Deep Space Network Maintenance Cost Compared to Other Industries and Organizations

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This article describes a preliminary study of estimated maintenance costs of various industries and organizations as compared with the Deep Space Network (DSN). The survey shows that the annual maintenance cost for industries performing similar work as the DSN (communications and data processing) is about 3.6 percent of estimated total equipment replacement cost, as compared to about 1.3 to 1.7 percent for the DSN.

I. Overview

Consider the following question: Is NASA investing too much, about the right amount, or too little on maintenance for the Deep Space Network (DSN)? There are various approaches that might be used to tackle this question. In the approach described here, the annual maintenance cost was estimated as a percentage of the equipment replacement cost (maintenance cost ratio) in the DSN, and then the DSN costs were compared with corresponding costs experienced by other organizations.

First, the annual sustaining costs for the DSN were tabulated for the fiscal years 1979 through 1989. In addition, the DSN maintenance and nonmaintenance costs were defined in detail (see Table 4). The portion of those sustaining costs attributable to maintenance was calculated for selected years (FY'81, FY'85, FY'88, and FY'89) to represent a variety of DSN activities. The results are shown in Table 1.

Second, the network replacement value (Network Capital Investment) of the DSN was estimated by two techniques.

Third, the maintenance cost ratios (annual maintenance cost/network replacement value in percent) were

calculated for these two equipment replacement values as well as for a range of other possible values. These data are shown in Table 2.

Fourth, similar data[1,2] from organizations in somewhat related fields were obtained from a literature search and a telephone survey and are presented in Table 3. Comparative plots of all the maintenance cost ratios are given in Fig. 1, and the DSN maintenance cost ratio is shown to be below those of other industries and organizations surveyed.

The methodology and results are described in more detail in the following sections.

II. DSN Maintenance Cost

In this article, DSN maintenance cost is considered to be included in a subset of the DSN System sustaining cost (NASA Code 31430-4) and the DSN Operations Network sustaining cost (NASA Code 31440-4).

Table 1 shows a historical annual total cost at the Goldstone complex for these two sustaining activities in 1988 dollars for the last 11 years. The average annual sustaining cost for this period was 27 $M (FY'88). These data were obtained from the Work Authorization Document (WAD) obligations performance reports of Telecommunications and Data Acquisition (TDA) for fiscal years 1979 through 1989. In order to determine the average maintenance expenditures as a percent of these sustaining expenditures, maintenance and nonmaintenance were defined, as shown in Table 4. The major categories that are not included in maintenance are:

(1) Costs of operating calibration and standards laboratories in the DSN facilities, including transportation of test instruments for calibration.

(2) Costs of training operators.

(3) Costs of Engineering Change Order (ECO) modification kits which upgrade the equipment or operational performance including transportation costs.

(4) Costs of system engineering, system analysis, and system documentation.

(5) Costs of management functions such as maintaining the software database, DSN management, and engineering activities related to project and station implementation and scheduling.

The guideline definition of maintenance used for the study is given in Table 4. This definition was applied to the WAD obligations performance data for a set of selected years (FY'81, FY'85, FY'88, and FY'89), which reflects a diversity of tasks impacting the DSN. These maintenance cost data are shown in Table 1, where it is seen that, on the average, about 25 percent of the sustaining funds was spent on maintenance. When this average of 25 percent is applied to the average annual sustaining cost in Table 1 of 27 M$ (FY'88), the average annual maintenance cost is about 7 $M (FY'88).

A breakdown of maintenance and nonmaintenance expenditures was done for FY'88 as a typical year using Table 4 for the guideline definitions of maintenance and nonmaintenance. Figure 2 shows sustaining costs in the maintenance category and a breakdown within the nonmaintenance category. Table 5 shows a breakdown of sustaining costs in each subcategory. In 1988, the maintenance category totaled 21 percent of the sustaining costs and the nonmaintenance category totaled 79 percent. Table 5 reveals that of the nonmaintenance items, major costs were ECO upgrade at 33 percent, system engineering at 29 percent, and management and operations at 13 percent.

In addition to the maintenance portion of the sustaining costs, G. H. Winn[3] pointed out that approximately 2 $M (FY'88) is funded annually by NASA for JPL's use in obtaining replacement parts from Goddard Space Flight Center's central supply facility, with no direct charge to JPL. This brings the average annual DSN maintenance cost for the Goldstone complex to approximately 9 $M (FY'88).

