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# Determining Maintenance Cost Ratios

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**M**aintenance is a necessary (and usually burdensome) function for practically all natural and man-made elements. Simply defined, maintenance is the effort to keep a device or system working. The amount of funding allocated for maintenance by an organization is necessarily a compromise, possibly viewed as too much by management and too little by the operators/maintainers. The objective of our study was to report on the wide range of costs involved in maintaining equipment. We discuss some methods that different industries use to measure and report their maintenance costs; we summarize the results of a literature search on the range of maintenance costs for several industries; and we report on our own study of maintenance costs in the National Aeronautics and Space Administration (NASA) Deep Space Network (DSN) and how these maintenance costs compare to the other reported results.

In this study, maintenance is defined as the activity/expenditure that keeps the operation and performance of equipment at the original as-built level. In the case of the equipment used in the DSN that the Jet Propulsion Laboratory (JPL) operates for NASA, a more specific definition applicable to DSN equipment is used (see table 1). When compiling maintenance costs of various organizations, we found that organizations report maintenance cost data in various ways:

- as a percentage of total equipment replacement cost,
- as a percentage of total software life-cycle cost (assumes 5-yr life),
- as a percentage of current plant and equipment cost, and
- as a cost per square meter (square foot) of building.

In some cases, still other factors are used, such as $/net megawatt hour used in the nuclear industry. However, in the industries most comparable to activities in the DSN, equipment replacement cost is used. To make meaningful comparisons, the maintenance cost ratio is defined as:

$$\text{Maintenance Cost Ratio } (\%) = \frac{\text{Annual Maintenance Cost \$}}{\text{Capital Replacement Cost \$}}$$

Data were obtained from several industries and organizations. Table 2 includes organizations engaged in network tracking. The US Federal Aeronautics Administration (FAA) and the Communications Satellite Corp. (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-meter (33-foot) to 14-meter (46-foot) 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

## Table 1—Maintenance Definition*

| Maintenance | Nonmaintenance |
|---|---|
| **A. Sustaining Budget Items** | |
| 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. |
| Cost of those Engineering Change Order (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 DSN management functions. |
| Costs and transportation of spare parts for replacement. | Costs of project, station implementation, and scheduling engineering. |
| | Costs of software database management functions. |
| **B. Goldstone Contractor Budget** Maintenance portion of Goldstone contractor costs. | |
| **C. Replacement Parts** Replacement parts supplied from Logistic Supply Depot operated by Goddard Space Flight Center. | |

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

3.6 percent. (The numbers for the European Space Agency reflect only its microterminal satellite telecommunication systems, which do not seem comparable to the DSN in scope.)

Maintenance cost ratios were also obtained for software, as shown in table 2. These ratios are reported in the literature as a percent of total software life-cycle costs. If it is assumed that software has a 5-year life, then these annual maintenance cost ratios are about 8 to 16 percent. Maintenance cost ratios for computers range from 4 percent to greater than 15 percent, depending on whether they are large mainframes or work stations, respectively. Industrial and specialty chemical companies (also shown in table 2) vary from 2.3 to 13.5 percent, and, finally, petroleum companies are about 5 percent.

Figure 1 shows the ranges of maintenance cost ratios for the various organizations surveyed. As seen in the figure, the DSN has the lowest maintenance cost ratio of the industries and organizations surveyed. It should be emphasized, however, that the definition of maintenance varies with each person and within industries and organizations; it is not clearly spelled out. As stated above, people report this data in at least three ways. In figure 1 and table 2, the definitions used for the reported results are spelled out. We should also recognize that *computers* and *communication* networks are difficult to compare by the nature of their equipment, even though they report their maintenance cost ratios on the same basis.

### Estimating the DSN Maintenance Cost Ratio

The NASA Deep Space Network is a multimission telecommunications and radiometric data facility used to support NASA's exploration of space, research in space science, and advanced technology investigations. The network has facilities located on three continents: North America (Goldstone, California), Europe (Madrid, Spain) and Australia (Canberra), providing tracking complexes at intervals of 120 degrees of longitude.

The network basic services are: (1) reception of telemetry from spacecraft; (2) transmission of commands to spacecraft; (3) measurement of radio metric data for spacecraft navigation; and (4) radio science measurements. Each tracking complex includes one 70-meter (230-foot), two 34-meter (112-foot) and one 26-meter (85-foot) tracking antennas, and state-of-the-art receiving, transmitting, and signal processing equipment.

