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The Cost of Doing a Cost Estimate

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Large cost overruns for major projects are a frequent occurrence. In a study performed on 44 technically advanced commercial-scale energy and chemical process plants, the average final cost exceeded the original order of magnitude estimated cost by 104 percent. These were projects with an average capital investment of US $309 million (FY 1990) [4,5]. The following Jet Propulsion Laboratory (JPL) spacecraft projects for the US National Aeronautics and Space Administration (NASA) also had final costs that exceeded the original cost estimates by over 45 percent [7]. These were Landsat-D (48 percent), IRAS (60 percent), ERBE (61 percent), Gamma Ray Observer (98 percent), Space Telescope (98 percent), Galileo (100 percent), TDRSS (130 percent), and Pegasus (700 percent). Within NASA and other government agencies, cost overruns are a major problem, especially with today's emphasis on tight budgets. Overruns may lead to cancellation of a 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. Another major reason is that the implementers were not involved in the estimating. The purpose of this article is to address the issue of the cost to do a cost estimate [8]. We will report on how others handle this issue and make suggestions on how the Deep Space Network (DSN) should estimate the amount to spend on a cost estimate and its impact on reducing the probability of a cost overrun.

We will report on our literature search and actual data from JPL procurement on what others charge JPL for a cost estimate. Our goal is to come up with guidelines and a methodology for estimating how much to spend on a cost estimate to achieve a desired accuracy. We think that many companies and government agencies typically underallocate resources for producing a cost estimate and, as a result, do not take the time to include all the necessary cost elements. This leads to cost overruns and/or de-scoping of the functional requirements of projects.

The Cost of Estimating Accuracy

The cost of doing a cost estimate depends on how well the project is defined, who's 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 also increase. We will use a metric defined as the cost to do a cost estimate, which is the percentage of

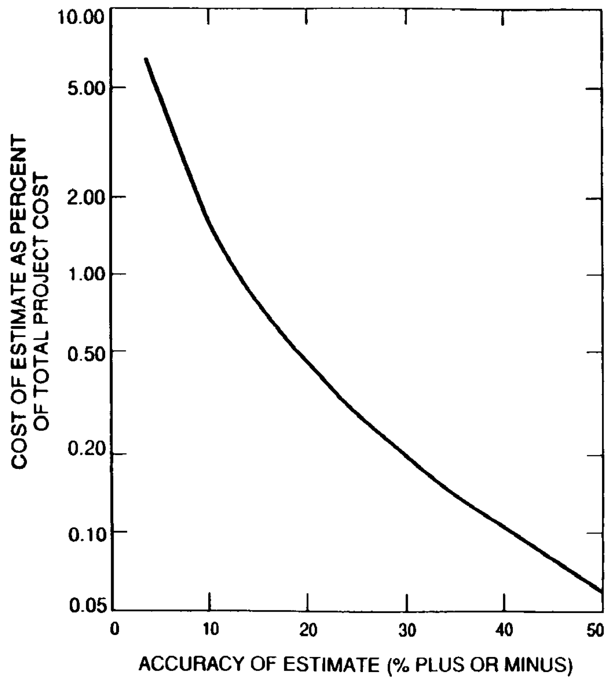

Figure 1—Cost of a cost estimate for $3 million project (1990) [6,5]

