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A Model for the Cost of Doing a Cost Estimate

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This article provides a model for estimating the cost required to do a cost estimate for DSN projects that range from \$0.1 to \$100 million. The cost of the cost estimate in thousands of dollars, C_E, is found to be approximately given by $C_E = KC_p^{0.35}$, where C_p is the cost of the project being estimated in millions of dollars and K is a constant depending on the accuracy of the estimate. For an order-of-magnitude estimate, K = 24; for a budget estimate, K = 60; and for a definitive estimate, K = 115. That is, for a specific project, the cost of doing a budget estimate is about 2.5 times as much as that for an order-of-magnitude estimate, and a definitive estimate costs about twice as much as a budget estimate. Use of this model should help provide the level of resources required for doing cost estimates and, as a result, provide insights towards more accurate estimates with less potential for cost overruns.

I. Introduction

Large cost overruns for major projects are a frequent occurrence. For example, the following projects are reported to have had final costs that exceeded the original cost estimates by over 45 percent.[2] These were Landsat-D (48 percent), Infrared Astronomical Satellite (60 percent), Earth Radiation Budget Experiment (61 percent), Gamma Ray Observer (98 percent), Space Telescope (98 percent), Galileo (100 percent), Tracking and Data Relay Satellite System (130 percent), and Pegasus (700 percent). Considering the current emphasis on fiscal responsibility within NASA and other government agencies, cost overruns are a major problem. Overruns may lead to cancellation of the project. In some cases, a potential overrun results in modifying the project to a design-to-cost task.

There are many reasons for cost overruns, but one of the key factors is the lack of resources (time, money, and staffing) spent to do proper up-front cost estimates. An-

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[2] H. W. Partma and W. E. Ruhland, *Predicting Financial Risk for the Development of Space Flight Projects* (internal document), Jet Propulsion Laboratory, Pasadena, California, September 1988.

other major reason is that the implementers did not do the estimating. The purpose of this article is to address the issue of the cost to do a cost estimate. The authors will report on how others handle this issue, offer suggestions on how the DSN should estimate the amount to spend on a cost estimate, and discuss its impact on reducing the probability of a cost overrun.

The authors will report on their literature search and actual data from JPL Procurement on what others charge the Laboratory for a cost estimate. The goal is to determine guidelines and a methodology for estimating how much to spend on a cost estimate to achieve a desired accuracy. Underallocation of resources for producing a cost estimate is not uncommon. All the necessary cost elements are usually not included because of time constraints. This leads to cost overruns and/or descoping of the functional requirements of projects.

II. The Cost of Estimating Accuracy

The cost of doing a cost estimate depends on how well the project is defined, who is doing the estimate, the amount of information available, and the level of accuracy required. An order-of-magnitude estimate will cost much less than a definitive estimate. The accuracy of a cost estimate increases within certain limits as the amount of resources spent on the cost estimate increases. The authors defined a metric for the cost to do a cost estimate as the percent of the cost of the estimate as compared with the total cost of the project.

$$\text{cost of a cost estimate (percent)} = \frac{\text{cost of the estimate } (C_E)}{\text{total cost of the project } (C_p)} \times 100 \text{ percent}$$

Figure 1 shows the relative cost of a cost estimate [1] as a function of the accuracy of an estimate for a project costing approximately \$3 million that the authors updated to 1990 dollars using the *NASA Inflation Index* [3]. For example, an estimate that is accurate enough to be within ±30 percent would cost 0.2 percent, or \$6 thousand, whereas an estimate accurate to within ±10 percent would cost 1.5 percent, or \$45 thousand, of the total project cost. The more one invests up front in defining the requirements and the deliverables, the more accurate the final estimate will be.

For projects much larger than \$3 million, the cost of the estimate as a percent of the total project cost would be less than that shown in Fig. 1, whereas for smaller projects costing much less than \$3 million, the percent spent on the cost estimate would be higher. Figure 1 represents a model typical of the process industry; however, the concept applies to the DSN. The authors will now report on a recent set of data that is applicable to the DSN.

This second set of data [2] shows the cost to prepare cost estimates for three accuracy ranges varying from order of magnitude, -30 to $+50$ percent; budget, -15 to $+30$ percent; and definitive, -5 to $+15$ percent, for projects ranging from approximately \$0.1 to \$80 million. Notice that the high limits of the ranges are greater than the low limits because there is usually a lack of consideration of all the necessary cost elements. As a result, there is usually more chance of a cost overrun than an underrun. By making several smoothing assumptions and updating the data to 1990 using the *NASA Inflation Index* [3], the authors plotted the resulting data set as shown on a log–log plot in Fig. 2. A model developed based on these parameters is described below.