To more accurately identify DSN maintenance costs, a definition of maintenance was generated and tabulated in table 1. The major activities *not* included in maintenance are:

- costs of operating calibration and standards laboratories in the DSN facilities, including transportation of test instruments for calibration;

## Table 2—Maintenance Cost Ratios

| Item | Industry | Annual maintenance cost, percent | Comment |
|------|----------|--------------------|---------|
| 1. Communications and data processing | | | |
| | Communications (network tracking) | | |
| | Federal Aviation Administration (FAA) [1] | 3.2 | A |
| | Communications Satellite Corp. (COMSAT) [2] | 4 | A |
| | European Space Agency (ESA) [3] | 8-12.5 | A |
| | Software [4] | | |
| | GTE | 10 | B |
| | GM | 15 | B |
| | USAF | 14 | B |
| | Software (in general) | 8-16 | B |
| | Computers | | |
| | Large machines [5,6] | 4-7 | A |
| | Minicomputers (contract) [5] | 10 | A |
| | Workstations | | |
| | (a) Contract [5] | >15 | A |
| | (b) 24-hr service [5] | ≥20 | A |
| | Avg. all comp. industry [5] | 10 | A |
| 2. Industrial chemical companies (Dow, Union Carbide, Ethyl, etc.) [7] | | 3.3-13.5 | C |
| 3. Specialty chemical companies (Corning, Petrolite, Loctite, etc.) [7] | | 2.3-9.8 | C |
| 4. Petroleum [8] | | 5 | C |

A. Annual maintenance cost as a percentage of total equipment costs (replacement).
B. Annual maintenance cost as a percentage of total software life-cycle (assumes 5-yr life).
C. Annual maintenance cost as a percentage of current plant and equipment cost.



Figure 1—DSN Maintenance Cost Ratio Compared to Other Industries and Organizations

- costs of training operators;
- costs of engineering change order (ECO) modification kits that upgrade the equipment or operational performance, including transportation costs;
- costs of system engineering, system analysis, and system documentation; and
- costs of management functions such as software database maintenance, DSN management, and engineering activities related to project and station implementation and scheduling.

At the Goldstone, California facility, maintenance costs are broken down into three categories: the sustaining budget, the contractor budget, and replacement parts.

The guideline definition of maintenance given in table 1 was carefully applied to the network sustaining cost data at Goldstone for a set of selected fiscal years (FY81, FY85, FY88, and FY89) that reflects a diversity of tasks impacting the DSN. These maintenance cost data and sustaining cost data for FY79 through FY89 are shown in table 3, 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 of almost $27 million for FY88 (shown in table 3), the average annual maintenance portion is about $7 million. In addition, the portion of the Goldstone contractor salary and support costs attributable to maintenance averages about $4 million annually, as shown in table 4. Also, approximately $2 million (FY88) is funded annually by NASA for JPL's use in obtaining replacement parts from the Goddard Space Flight Center's central supply facility. This brings the average annual DSN maintenance cost for the Goldstone complex to approximately $13 million (FY88), as shown in table 5.

