# COST GROWTH IN NEW PROCESS FACILITIES

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This paper describes the causes of cost misestimation for major plants and speculates about why the estimation problem has been so resistant to resolution. My discussion is based on a substantial body of Rand work that developed methods for evaluating the cost, schedule, and performance of process plant projects.[1]

Figure 1 displays both the nature and the magnitude of the cost misestimation problem. This figure shows estimates for more than 40 chemical process plants built from the late 1960s to the early 1980s. When we categorize the estimates according to the project stage at which they were made, we see the size of the misestimation in early cost estimates, especially when new technology is involved. Even after the effects of inflation, unanticipated regulatory changes, and the like have been removed, estimates made before detailed engineering is well advanced are, on average, very poor predictors of the actual cost of plants. As we suggest below, this problem of *average* underestimation is but one manifestation of the difficulties of arriving at reasonably accurate, reasonably early estimates.

## APPROACH TO THE ANALYSIS

Our work was prompted by the systematic estimating errors witnessed during the 1970s for synthetic fuels and other energy process plants. Our basic approach was to use historical data to develop estimating relationships for cost, schedule, and performance. These estimating relationships statistically link system characteristics and characteristics of the particular projects with what actually happened

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[1]The empirical analyses underlying the discussion in this paper were the product of a team of researchers at Rand. In particular, I acknowledge the role of my coauthors, K.E. Phillips and C.W. Myers, on the report from which this paper is drawn. See: E.W. Merrow, K.E. Phillips, and C.W. Myers, *Understanding Cost Growth and Performance Shortfalls in Pioneer Process Plants,* The Rand Corporation, R-2569-DOE, September 1981.

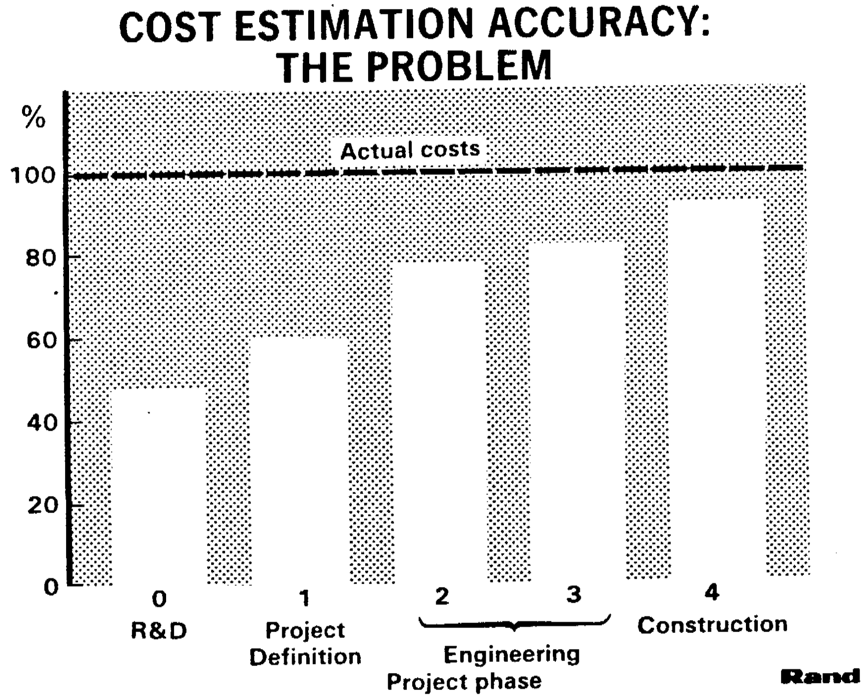


Fig. 1

on the projects in terms of cost estimation accuracy, schedule slippage, and plant performance after start-up. In this discussion, we will consider only the cost estimation part of the analysis.

### Developing a Model

When we started the Pioneer Plants Study five year ago, we were surprised to discover that there were no publicly available empirical analyses of the problems of cost growth in process plants. The literature was (and continues to be) largely anecdotal. This situation was not unique to process plants: The only systematic empirical analyses of cost growth that were publicly available were studies of the acquisition of major weapons systems by the United States Government.[2]

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[2]See for example, R.L. Perry et al., *System Acquisition Strategies, The Rand Corporation*, R-733-PR/ARPA, June 1971; E.W. Merrow, S.W. Chapel, and C. Worthing *A Review of Cost Estimation in New Technologies: Implications for Energy Process Plants,* The Rand Corporation, R-2481-DOE, July 1979; and Robert Summers, *Cost Estimates as Predictors of Actual Weapons Costs: A Study of Major Hardware Articles* The Rand Corporation, RM-3061-PR, March 1965.