The maintenance costs for the overseas complexes at Canberra, Australia and Madrid, Spain have been estimated to be related to the Goldstone costs in the ratio of estimated equipment replacement costs. As described in the following section, each overseas complex is estimated to have a replacement value of 60 percent of that for Goldstone. Using these assumptions, the total DSN annual maintenance costs average approximately 19 $M (FY' 88).

III. DSN Maintenance Cost Ratio

When comparing DSN experience to that of other organizations, it was found that other organizations usually

[1] Mark Erp, Federal Aviation Administration, Maintenance Engineering Division, personal communication, April 1990.

[2] Michael Auth, Communications Satellite Corporation, Earth Station Services, personal communication, April 1990.

[3] G. H. Winn, TDA Mission Support and DSN Operations, personal communication, March 1990.

report maintenance cost data as a percent of equipment replacement cost. In some cases other factors are used, but in the industries most comparable in activities to the DSN, equipment replacement cost is used. In order to make meaningful comparisons, the DSN maintenance cost ratio is defined as:

$$\text{DSN Maintenance Cost Ratio (\%)} = \frac{\text{Maintenance Cost}}{\text{ReplacementCost}}$$

IV. DSN Replacement Cost

For the purpose of comparing DSN maintenance costs with industry-wide data, a value had to be determined for the total DSN plant and equipment costs. A replacement cost value was established which is consistent with the FAA and COMSAT data shown in Table 3. The methodology and results are described below.

The DSN Network replacement cost has been estimated as 1500 $M in FY'88 dollars in the *DSN Long-Range Plan.*[4] A more recent estimate[5] with a different set of assumptions was 500 $M for Goldstone and 300 $M (60 percent of the Goldstone costs assumed) each for the overseas complexes, for a total of 1100 $M in FY'88 dollars. However, the first estimate includes about 200 $M for the Network Operations Control Center (NOCC), which is not included in the more recent estimate. These two estimates of the DSN replacement cost are thus believed to be equivalent to Class C estimates[6] at best, but no other values are known to be available. Both of these replacement values are used to calculate the DSN maintenance cost ratio.

Using the values of 1100 $M and 1500 $M for replacement costs, the DSN maintenance cost ratio is

$$19\ \$M/1100\ \$M \times 100 = 1.7\%$$

and

$$19\ \$M/1500\ \$M \times 100 = 1.3\%$$

If the average annual maintenance cost from Table 1 of 6,668 $K with a 95-percent confidence interval (2-sigma) is used, the bounds of the maintenance ratio obtained are 1.0 and 2.1 percent.

Table 2 shows the sensitivity of the DSN ratio to a variety of estimates of Network replacement costs, including the two specific estimates above.

V. Maintenance Cost Ratios for Other Industries and Organizations

It is hard to find organizations of comparable size engaged in a task similar to that of the DSN. Also, some organizations, such as the Air Force, were unable or unwilling to give out data.

Another area of concern in comparing another organization's maintenance data is the uncertainty of the precise definition of maintenance activity. It was assumed that the JPL definition of maintenance is comparable to the way others define it.

Data were obtained from several industries and organizations. Table 3 lists organizations that engage in network tracking. Both FAA and COMSAT are somewhat similar to the NASA network in operation and both provided estimated data. The FAA network includes radar antennas, transmitters, receivers, and communication equipment in all significant commercial airports in the United States, all communication circuits between airports and tracking centers, and computers. The COMSAT network includes 17 antennas in the 10- to 14-m range, plus additional smaller antennas, with all associated electronic and digital circuits, switching circuits, and uplink and downlink transmitters and receivers. The FAA and COMSAT maintenance cost ratios averaged about 3.6 percent. The 19 $M that NASA spends on DSN maintenance would support a 530 $M replacement capital investment, if a 3.6 percent maintenance cost ratio is assumed. This is far below the 1100 to 1500 $M replacement estimate for the DSN.

The numbers for the European Space Agency reflect only their micro-terminal satellite telecommunication systems, which do not seem comparable to the DSN in scope. Some approximate costs were obtained for the National Radio Astronomy Observatory's Very Large Array (VLA). These costs were not included because their scope of maintenance is very budget-limited, consistent with the academic and noncritical nature of their scheduling task. As

[4] *Deep Space Network Long-Range Plan*, TDA Document 801-1 (internal document), Jet Propulsion Laboratory, Pasadena, California, pp. 1–2, March 15, 1989.

