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# Designing to Reduce Construction Costs[a]

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## Introduction

This paper describes the interrelationships between engineering design, construction, and operation costs for a facility, and shows how the level of control over those costs decreases as the project evolves. The concept to be explained lies at the heart of modern approaches, such as "life-cycle costing," "construction management," "design-construct," and "value engineering," but it is often lost among the flamboyant promotional ballyhoo sometimes associated with these methods. The concept is also one worth crystallizing in its own right for the benefit of those who might otherwise compromise the engineering and design phase of a project through the false-economy of competitive bidding for professional services.

The basic idea here is not new. Variously described as "level of influence," "percentage of effective control," "possible cost savings," "ability to control," and "degree of effectiveness," it has been well understood in some sectors of industry for many years, particularly in manufacturing (4), in heavy-industrial design-construct work (2,3), and more recently by general contractors interested in construction management (1). In most cases, however, descriptions of the concept have been fairly brief. This paper will adopt the term "level of influence," and explore some of its implications in more detail. For a more general perspective on project control, the interested reader may wish to refer to one of the writer's earlier papers (5).

## Level of Influence on Project Costs

Fig. 1 shows essential features of the level of influence concept. The lower portion simplifies the life of a project to a three-activity bar chart consisting of: (1) Engineering and design: (2) procurement and construction; and (3) utilization or operation. The upper portion plots two main curves. The curve ascending

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to the right-hand ordinate tracks cumulative project expenditures. The curve descending from the left-hand ordinate shows the decreasing level of influence. The bar chart and both curves are plotted versus the same horizontal abscissa—project time.

The parts of the figure interrelate as follows. In the early phases of a project, i.e., during feasibility studies, preliminary design and even detail design, the relative expenditures are small compared to the project as a whole. Typically, engineering and design fees amount to well under 10% of total construction costs. Similarly, capital costs invested by the time construction is completed often are but a small fraction of the operation and maintenance costs associated with a project's complete life cycle. However, although actual expenditures

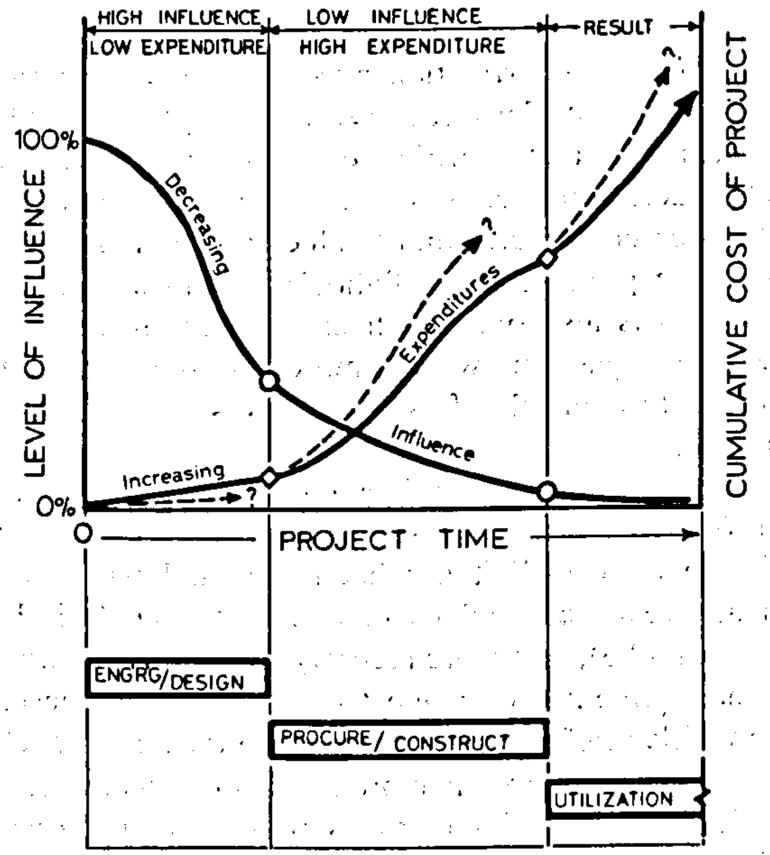


FIG. 1.—Level of Influence on Project Costs

during the early phases of a project are comparatively small, decisions and commitments made during that period have orders of magnitude greater influence on what later expenditures will actually be.

On the first day, management has a 100% level of influence in determining future expenditures. Paraphrased simply, the question is: to build or not to build? The latter requires no expenditure at all for the project. The former requires more decision making, but initially at a very broad level. For example, shall a new power plant use fossil or nuclear fuel? If nuclear, how many units and how big? Shall the basic technology be pressure water reactor (three-cycle PWR), or boiling water reactor (two-cycle BWR)? (Those knowledgeable of the industry know that this decision alone narrows down the potential choice of vendors for the nuclear steam supply system.) As engineering and design continues, decisions become more detailed, but the implications are no less significant. Shall we use a thicket of number 11 bars (35 mm) or more widely spaced number 18 bars (54 mm) in reinforcing this part of the containment . . . and so on until the final drawing change is stamped, signed, and approved.