These weapons acquisition analyses were extremely important in helping us frame the right questions and in guiding our choice of analytic methods. While it is too strong to say that if you've seen one major technology development program, you've seen them all, it is quite clear that there are fundamental commonalities among high technology development and commercialization programs. The problems faced by the cost estimator in the early stages are, we believe, generic. Therefore, many of the ideas and conclusions that have been developed in one area should be transferable in broad outline to other arenas.

After about six months of discussions with industry engineers to help define our data needs, we solicited data for process plants using the following criteria: (1) the plant had been built after 1965 (we believed that we could not use plants built earlier and still make adequate adjustments for inflation) and (2) the plant was in the U.S. or Canada (again for reasons of making constant dollar cost adjustments). We did express a preference for plants that had some new technology. However, we explicitly asked that industry participants not select plants simply because they had had problems. We ultimately collected data from more than 40 plants built by more than three dozen companies in the oil and chemical industry.

The composition of the sample is shown in Figure 2. The sample is skewed toward innovative plants. However, there are a sizable number of relatively standard units that constitute a baseline for the analysis. About two-thirds of the plants are hydrocarbon and hydrocarbon chemicals units. However, we do have a number of other kinds of plants, including some specialty chemicals, some chlorine-based chemicals, and some minerals. For each plant in the data base, there is a wealth of information that describes various aspects of the plant and of project outcomes. Data include:

- Technical characteristics of the plant--in particular, items that measure the degree to which the plant is innovative,
- Cost estimates, the project stage at which they were made, and what they include,

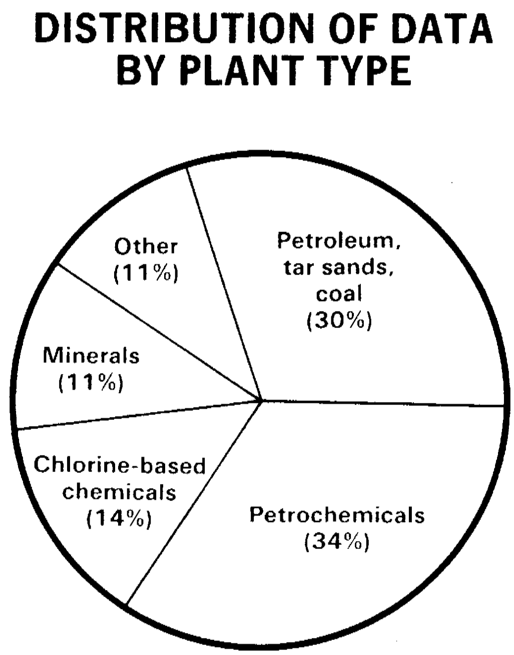



Fig. 2

- Actual plant costs,
- Nature of any management problems,
- Operating data after startup.

Of particular importance to our subsequent analysis were the details we were able to obtain on the degree to which a project had been defined when an estimate was made and how inclusive of various cost items the estimates were. Companies were also willing to give us information on the status of process development at each estimating point.

## ANALYZING COST GROWTH IN PROCESS PLANTS

Let me now describe the way in which we examined the causes and correlates of cost estimation error. Recall from Figure 1 that the problem, on average, is clearly underestimation of cost--which is, of course, the conventional wisdom. Virtually all of the early estimates in our data base were less than actual cost in constant dollar terms.

To begin our analysis, we removed those items from the actual costs that could not reasonably be foreseen by a cost estimator in the early period. These we call "external factors": changes in scope, unanticipated inflation, unanticipated changes in regulatory standards, unusually bad weather, labor strikes, shortages of equipment and bottlenecks in materials delivery, etc. These kinds of events can have a severe effect on schedule and therefore on plant cost. We removed such external factors before examining cost estimation accuracy because the external factors are not the result of project-related decisions and because they will always contain a sizeable random element and therefore obscure, rather than enhance, our ability to look at the basic causes of cost estimation difficulties.

