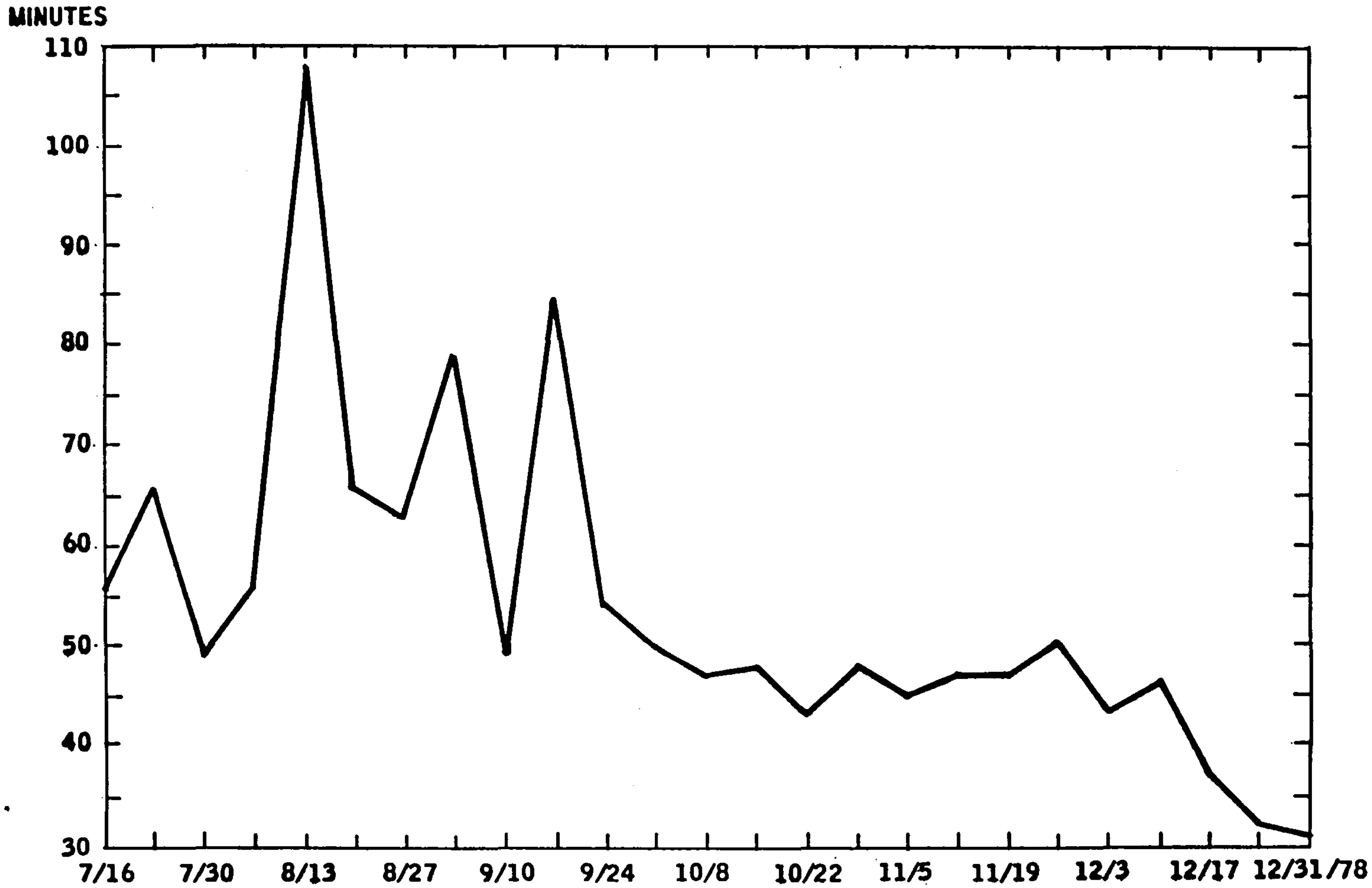

Fig. 6. DSS 11 precal time per track

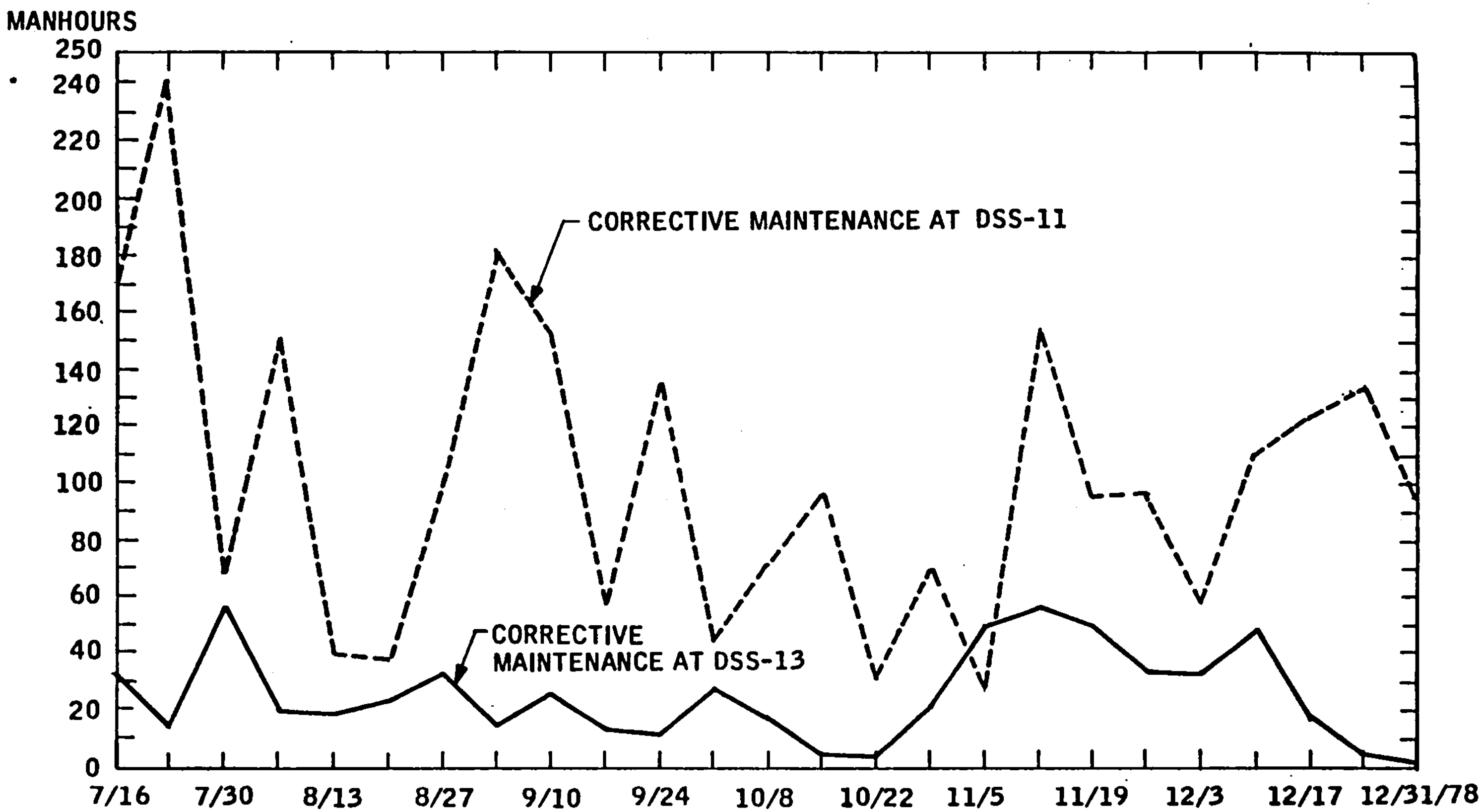

Fig. 7. Comparison of