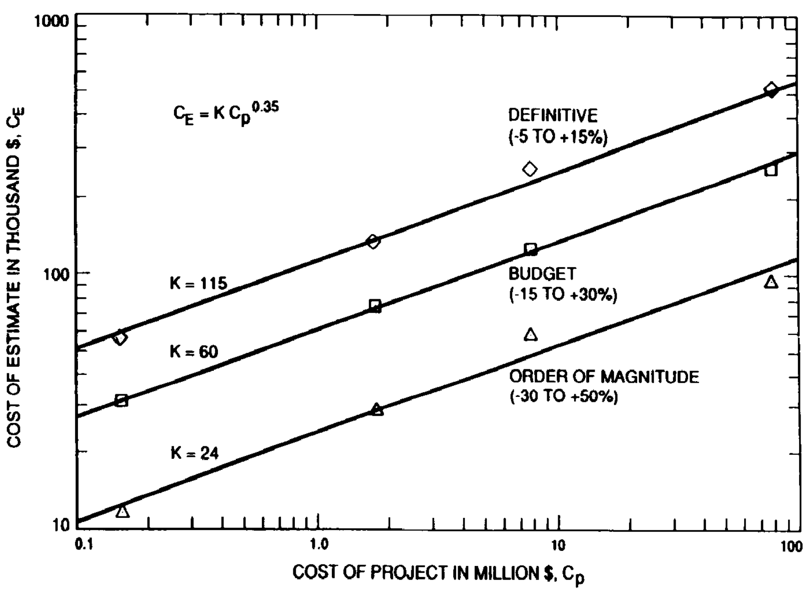

Figure 2—Cost of a cost estimate

the cost of the estimate compared to the total cost of the project.

Cost of a cost estimate (%) =

$$\frac{\text{cost of the estimate } (C_E)}{\text{total cost of project } (C_P)} \; x \; 100\%$$

(equation 1)

Figure 1 shows the cost of a cost estimate as a function of the accuracy of an estimate. This holds for a $3 million project in the chemical process industry when updated to 1990 costs using the NASA inflation index [6,5]. For example, an estimate that is accurate enough to be within ± 30 percent would cost 0.2 percent or $6K, whereas an estimate accurate to within ± 10 percent would cost 1.5 percent or $45K of the total project cost. The more you invest 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 percentage of the total project cost would be less than that shown in figure 1; for smaller projects, costing much less than $3 million, the percentage 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.

A second set of data [2], which is applicable to the DSN and many companies and government agencies, shows the cost to prepare cost estimates for three accuracy ranges varying from order of magnitude, -30 percent to +50 percent, budget at -15 percent to +30 percent, and definitive at -5 percent to +15 percent for a range of industrial projects from about $0.1 to $80 million dollars. 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 [5], we plotted the resulting data set on a log-log plot in figure 2. A model we developed based on these parameters is described below.

Model for the Cost of Estimating Accuracy

On the log-log plot of figure 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, we get:

$$\log C_E = R \log C_P + \log K$$

(equation 2)

This represents a straight line where R is the slope of the line in figure 2, and log K is the Y intercept. The lines shown in figure 2, therefore, reflect a convenient power function equation that we can use as our model:

$$C_E = KC_P^R$$

(equation 3)

where

C_E = Cost of the cost estimate in thousands of dollars ($K),
C_P = Cost of the project being estimated in millions of dollars ($MM),
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 $100MM. 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.

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

Source	*Notes	Cost of Projects C_P in $MM	Cost of Estimate C_E in $K	$(C_E/C_P) \times 100$ %
Motorola	1	1.96	56	2.9
Sect 332 PER	2	10.83	146	1.3
Sect 332 PER	3	24.00	360	1.5

***Notes:**

1. Modification to Motorola contract (Magellan Ground Hardware) for adding C-band uplink capability to DSN receiver-exciter subsystems.
2. Preliminary engineering report (PER) for 34 meter antenna - JPL support effort plus contractor production of PER.
3. PER for new Telecommunication Research Laboratory building.

Levels of Cost Estimates

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

Class	Accuracy
1. Order-of-Magnitude	-30 to +50%
2. Budget	-15 to +30%
3. Definitive	-5 to +15%

In the DSN, 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. The budgetary level of a cost estimate is based on system functional requirements with at least preliminary deliverables, receivables, and schedules presented by subsystem. The definitive level of a cost estimate is based on a subsystem functional design, and the deliverables, receivables, and schedules are carefully defined and thus are final.

