CHAPTER 9

VALUE ENGINEERING AND LEAST COST ANALYSIS

INTRODUCTION

This chapter deals with the important subject of cost efficiency. Today's engineer is turning to rational cost analysis in lieu of subjective selection of materials and designs. This requires both value engineering and least cost analysis. Value Engineering is the critical first step to insure that correct alternates are used in the least cost analysis. Otherwise, the engineer may be comparing apples and oranges.

This handbook offers guidelines for designing corrugated steel pipe systems that are structurally adequate, hydraulically efficient, durable and easily maintained. By following these guidelines equal or superior performance can be realized through use of CSP products. Therefore, the basic techniques of value engineering are applicable. By allowing design and bid alternates, including the proper corrugated steel pipe system, savings on the order of 20% can frequently be realized. Alternative designs offer even more promise and savings of as much as 90% are possible compared to the costs of conventional design. Thus, innovative use of corrugated steel pipe design techniques can offer truly substantial savings, with no sacrifice in either quality or performance.

Backfilling long span structure with structural plate ribs.

VALUE ENGINEERING

Value engineering is defined by the Society of American value engineering as: "The systematic application of recognized techniques which identify the function of a product or service, establish a value for that function and provide the necessary function reliably at the lowest overall cost." In all instances, the required function should be achieved at the lowest possible life cycle cost consistent with requirements for performance, maintainability, safety and aesthetics.

Barriers to cost effectiveness are listed as lack of information, wrong beliefs, habitual thinking, risk of personal loss, reluctance to seek advice, negative attitudes, overspecifying and poor human relations.

Value engineering is functionally oriented and consists of the systematic application of recognized techniques embodied in the job plan. It entails:

1) Identification of the function
2) Placing a price tag on that function, and
3) Developing alternate means to accomplish the function without any sacrifice of necessary quality.

Many value engineering recommendations or decisions are borne of necessity involving perhaps the availability of equipment or material, or physical limitations of time and topography. These are the very reasons that it came into being and in these instances, the alternative selected should not be considered an inferior substitute. Such circumstances force a re-study of the function. If the appropriate job plan is carefully followed, the alternative selected should be equal if not better, and capable of functioning within the new limitations.

A value engineering analysis of standard plans can be very revealing and beneficial in most cases. This may be done as a team effort on all standards currently in use by an agency or it may be done on a project by project basis. Standard specifications should also be subjected to detailed analysis.

Designers are in some cases encouraged to be production oriented and to prepare completed plans as quickly as possible. However, time and effort are frequently well spent in applying the principles to individual project design.

Do local conditions indicate that receipt of bids on alternate designs is warranted? Do plans permit contractor selection of alternate designs and materials for specific bid items?

These questions may be very pertinent in ensuring the most efficient culvert and storm sewer designs. Affording contractors an opportunity to bid on alternates may result in a saving that was not previously evident. Permitting alternatives may further encourage contractors and suppliers, who would not otherwise do so, to show interest in a proposal.

The utility of value engineering as a cost control technique has long been recognized by the U.S. Federal Government. It was first used by the Navy in 1954 and since then at least 14 Federal Agencies, including the U.S. Army Corps of Engineers have used these analyses in the design and/or construction of facilities.

As an example, the 1970 Federal Aid Highway Act required that for the projects where the Secretary deems it advisable, a value engineering or other cost reduction analysis must be conducted. In addition, the EPA developed a mandatory value engineering analysis requirement for its larger projects and is actively encouraging voluntary engineering studies on its larger projects. Thus, these agencies obviously feel that the potential benefit resulting from such analysis far outweighs the cost incurred by the taxpayer in conducting them.

INCLUSIONS OF ALTERNATIVE MATERIALS IN A PROJECT INDUCES LOWER PRICES

A publication of the AASHTO-AGC-ARTBA entitled "Guidelines for Value Engineering" summarizes the basic processes as applied to street and highway construction. Value engineering provides a formalized approach which encourages creativity both during the design process and after the bid letting. During the design process it involves the consideration of both alternate products with equal performance and alternative designs. After bid award, it involves the substitution of different project plans together with revised design or materials to meet time constraints, material shortages, or other unforeseen occurrences which would affect either the completion date or quality of the finished product. The following recommendations on alternate designs is reproduced in its entirety from a study by the Subcommittee on Construction Costs.