In fact, these factors make a relatively minor contribution to misestimation. As Figure 3 shows, all of these external events taken together account for only about a quarter of the average growth in cost from estimates to actual cost of plant. This is an interesting finding because it contradicts the conventional wisdom of the 1970s that inflation and changes in regulatory standards were the primary drivers of increased cost for process plants in general, and synthetic fuels plant in particular. Our data show that inaccurate projections of inflation seriously contributed to underestimation of costs only in an 18-month period in 1973-74; in contrast, in late 1974 and 1975, the inflationary rate tended to be *overestimated.* The number associated with changes in regulatory standards--11 percent--is somewhat misleading. Only a very small number of estimates were affected at all by changes in regulatory standards, but those few were affected very severely. It is the remaining 3/4 of this pie, which we call cost growth, that was the object of our analysis.

The next figure (Figure 4) poses a strawman view of well-behaved cost estimates. Early estimates will be uncertain in the sense that there will be substantial variation around the actual cost of plant, but that uncertainty will decline in a reasonably systematic way as the project moves toward completion.

## IMPORTANCE OF COST GROWTH VS. EXTERNAL FACTORS IN UNDERESTIMATION OF COSTS

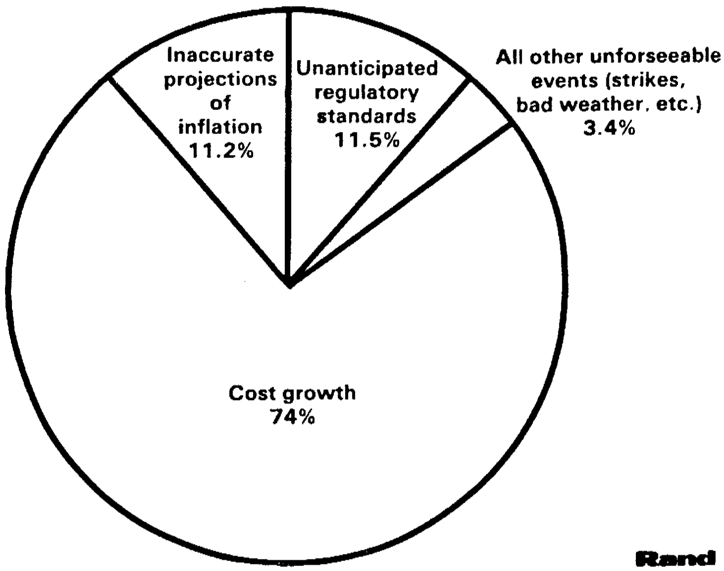



Fig. 3

## THE CONVENTIONAL VIEW OF ESTIMATION ACCURACY

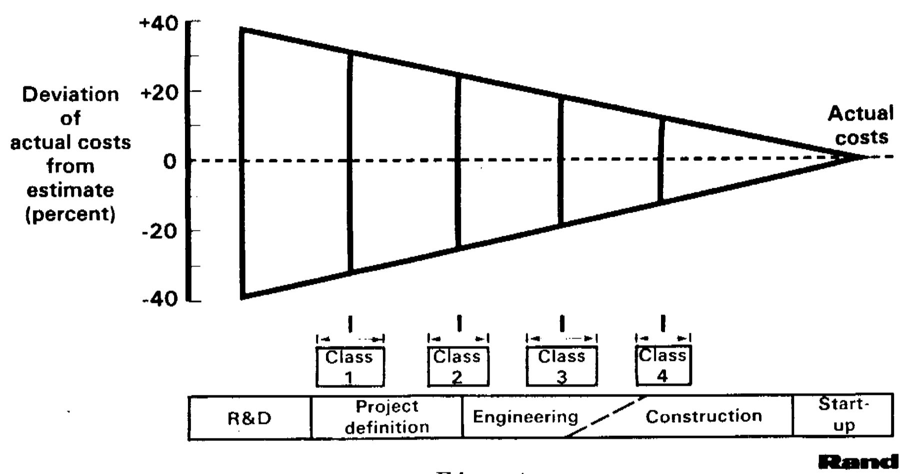



Fig. 4

Figure 5 shows that cost estimates do not really behave in this fashion. The early estimates are indeed more uncertain in the sense of showing greater variance around the average, but there is a systematic tendency for the estimates to be lower than actual costs, and the variation around the average underestimation is so large that the estimates are, when considered in just this raw distribution, worthless from the point of view of predicting actual plant cost.