III. Model for the Cost of Estimating Accuracy

On the log–log plot of Fig. 2, a set of straight lines conformed closely to the data points. On a log–log plot, a straight line represents a convenient power function equation of the form $C_E = KC_P{}^R$. That is, by taking the log of both sides of the equation, one gets

$$\log\ C_E = R\ \log\ C_P + \log\ K \tag{1}$$

This represents a straight line where R is the slope of the line in Fig. 2 and log K is the Y intercept. The lines shown in Fig. 2 therefore reflect a convenient power function equation that can be used as a model.

$$C_E = KC_P{}^R \tag{2}$$

where

C_E = cost of the cost estimate in thousands of dollars

C_P = cost of the project being estimated in millions of dollars

K = a constant depending on the accuracy of the estimate

R = slope of lines

Figure 2 shows the slope R and the constant K for each class of cost estimate. For each class of estimate, $R = 0.35$ for project costs in the range of \$0.1 to \$100 million. The constant K is 24 for an order-of-magnitude estimate, 60 for a budget estimate, and 115 for a definitive estimate. Or to look at it another way, a budget cost estimate costs about two-and-one-half times as much as an order-of-magnitude estimate, and a definitive estimate costs about twice as much as a budget estimate.

IV. Discussion of Levels of Cost Estimates

The levels of cost estimates discussed in this article correlate with the condensed classification of cost estimates proposed by the American Association of Cost Engineers [2]. These are as follows:

Class	Accuracy, percent
Order of magnitude	−30 to +50
Budget	−15 to +30
Definitive	−5 to +15

An order-of-magnitude level of cost estimate is usually based on very preliminary statements of requirements. This is done in the requirements definition stage when there is a preliminary listing of deliverables. This class of estimate roughly coincides with that needed for a Level A design review[3] when a maximum uncertainty of 30 percent is desired.

The budgetary level of a cost estimate is based on system functional requirements with at least preliminary deliverables, receivables, and schedules presented by a subsystem. This class of cost estimate is appropriate for Level B and/or Level C design reviews when a maximum uncertainty of 20 percent is desired.

The definitive level of a cost estimate is based on a subsystem functional design, and the deliverables, receivables, and schedules are carefully defined and final. This class of cost estimate is appropriate for a Level D design review with a maximum uncertainty of 10 percent.

[3] R. P. Mathison and P. T. Westmoreland, "Cost Review Format," JPL Interoffice Memorandum 3300-88-08 (internal document), Jet Propulsion Laboratory, Pasadena, California, January 6, 1988.

A more detailed description of the DSN classes of cost estimates as they relate to design reviews is presented in the Mathison–Westmoreland JPL Interoffice Memorandum.[4]

V. Example Using the Model

Assume that one has to estimate the cost required to do a cost estimate for a project that is expected, based on other similar projects, to cost approximately \$20 million. Use Eq. (2) or Fig. 2 where

$$C_E = KC_P{}^R$$

$C_P = 20$, $R = 0.35$, and $K = 24$, 60, and 115 for an order-of-magnitude, a budget, and a definitive estimate, respectively. Using $C_E = 24 \times 20^{0.35}$, one gets \$68,000 for an order-of-magnitude estimate. For a budget estimate, one gets \$171,000 and a definitive estimate costs \$328,000. Armed with these data, a decision can be made to proceed with the cost estimate after allocating the necessary funds.

This method may reduce underallocation of resources for producing cost estimates, and thereby more realistic project cost estimates may be obtained. Of course, if the actual estimate of the project turns out to be more or less than the so-called ballpark guesstimate, the budget for doing the cost estimate can be adjusted accordingly. In the next section, data obtained from JPL Procurement will be presented on the cost of actual cost estimates.

VI. JPL Procurement Data for Cost Estimates

The authors obtained data based on JPL procurements for outside contractors to do cost estimates for DSN projects.[5,6,7] These data points are summarized in Table 1. The first data point reflects a Motorola estimate

[4] Ibid.

[5] R. S. Hughes, personal communication, Radio Frequency and Microwave Subsystems Section, Jet Propulsion Laboratory, Pasadena, California, December 5, 1989.

[6] R. L. White, personal communication, Ground Antennas and Facilities Engineering Section, Jet Propulsion Laboratory, Pasadena, California, January 23, 1991

[7] L. H. Kushner, personal communication, Ground Antennas and Facilities Engineering Section, Jet Propulsion Laboratory, Pasadena, California, February 5, 1991.

for a significant supplement to an existing Motorola contract. The second and third data points show the costs of two externally generated Preliminary Engineering Reports (PER's) that developed the estimated costs for cost-of-facilities projects

The costs of the cost estimates for these three projects varied from 1.3 to 2.9 percent of the total project cost. The high value of 2.9 percent was for a relatively small project of about $2 million, whereas the lower values of 1.3 to 1.5 percent were for projects in the $11 to $24 million range. These results fall into the band of curves shown in Fig. 2. This provides an independent check of the model proposed earlier.

VII. Summary

A model for estimating how much should be allocated to do DSN cost estimates for new capabilities has been developed. This model may help the DSN make better cost estimates and thereby reduce the possibility of producing cost estimates that are too low. These low cost estimates could lead to cost overruns or reduction of some functional requirements or both.