[5] F. D. McLaughlin, TDA Planning Office, personal communication, March 1988.

[6] B. C. Murray, "Flight Project and Flight Equipment Cost At Completion Guidelines," JPL Interoffice Memorandum to Director's Mailing List No. 2 (internal document), Jet Propulsion Laboratory, Pasadena, California, December 14, 1976.

a result, a direct comparison of their maintenance costs is not meaningful.

Maintenance cost ratios were also obtained for software, as shown in Table 3. These ratios are reported in the literature as a percent of total software life-cycle costs. If it is assumed that software has a five-year life, then these annual maintenance cost ratios are about 8 to 16 percent. Maintenance cost ratios for computers and chemical/petroleum companies are also shown in Table 3, and vary from 2.3 to 13.5 percent.

Figure 1 shows the ranges of maintenance cost ratios for the various organizations surveyed and can be easily compared with the range calculated for the DSN. As seen in the figure, the DSN has the lowest maintenance cost ratio of the industries and organizations surveyed. One should keep in mind, however, that the definition of maintenance varies with each person and within industries and organizations, and is not clearly spelled out.

VI. Summary

The preliminary study described in this article compares DSN maintenance expenditures with those of other industries and organizations.

The DSN maintenance cost ratio is estimated to be 1.3 to 1.7 percent of replacement cost. Comparable organizations, such as the FAA and COMSAT, have ratios of 3.2 to 4 percent. As shown in Figure 1, the DSN maintenance cost ratio suggests that the DSN maintenance expenditures are a smaller portion of the Network replacement value than those of the other industries and organizations surveyed.

References

[1] *European Space Agency: Business Telecommunications Using Satellite Micro Terminals*, Noordwijk, The Netherlands: ESA Publication Division, ESTEC, 1988.

[2] B. Boehm, *Software Engineering Economics*, Englewood Cliffs, New Jersey: Prentice-Hall, 1981.

[3] S. E. Brady, "Getting a Hand on Maintenance Costs," *Datamation*, vol. 33, no. 16, pp. 62–71, August 15, 1987.

[4] "Evaluating Vendor Service and Cost of Ownership," *Digital Report*, January 1988.

[5] *Chemical Week*, vol. 139, no. 3, p. 36, July 16, 1986.

[6] K. K. Humphreys, *Jelen's Cost and Optimization Engineering*, Third Edition, New York: McGraw-Hill, 1991.

Table 1. Historical annual sustaining costs for the DSN, 1988 $K (Goldstone only)

Year	Annual sustaining costs, 1988 $K[a]	Annual maintenance costs, 1988 $K	Maintenance costs as percent of sustaining costs
1979	31,974		
1980	36,627		
1981	26,305	6,743	25.6
1982	23,245		
1983	23,217		
1984	19,346		
1985	18,456	5,315	28.8
1986	24,364		
1987	25,522		
1988	32,703	6,937	21.2
1989	32,530	7,677	23.6
Average annual costs	26,754	6,668	24.8
Standard deviation	5,912	988	3.2

[a] For NASA Codes 31430-4 and 31440-4.

Table 2. Maintenance cost ratios as a function of capital investment

Network capital investment, 1988 $M	Network average annual maintenance cost, 1988 $M	Maintenance cost, percent
2400	19	0.79
2000	19	0.95
1600	19	1.19
1500[a]	19	1.27
1100[b]	19	1.73
1000	19	1.90
800	19	2.38
530	19	3.58
500	19	3.80

[a] From *Deep Space Network Long-Range Plan*, TDA Document 801-1 (internal document), Jet Propulsion Laboratory, Pasadena, California, pp. 1–2, March 15, 1989.

[b] F. D. McLaughlin, TDA Planning Office, personal communication, March 1988.