Our analytic goal was to debias the cost estimates. Our approach was straightforward. Based on studies of weapon systems and our discussions with industry personnel that preceded the data collection phase, we had formed hypotheses about the factors that caused underestimation of costs. The data from industry enabled us to develop quantifiable measures for these factors, which we then regressed against the degree to which the estimates for the plants in our data base deviated from actual costs.

Figure 6 shows the results of this regression analysis. This is the set of factors that, taken together, form the best set of predictors of the degree of cost growth from our initial sample. In summary, cost

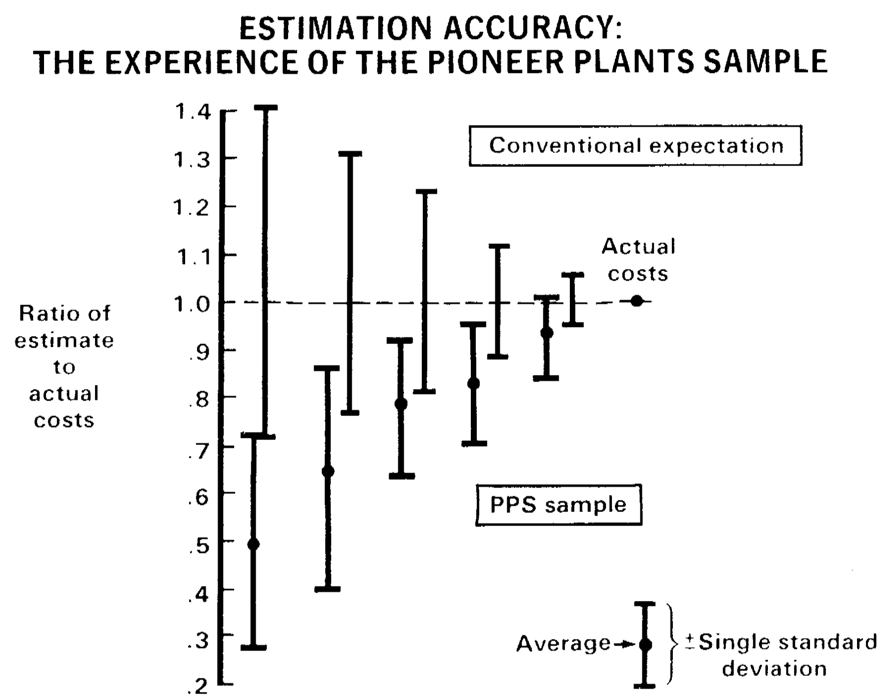
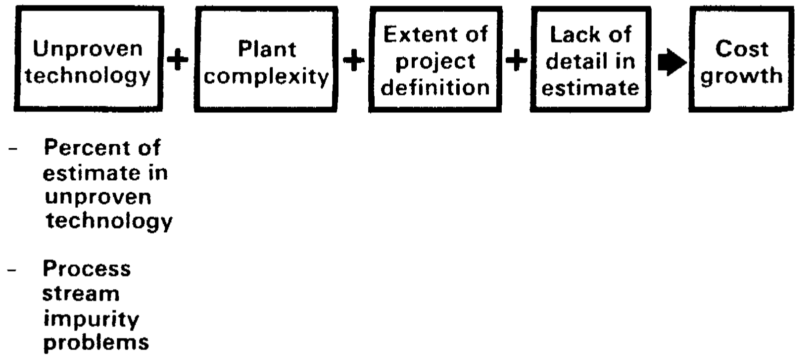



Fig. 5

## FACTORS ASSOCIATED WITH COST GROWTH OF PROCESS PLANTS: RESULTS




Rand

Fig. 6

growth can be predicted with substantial accuracy using:

- two measures of unproven technology,
- the complexity of the plant,
- the extent to which the plant and project have been defined, and
- the degree of detail incorporated in the cost estimate.