As these decisions evolve and commitments are made, the remaining level of influence on what the project costs will ultimately be drops off precipitously. For example, a rough but educated guess would put the remaining level of influence at about 25% of the original by the time field construction commences on a grass-roots petroleum refinery. This 25% represents the control that construction contractors have through productive use of labor, innovative uses of equipment and methods, and wise materials procurement practices. But it was the designer who more radically influenced construction costs. It was the designer who may or may not have packed the reinforcing steel so densely that concrete cannot be placed by economical procedures. It was the designer who may or may not have specified nonstandard sizes, impossible formwork configurations, techniques requiring incompatible mixtures of labor crafts, bronze fittings where galvanized were more than adequate, etc. All too often such decisions are made without the slightest notion as to their impact on construction costs, but they influence the costs nonetheless. "Value engineering" clauses in construction contracts are at best after-the-fact remedies for such fundamental oversights.

In like manner, decisions made during construction, even within the 25% or so remaining level of influence, can have orders of magnitude greater impacts on the costs of operating and maintaining a facility. Skimping on quality in workmanship or substituting inferior materials might save a few dollars in construction costs, and in contracts with a "profit-sharing" clause even the owner might be pleased in the short-run, but costs resulting from excessive maintenance and downtime, and from inefficient operations, can consume those "savings" many times over. By the time construction is completed, however, the die is cast. What little influence remains after project start-up often takes the form of shutting the facility down for expensive rework, modifications, or retrofitting.

## Costs to Whom?

Many problems associated with the level of influence concept result from cost suboptimization inherent in the contractual structure for a project. As a hypothetical example, assume that an owner desiring a new ore-processing facility has obtained a fixed fee contract with an engineering firm and plans to let a competitively bid construction contract once designs are complete. Assume also that the engineer has designed several similar plants in the past, and has thus negotiated his fee, say $400,000 including 20% ($80,000) profit and general overhead, on the assumption that much of the design can be adapted from earlier drawings.

Two of the required drawings describe the electrical instrumentation and controls for a crushing and grinding circuit. Since it is similar to one done before, the engineering budget provided for it as follows: 80 design-hours × $30 design-hour = $2,400. However, assume that these drawings represent $320,000 worth of equipment, materials, and field construction labor.

When the electrical engineer was about 60% complete on these drawings, he got into a discussion with a vendor who described a new system for this application that, through the use of solid state technology, could save approx 20% of the costs of purchasing and installing a conventional facility, or $64,000 in this case. The vendor had the facts to back up his numbers.

After this talk, the electrical engineer went to his supervisor to suggest that this change be incorporated. His supervisor denied the request with the following reasoning:

1. Costs to date for adapting conventional design: 60% of $2,400 = $1,440
2. Estimate for revised design new technology:
200 design-hour × $30/design-hour = 6,000
Subtotal: $7,440
3. Initial estimate for drawings E-247 and I-186: ($2,400)
Design cost overrun: $5,040

The fact that this potential 210% overrun on these two drawings represented over 6% of the profit and overhead for the whole job was but one problem. It might have been negotiated as a change with the owner. However, the design as a whole was already 2 months behind schedule, and the client was thought to be in no mood to even hear of, let alone approve, such a change at this time, or so rationalized the supervisor to the electrical engineer. Also, he argued, "This new technology is not well proven yet. Stick with conventional designs that we know will work."

Similar decisions are made every day in practice. The one above suboptimized costs at the level of the engineering and design firm at the expense of potentially much greater savings ($64,000 versus $5,040) at the capital-cost level. Analogously, capital costs are too often suboptimized at the expense of life-cycle costs. For example: (1) Unit A costs $250,000 and operates at $1.20/ton ($0.001/kg); (2) Unit B costs $300,000 and operates at $1.15/ton ($0.001/kg); and (3) annual production is 800,000 tons (720,000,000 kg). The $0.05/ton ($0.0001/kg) saved by Unit B times 800,000 tons/yr (720,000,000 kg/yr) represents annual savings in operation costs of $40,000. This should quickly recoup the extra $50,000 capital cost, but again if a design-construct contract puts too strong an incentive on reduced capital costs, a bad economic decision for the owner may result.