References

[1] W. R. Park, *Cost Engineering Analysis—A Guide to the Economic Evolution of Engineering Projects*, New York: John Wiley & Sons, p. 133, 1973.

[2] K. K. Humphreys, *Jelen's Cost and Optimization Engineering*, third edition, New York: McGraw-Hill, p. 370, 1991.

[3] National Aeronautics and Space Administration, Cost and Economic Analysis Branch, *NASA Inflation Index*, Washington, DC, February 28, 1991.

Table 1. JPL procured cost estimates in FY'90 dollars.

Source	C_P, millions of dollars	C_E, thousands of dollars	$(C_E/C_P)100$, percent
Motorola[a]	1.96	56	2.9
Section 332[b] PER[c]	10.83	146	1.3
Section 332 PER[d]	24.00	360	1.5

[a] Modification to Motorola contract (Magellan ground hardware) for adding C-band uplink capability to DSN receiver–exciter subsystems.

[b] Ground Antennas and Facilities Engineering Section.

[c] For 34-m antenna JPL support effort plus contractor production of PER.

[d] For new Telecommunication Research Laboratory (building).

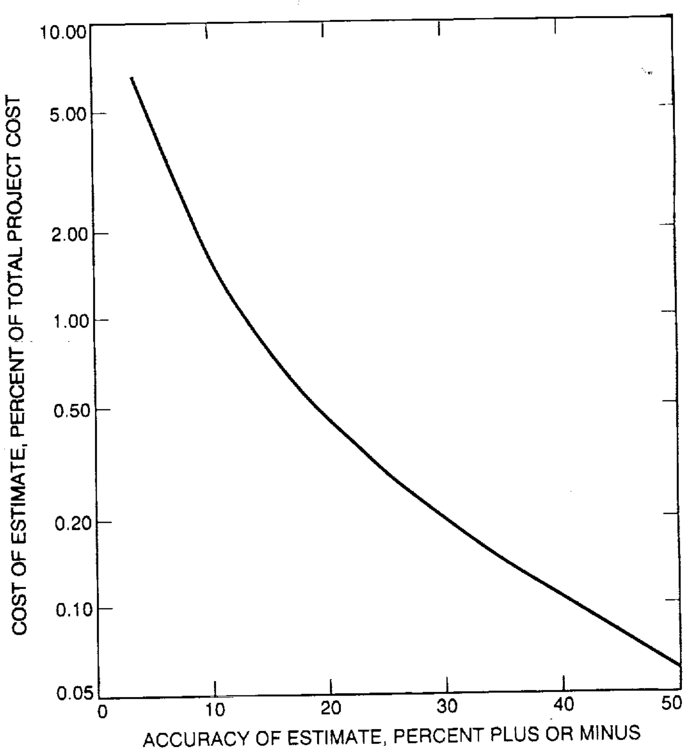

Fig. 1. Cost of a cost estimate for a $3 million (1990) project [1].

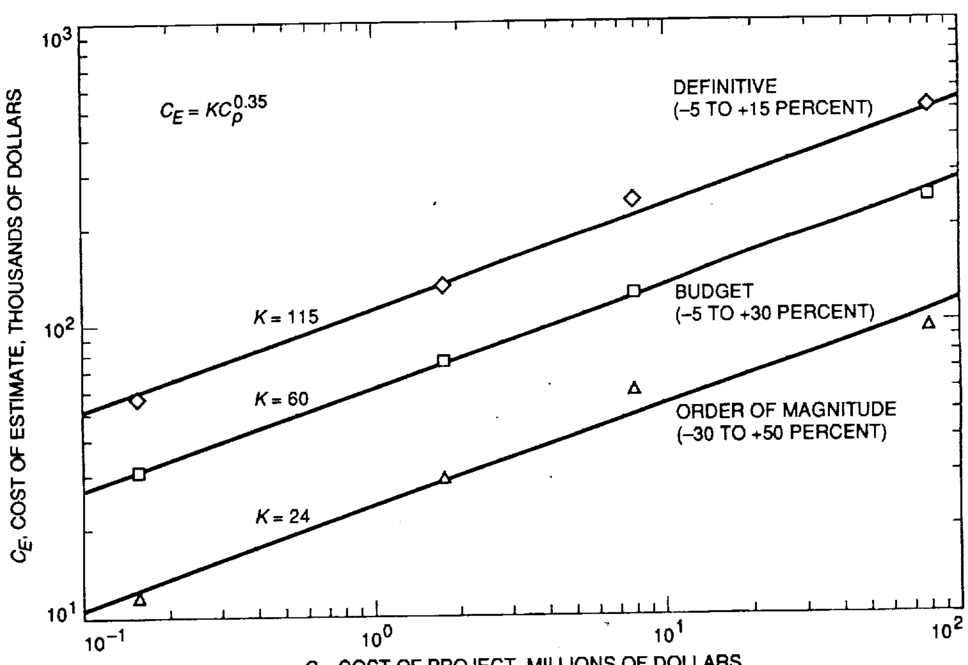

Fig. 2. Cost of a cost estimate for three accuracy ranges.

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