There is an additional effect that involves the interaction between whether or not one is in the R&D stage of process development when an estimate is made and the degree of definition. We developed a scale that defines the degree of project definition. As shown in Figure 7, a fully defined plant is a 2 on the scale and a minimally defined plant is placed at 8. The scale is based on the degree of engineering completed when the estimate was made and several measures of site-definition. As you can see, there are greater improvements in estimates to be gained from better project definition for projects in the R&D stages than for projects based on more mature technology. On the other hand, more mature technology is, of course, associated with less underestimation of

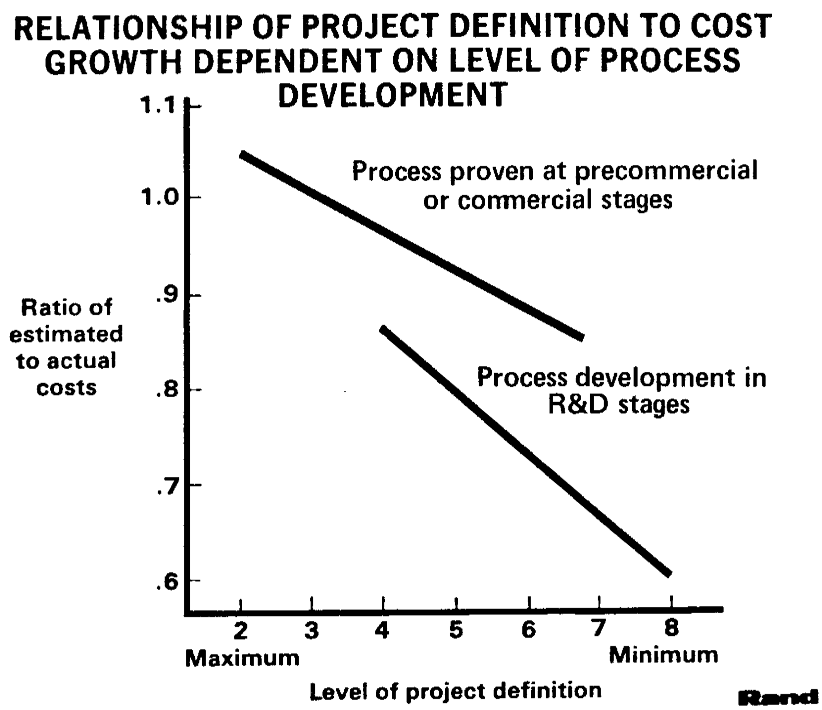



Fig. 7

cost. What is important here is that even those plants that incorporate little or no new technology are poorly estimated when the level of definition is low.

Let me illustrate this last point with the following figure that separates the average estimating error for plants with less than 25 percent of their average capital cost in new technology from the error for plants with a greater amount (see Figure 8). As you can see, although the more standard plants are considerably better estimated, the estimating errors are still, on average, quite large.

I have been discussing in a very abbreviated manner only one aspect of our analysis in the Pioneer Plants Study. Details of the entire analysis and of the estimating equation derived from it can be found in *Understanding Cost Growth and Performance Shortfalls in Pioneer Process Plants.*[3]

Recall that the estimating errors for the plants in our data base were very large, especially for early estimates of plants incorporating

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[3] E.W. Merrow, K.E. Phillips, and C.W. Myers, *Understanding Cost Growth and Performance Shortfalls in Pioneer Process Plants,* The Rand Corporation, R-2569-DOE, September 1981.