Even at the owner's level, costs can be suboptimized at the expense of industry as a whole or of society. An owner sometimes moves into an area to construct a large project where "time is of the essence" and construction cost is secondary. Perhaps the objective is a factory to produce a new small car to stem the tide of foreign competition, or a pipeline of high national priority to deal with the energy crisis. Too often, however, the costs resulting from the distortion of the labor market, the economic and social impact on nearby communities, and the disruption to other firms competing for the same scarce labor and material resources, far exceed the savings to the individual owner.

The point here is that contractual structures can be adjusted to minimize the consequences of suboptimization of the type described herein. The first prerequisite, however, is an understanding of some of the economic forces involved. The level of influence concept as shown in Fig. 1 may help toward this end.

### Contractual Implications

Two important conclusions can be drawn from the level of influence concept. First, due to the tremendous impact that design decisions have on construction and operation costs, contractual arrangements should be drawn to assure that construction and, where appropriate, operations thinking is strongly injected in the conceptual, preliminary, and detail design processes. Second, governmental tendencies to suboptimize design costs by requiring competitive bidding for professional engineering and architectural services can have disasterous consequences for taxpayers' pocketbooks when construction and utilization costs are considered.

**Injecting Construction Knowledge.**—In the first case, several current contractual arrangements, if properly applied, can at least inject construction thinking into the design phase. Major examples include "construction management" (CM) and "design-construct" or "turnkey" contracts. The name alone, however, does not guarantee results. For example, an architect may offer "construction management" services. If by this he means that he will let and administer separate construction contracts acting as agent for the owner, possibly on a phased-construction basis, one has to assume this architect has a wealth of contractor-type construction knowledge if there are too be any savings at all. Knowing how to package separate construction contracts along recognized trade and jurisdictional boundaries, as well as accurate knowledge for estimating time and costs for the different operations, are essential. Few design consultants really have such capabilities.

"Design-construct" has its pitfalls also. First, third-party objectivity and interaction at the design-construct interface are lost. Even in a fully professional and highly ethical firm, organizational inertia can perpetuate obsolete practices to the exclusion of innovative thinking. Where separate design and construction management firms are teamed in different combinations, innovations are more likely to be transferred. Another problem is that even in design-construct firms, too often one finds people on the drawing boards who rarely if ever get to the field to see the physical results of their decisions, for better or worse.

It is also important to recognize that no one contractual arrangement is best for all situations. For example, Stanford University increasingly uses construction management only in the design phase, and sees considerable benefits from injecting construction thinking there. However, the University sees much less benefit for CM during construction, where it has gone back to letting conventional competitively bid general contracts instead. Construction management enthusiasts would object that the latter foregoes the time savings resulting from phased construction. Where there are revenue-generating time pressures for beneficial occupany, phased construction's uncertainty and the possible increase in direct costs is often a risk worth taking. In the University's case, however, risk of overrun when the later contracts are let is unacceptable because fund limitations are often absolute. Also, time-pressures for beneficial occupancy are much lower, and potential short-run economic returns are more difficult to quantify, since the size of the student body, faculty, and staff is held constant. New facilities serve mainly for replacement or enhancement rather than for generating new revenue.

**Competitive Bidding.**—The second case, that of competitive bidding for professional services, is more insidious. Volumes of material have been written on this subject in recent years, and much of it has been read into the *Congressional Record*. It is nevertheless important to view the subject again in light of the level of influence concept.

The assumption that one can save money by choosing an architect-engineer solely on the basis of lowest design fee is false economy of the worst sort. On the other hand, this need not imply that there is a direct linear correlation between the amount spent on design and the quality or utility of the structure. But knowledgeable public officials need the authority to evaluate alternative professional firms through selection procedures that will engage the firm that can most competently produce a structure of maximum utility for the lowest overall costs, including social and environmental costs as well as design, construction, and operation costs. Selection solely on the basis of lowest fee is likely to perpetuate obsolete designs based upon drawings long since filed away, and force the use of other short-cuts for cost-shaving.

## Summary and Conclusions

Herein, the writer has shown how the level of influence in determining and controlling costs drops rapidly as a project evolves from preliminary and detail design, through procurement and construction, to beneficial operation or utilization. The level of influence is by far the greatest during engineering and design, while actual expenditures at that stage are relatively small.

Understanding the level of influence concept can be helpful in forming contractual arrangements that minimize the suboptimization of costs for one party at the expense of overall project costs and benefits. Contractual arrangements should be drawn so as to assure that current construction and even operations knowledge will be injected in the design process. "Construction management" and "design-construct" are two forms that, if appropriately tailored to the needs of the particular situation, can be useful for this purpose.

A second important conclusion is that efforts to suboptimize design costs by requiring competitive bidding for professional services are likely to produce much higher project costs in the long run. Owners need much more flexibility than this allows in selecting those professionals who can design structures producing maximum benefits for the lowest overall costs.

## Appendix.—References


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