Table 3. Maintenance cost ratios

Item	Industry	Annual maintenance cost, percent	Comment
1.	Communications and data processing		
	Communications (network tracking)		
	Federal Aviation Administration (FAA)[a]	3.2	A
	Communications Satellite Corp. (COMSAT)[b]	4	A
	European Space Agency (ESA)[c]	8–12.5	A
	Software[d]		
	GTE	10	B
	GM	15	B
	USAF	14	B
	Software (in general)	8–16	B
	Computers		
	Large machines[e,f]	4–7	A
	Minicomputers (contract)[e]	10	A
	Workstations		
	(a) Contract[e]	>15	A
	(b) 24-hr service[e]	+30% of (a)	A
	Avg. all comp. industry[e]	10	A
2.	Industrial chemical companies (Dow, Union Carbide, Ethyl, etc.)[g]	3.3–13.5	C
3.	Diversified chemical companies (Shamrock, PPG, etc.)[g]	3.8–43.3	C
4.	Specialty chemical companies (Corning, Petrolite, Loctite, etc.)[g]	2.3–9.8	C
5.	Petroleum[h]	5	C

A. Annual maintenance cost as a percentage of total equipment cost (replacement).

B. Annual maintenance cost as a percentage of total software life-cycle cost (assumes 5-yr life).

C. Annual maintenance cost as a percentage of current plant and equipment cost.

[a] Mark Erp, Federal Aviation Administration, Maintenance Engineering Division, personal communication, April 1990.

[b] Michael Auth, Communications Satellite Corporation, Earth Station Services, personal communication, April 1990.

[c] From [1].

[d] From [2].

[e] From [3].

[f] From [4].

[g] From [5].

[h] From [6].

Table 4. Maintenance definition[a]

Maintenance	Nonmaintenance
Costs of operating the Maintenance Repair Facility.	Costs of operating other operations facilities such as calibration and standards labs and transporting test instruments for periodic calibration.
Costs of training the maintenance and repair staff as applicable.	Costs of training the operators.
Costs and transportation of spare parts for replacement.	
Costs of those ECO mod kits required to maintain the original as-built performance. This includes the costs of development, design, and procurement (including Cognizant Development Engineer [CDE] and Cognizant Operations Engineer [COE] efforts) and transportation.	Costs and transportation of those ECO mod kits which upgrade equipment or operational performance above the original as-built performance.
CDE and System Cognizant Operations Engineer (SCOE) efforts as appropriate to the maintenance function (assumed 50%).	Costs of system engineering, system analysis, and system documentation.
	Costs of software database management functions.
	Costs of DSN management functions.
	Costs of project, station implementation, and scheduling engineering.

[a] Maintenance is that activity/expenditure which keeps the operation and performance of the DSN equipment at the as-built level.

Table 5. DSN sustaining allocation

Maintenance category[a]	Percent of total sustaining costs, FY'88[b]	Nonmaintenance	Percent of total sustaining costs, FY'88[b]
Costs of operating the maintenance repair facility.	2	Costs of operating other operations facilities such as calibration and standards labs and transporting test instruments for periodic calibration.	1
Costs of training the maintenance and repair staff as applicable.	1	Costs of training the operators.	3
Costs and transportation of spare parts for replacement.	4		
Cost of those ECO MOD kits required to maintain the original as-built performance. This includes the costs of development, design, and procurement (including CDE and COE efforts) and transportation.	12	Cost and transportation of those ECO MOD kits which upgrade equipment or operational performance above the original as-built performance.	33
CDE and SCOE efforts as appropriate to the maintenance function (assumed 50%).	2	Cost of system engineering, system analysis, and system documentation.	29
		Costs of software database management functions.	
		Costs of DSN maintenance functions.	
		Costs of project, station implementation, and scheduling engineering.	13
Total	21	Total	79

[a] Maintenance is that activity/expenditure which keeps the operation and performance of the DSN equipment at the as-built level.

[b] For NASA Codes 31430-4 and 31440-4.