To compare 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 consistent with the FAA and COMSAT data shown in table 2. The DSN replacement
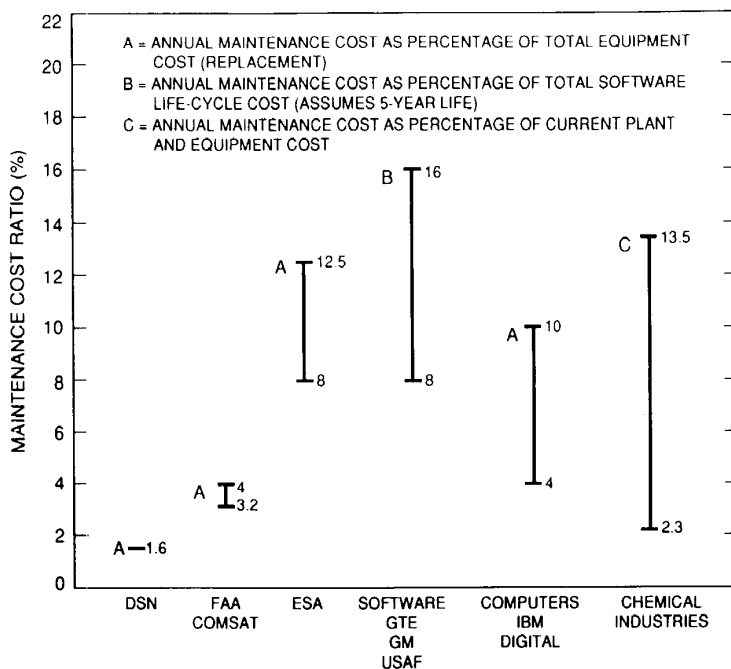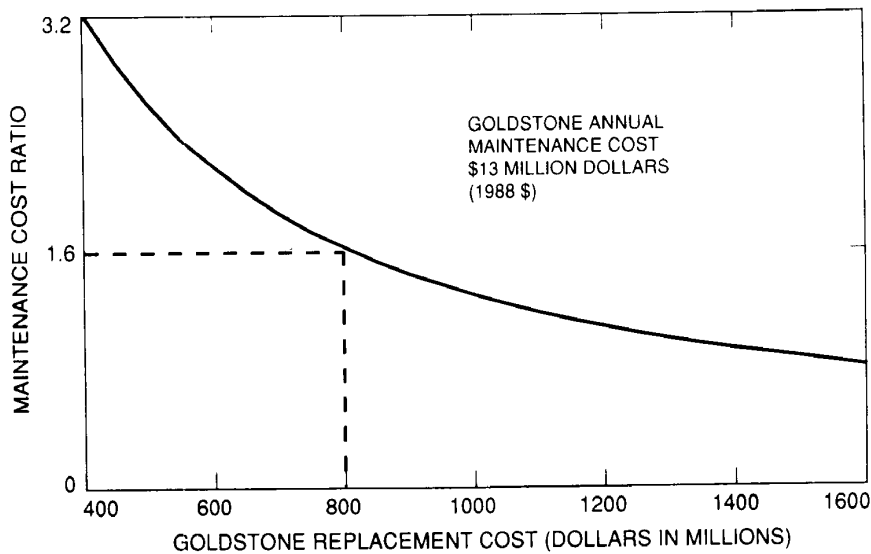
Figure 2—Sensitivity Analysis for Goldstone Maintenance Cost Ratio

cost (Goldstone only) has been estimated as $800 million (FY88) [9]. Using the values of $800 million for replacement costs, the DSN maintenance cost ratio is

$13M/$800M x 100% = 1.6%

Figure 2 shows the sensitivity of the DSN maintenance ratio to a variety of estimates of the network replacement cost from $400 million to $1,600 million. Even if our estimate of the network replacement cost is in error by as much as a factor of 2 (ie, if the cost were really $400 million), we see that the DSN is still near the low end of the maintenance cost ratio results (referring again to figure 1).

This preliminary study describes the methodology for calculating DSN and other maintenance cost ratios and presents *ball park* numbers for maintenance cost ratios, which may be helpful to the reader.

**Table 3—Historical Annual Sustaining Costs for the DSN, 1988 $K ($1000)**
(Goldstone only)

| Year | Annual sustaining costs, 1988 $K | Annual maintaining 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 |

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### Table 4—Goldstone Contractor Maintenance Costs

| Year | Annual Maintenance Costs 1988 $K |
|------|----------------------------------|
| 1981 | 4,845 |
| 1985 | 4,426 |
| 1988 | 4,220 |
| 1989 | 3,761 |
| **Average Annual Costs** | 4,313 |
| **Standard Deviation** | 451 |

### Table 5— Goldstone Average Maintenance Costs for FY '81,'85, '88, and '89

| Funding Source | Million $ (1988) | Percentage of Total |
|----------------|------------------|---------------------|
| **Sustaining Budget** | | |
| a) Cost of Operating the Maintenance Repair Facility | 0.635 | 4.9 |
| b) Costs of Training the Maintenance and Repair Staff as Applicable | 0.318 | 2.4 |
| c) Costs and Transportation of Spare Parts for Replacement | 1.270 | 9.8 |
| d) Costs 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 | 3.810 | 29.3 |
| e) CDE and SCOE Efforts as Appropriate to the Maintenance Function (Assumed 50%) | 0.635 | 4.9 |
| **Subtotal** | 6.7 $M | 51.3 |
| **Goldstone Contractor Budget** | | |
| a) Mgmt/Proc Staff | 0.069 | 0.5 |
| b) Maint Facility Team | 2.166 | 16.7 |
| c) Logistics & Services | 0.393 | 3.0 |
| d) 26-Meter Operations | 0.064 | 0.5 |
| e) Network Operations Control | 0.701 | 5.4 |
| f) Network Maintenance Facility | 0.589 | 4.5 |
| g) Network Operations Support | 0.345 | 2.7 |
| **Subtotal** | 4.3 $M | 33.3 |
| **Goddard** | | |
| a) Replacement Parts | 2.0 $M | 15.4 |
| **Total** | 13.0 $M | 100% |

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