corrective maintenance at DSS 13 and DSS 11

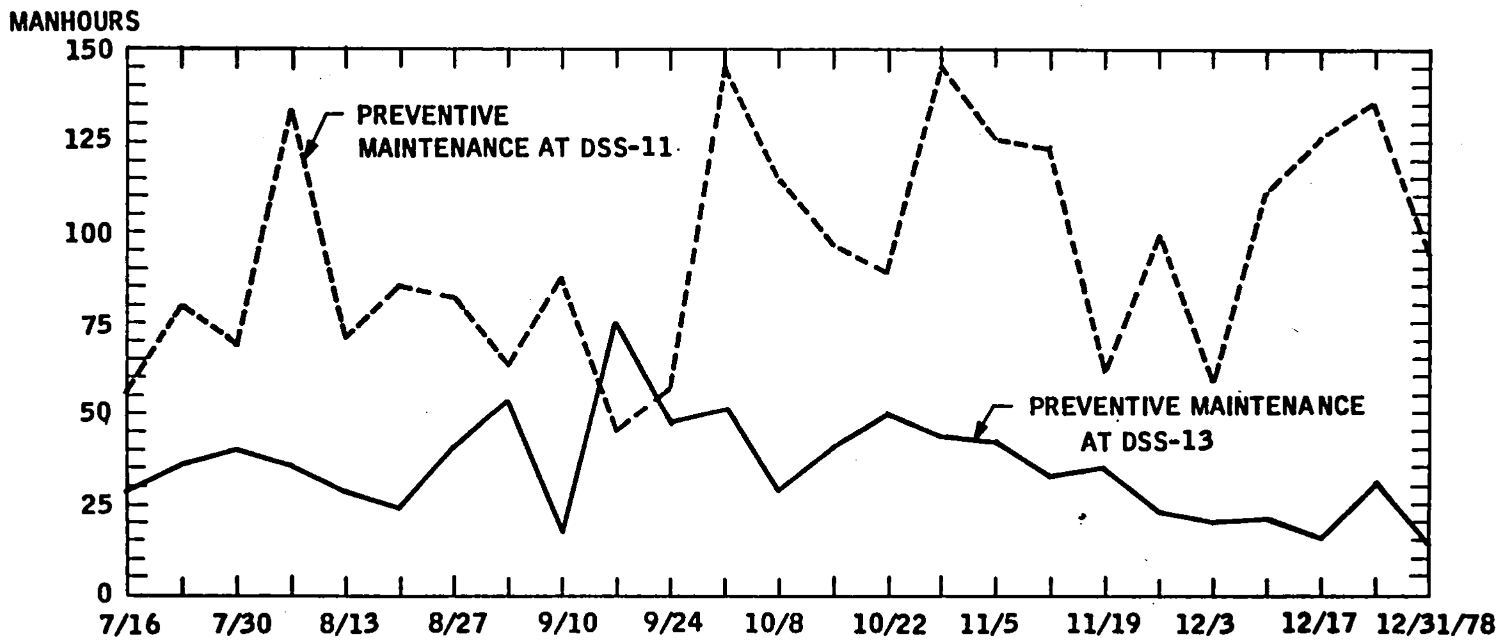

Fig. 8. Comparison of preventive maintenance at DSS 13 and DSS 11