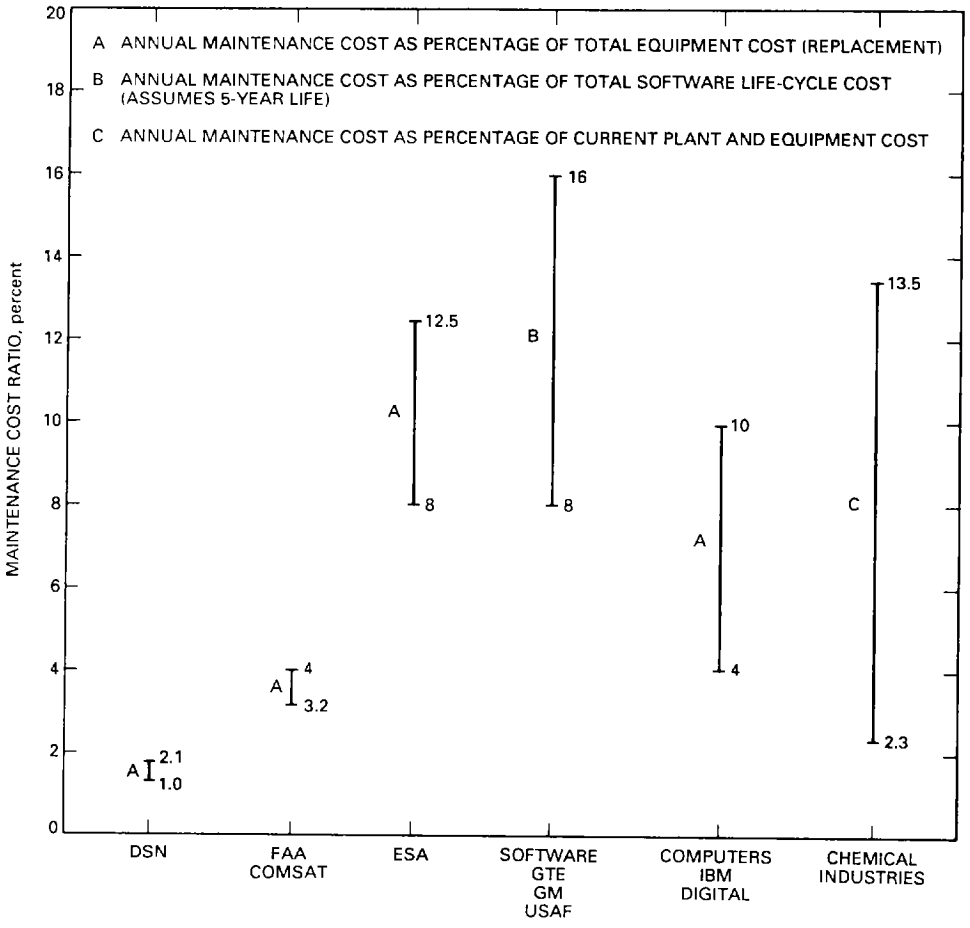

Fig. 1. DSN maintenance cost ratio compared to other industries and organizations.

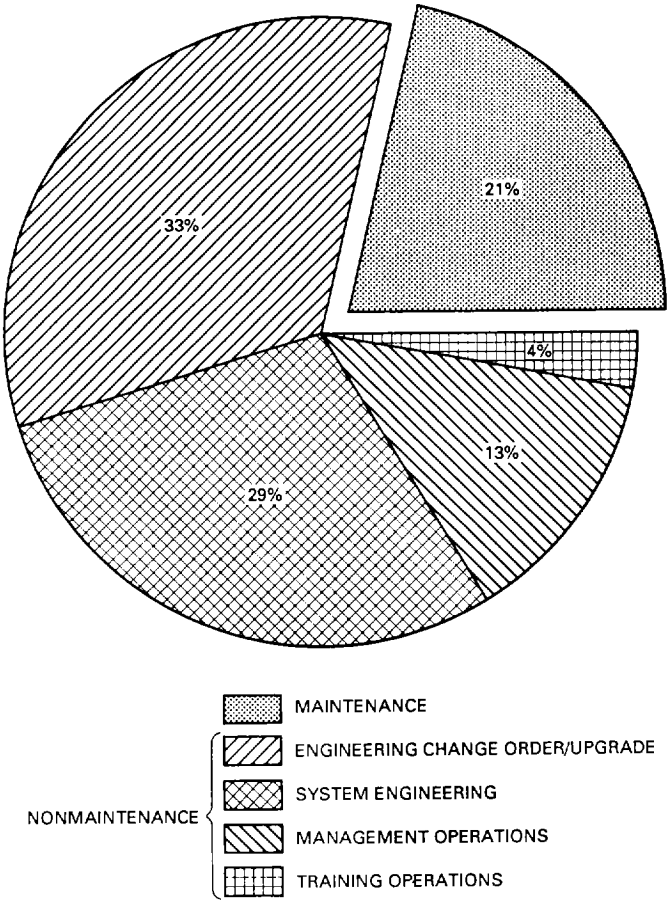

Fig. 2. Sustaining costs breakdown for FY'88, NASA Codes 31430-4 and 31440-4.