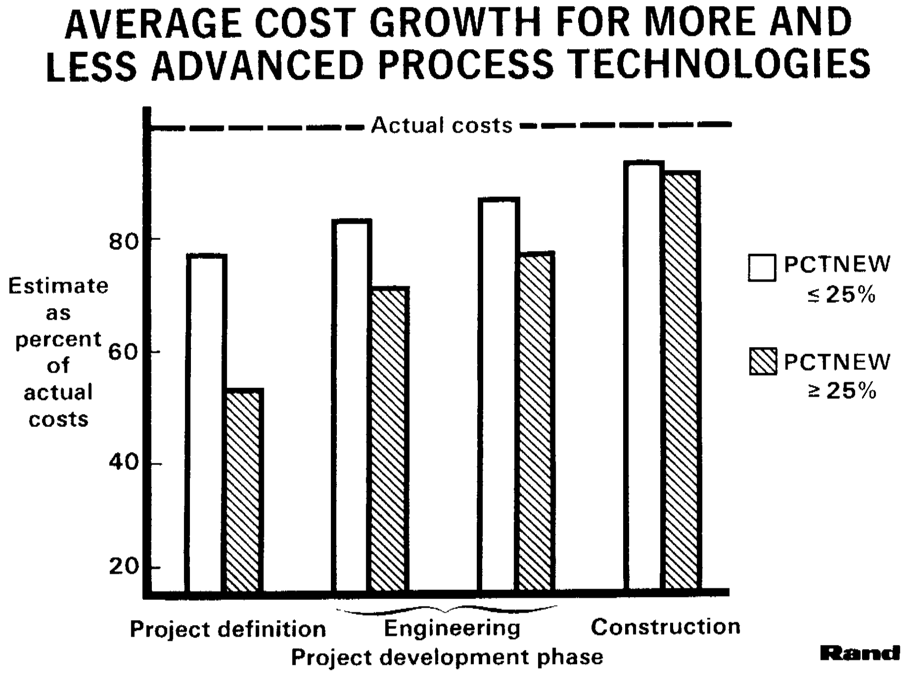


Fig. 8

new technology. Our goal was to develop a parametric cost model that would debias the estimates and provide a reasonable confidence range. The accuracy of the cost model is displayed on the following chart (see Figure 9). Using the model, one can recalibrate over 80 percent of the estimates to within plus or minus 10 percent of the actual cost of plant. (Subsequent to publishing those findings, we have run blind tests of the model with about a dozen additional facilities. These additional observations have fallen within the standard error of 8.3 percent and strengthen our confidence in the model's accuracy.)

## WHY HAS THE COST ESTIMATION PROBLEM PERSISTED?

When we have briefed our results to companies that supplied data for this study, they have repeatedly raised the same question: Why haven't we learned? Why do we have the same sorts of problems today that we had 15 years ago? The evidence we have collected does indeed suggest that despite new cost estimating techniques, new tools (such as the computer), and presumably better data bases, cost estimates today are no more accurate than in the 1960s. Figure 10 shows the relationship between estimation errors and years for the period 1969 to

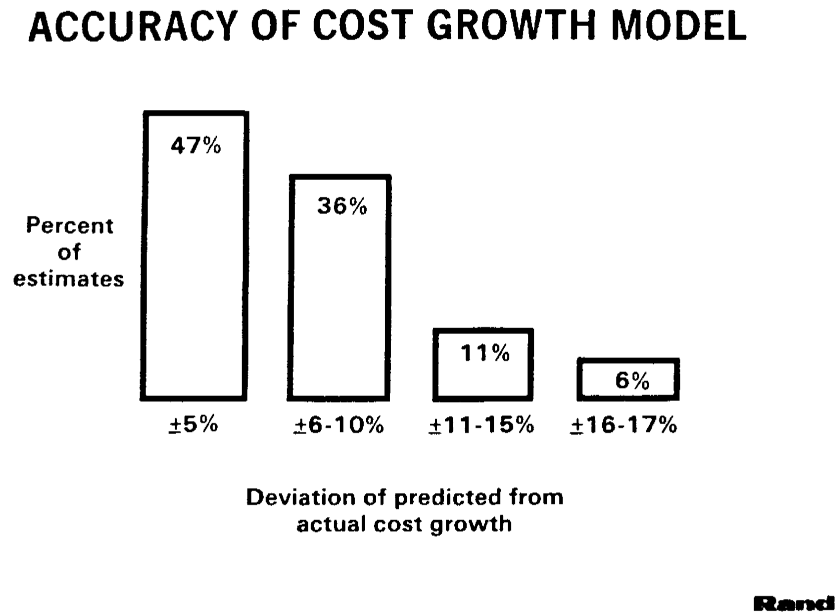


Fig. 9

1977. No trend toward improvement can be found. These data suggest that for every company that has improved its performance, another company's accuracy has declined.

We can only speculate about why estimates haven't become more accurate, but we can make some reasonable inferences. The causes fall into two basic categories: problems that derive from the estimating process itself and problems that have their source in management. The latter I will argue are ultimately more important and more difficult to circumvent.

## Difficulties in the estimating process

Estimating a major capital project is an extremely complex task. Without reviewing the difficulties of cost estimation[4], I believe that the key problems are:

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[4] For two discussions of estimating problems, see J.W. Hackney, *Control and Management of Capital Projects*, John Wiley and Sons, New York, 1965; and E.W. Merrow, S.W. Chapel, and C. Worthing, *A Review of Cost Estimation in New Technologies: Implications for Energy Process Plants*, The Rand Corporation, R-2481-DOE, July 1979.