Example Using the Model

Assume you have to estimate the cost required to do a cost estimate for a project that is expected to be in the ballpark of US $20 million, based on other similar projects. We will use equation 3 or figure 2 where

$$C_E = KC_P^R$$

(equation 3)

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 $C_E = 24 \times 20^{0.35}$, we get about $70K for an order-of-magnitude estimate. For a budget estimate we get $170K, and a definitive estimate will cost about $330K. Armed with this data, a decision can be made to proceed with the cost estimate after allocating the necessary funds.

This method may reduce under-allocation of resources for producing cost estimates and help in obtaining more realistic project cost estimates. Of course, if the actual estimate of the project turns out to be more or less than the ballpark "guesstimate," the budget for doing the cost estimate can be adjusted accordingly. In the next section we will present data on the cost of actual cost estimates obtained from JPL procurement data.

JPL Procurement Data for Cost Estimates

We obtained data based on JPL procurements for outside contractors to do cost estimates for DSN projects [1,9,3]. These data points are summarized in table 1. The first data point reflects a Motorola estimate for a significant supplement to an existing Motorola contract. The second and third data points show the cost of two externally generated preliminary engineering reports (PER) that develop the estimated costs for cost of facilities (C of F) projects.

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

The cost of a cost estimate derived in this section and shown by figure 2 correlates fairly well with actual cost estimate data we have experienced at JPL. The data shown by figure 1 reflects the chemical process industry (CPI). The cost to do an estimate in the CPI are less than for projects at JPL. This is expected because a JPL project usually has considerably less "inheritance" (repetition of previous design and documentation) than would be expected in the CPI, where cost factors have been developed and matured over a long time period.

Cost Elements

In this report, the cost elements that comprise the cost of a project C_P include the following:

- **project management**—management efforts required for project planning;
- **project planning**—high level design, task assignments, and scheduling;
- **prototype development or pilot plant testing (as required)**—design, fabrication, and evaluation. Note that research and development costs that precede the conceptual phase leading to project initiation are not included in these cost elements;
- **design**—preparation of specifications, design drawings, operators' manuals;
- **procurement**—prepare bid packages for all hardware, software, initial spare parts, evaluate bids, monitor negotiations and select successful bidder;
- **facilities**—modifications or acquisitions as required; and
- **fabrication, installation, and validation**—define and document manufacturing procedures, validation test procedures, quality assurance procedures, and installation planning. The costs of fabrication, testing and inspection, and installation are included.

If you include other major cost elements in your cost estimate that are not included above, such as research and development, then the values for K in Equation (2) may need to be increased.

In addition to the total cost elements listed above, the cost proposal includes an estimate of the cost profile over time, the work breakdown structure, staffing requirements, and schedule. The cost of the cost estimate C_E includes

1. the management efforts in defining the task so that the technical organization can do a cost proposal (this includes documenting the requirements and may include iterative efforts with technical, service, and contractor organizations); and
2. the technical organization's engineering and administrative time, consulting with the customer, documentation services, drafting services, prototype effort if required for estimate, and any other costs directly attributed to the cost proposal task, including services contracted to outside organizations.

The scope of detail described above in preparing a cost proposal varies widely depending on the estimate accuracy desired.

We have developed a model for estimating how much should be allocated to doing cost estimates for future DSN projects to support new space missions. This model may also help companies or government agencies to make better cost estimates and reduce the possibility of producing cost estimates that are too low, which has often been the case in the past. These low cost estimates have led to cost overruns, the reduction of some functional requirements, or both.

Results using this model should be monitored to see how well the model is working and refinements should be considered, based on future experience.

The methodology presented here should be applicable over a wide range of industries. However, the values of K and R may depend on the inheritance factor of the industry and/or project, and the cost elements included in C_P and C_E.

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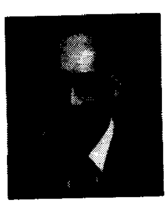

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