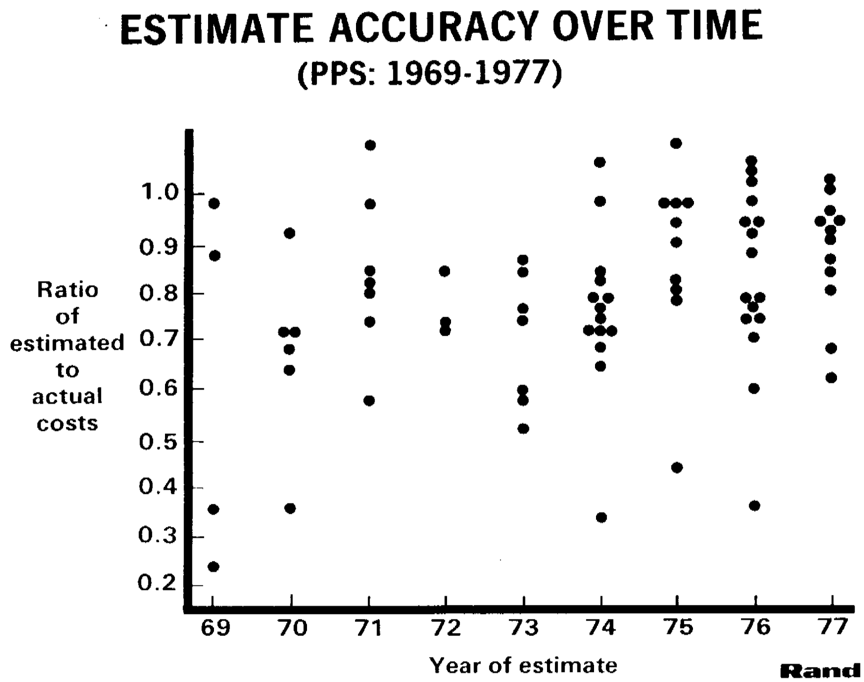


Fig. 10

- *The inherent biases of the problem.* When project costs are estimated using conventional engineering approaches, the opportunities to underestimate will always exceed the opportunities to overestimate. This will tend to be more true for innovative plants because more problems remain unresolved at every point than is the case with more standard units. On average, early estimates based on conventional estimating techniques will be biased low for all plants simply because more potential sources of misestimation remain unidentified in the early stages and sources of underestimation always tend to predominate. It is not surprising then, that early estimates for innovative facilities are typically the most underestimated of actual costs.

There are ways to address the deficiencies inherent in conventional approaches to estimation, including the sort of approach taken in Rand's work. These approaches generally require extensive data to establish although they are frequently quite inexpensive to apply once developed.

- *Attempts to economize.* Because of the inherent difficulties in preparing good engineering estimates, attempts to cut corners and prepare estimates very inexpensively or quickly will almost always result in underestimation when conventional estimating techniques are being employed. Of course, it is not really the estimator's time, but the time necessary to produce reliable inputs for the estimator that is expensive. Our work shows very clearly that after the effects of "pioneering" are controlled for, the biggest difference between the accuracy of estimates produced by various companies is the willingness to spend money early on to define the project. Unfortunately, constant vigilance is necessary to keep the quality of inputs consistently high.

## Managerial Obstacles to Estimation Accuracy

Although the obstacles posed by the estimating process itself are real enough, they cannot be more than a necessary condition of our failure to advance significantly the estimating art over the past decade. In fact, these obstacles arise in the estimating process in part because of management decisions--both explicit and implicit.

In the explicit category is the key fact that organizational incentives often work against realistic estimates. Whenever an estimate is prepared, there is someone in the organization who wishes it were lower. Especially if an estimate is more than the project advocates expected, the estimator or his boss will be forced to justify why the number shouldn't be less. (Of course, if the project advocates prepare the estimate without some external check, then management gets what it deserves.) Only rarely will there be countervailing pressure to justify why the estimate shouldn't be *higher*.

Less obvious, but more damaging, is the fact that management appears to be unwilling to invest in remembering the past. Among the 30 or so owner companies that I know reasonably well, I have yet to encounter a senior manager who did not bemoan inaccuracies in cost estimates. And yet not more than a handful of those companies are willing to invest seriously in internal efforts to fashion better estimating tools. In the course of collecting data for our analyses, we have discovered that many companies could not produce relevant costing data for even one plant. Among those who did keep full records, the data were often archived in a way that rendered them inaccessible. I have always found it ironic that companies willing to commit many millions annually to process R&D in the hopes of lowering production costs seem unwilling to commit even nominal amounts to research on better techniques for estimating the projects they build.

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