Alternate Designs and Bids on Pipe

A) Description of Proposal

In many cases the site conditions pertaining to pipe installations are such that alternative designs involving various pipe products will yield reasonably equivalent end results from the standpoint of serviceability. Moreover, in these cases no one pipe product is clearly less costly than the others, particularly where all suitable products are allowed to compete. Therefore, it is proposed that wherever site conditions will permit, alternative designs be prepared for all types of pipe that can be expected to perform satisfactorily and are reasonably competitive in price and the least costly alternative be selected for use, with the costs being determined by the competitive bidding process.

B) Examples or References

In the absence of unusual site conditions, alternative designs for a typical culvert installation may provide for bituminous coated corrugated metal pipe and reinforced concrete pipe, with a size differential when required for hydraulic performance. In bidding for the related construction work, bidders could be required to submit a bid for performing the work with the understanding that the successful bidder could furnish any one of the permitted types of pipe.

C) Recommendation for Implementation

The availability of competitive pipe products should be established on a statewide basis or on a regional basis within a state. Procedures should be instituted, where necessary, to assure that all suitable types of pipe are considered during the design of pipe installations. Any necessary changes in bidding procedures and construction specifications should also be instituted.

D) Advantages

Acceptance of this proposal should permit the greatest feasible amount of competition among pipe products. This will permit all related economic factors to operate freely in establishing the lowest prices for pipe installations.

E) Precautions

Complex bidding procedures should not be necessary and should be avoided. In any case, bidders should be fully informed as to how the procedures are intended to operate. Care must be taken to avoid alternative designs in situations where choice of a single design is dictated by site conditions.

There are two basic ways to use value engineering: (1) at the design stage to determine the most cost effective material or design to specify without alternates; (2) to select the most cost effective bid submitted on alternates.

In the first case it is important to use value engineering principles when calculating estimates for various materials being considered. This means including in the estimates all the factors bidders would consider in their bids. Installation cost differences between concrete and corrugated steel pipe result from pipe dimensions, foundation and bedding, required equipment and speed of assembly. Also, factors affecting public safety and convenience such as detours and total time on job should be considered. In the second case, where alternate bids are taken, it is important to clearly spell out in the plans and specifications the differences in pipe and trench dimensions for concrete and corrugated steel pipe. Foundation, bedding and minimum cover differences may also be significant. Construction time schedule differences could be a factor and should be required to be shown.

COST SAVINGS IN ALTERNATE DESIGNS

In addition to the savings resulting in allowing pipe alternates in conventional designs, alternative designs based on entirely different water management procedures can offer even more significant savings. One example is in the design of storm water systems which meet environmental requirements in force today. By using these techniques on a total system basis, it is possible to minimize the use of expensive surface lands for ponds, to reduce pipe sizes for conventional systems and the cost of the pipe itself can frequently be reduced.

An excellent example of the application of value engineering principles in a real situation is in the use of large diameter CSP as an alternative to bridge replacement. When faced with limited funds and the need to replace two deteriorating concrete flat slab bridges, a highways department developed an innovative approach. Utilizing 2.4 m diameter pipe at one location and 2840 x 1905 mm pipe-arch at the second, special head walls and wing walls and flowable fill to grout all voids, a 51% cost savings was realized:

Remove and Replace Alternative	
Class A Concrete	$277,200
Detours, Traffic control	74,000
Remove old structure	30,000
Total Estimated Cost	$381,200
Rehab with CSP	
Class A Concrete	$99,550
Corrugated Steel Pipe	78,200
Flowable Fill	7,174
Riprap	2,278
Total Actual Cost	$187,202
Cost Savings	
Amount	$193,998
Percent	51%

In addition to the lower cost, the CSP alternative did not impede traffic flow. No detours were necessary, the roadway was widened, and the load carrying capacity was increased.


Pipe nested for economical shipment.

LEAST COST ANALYSIS

Least cost analysis is a technique that compares differing series of expenditures by restating them in terms of the present worth of the expenditures. In this way, competing designs which have differing cost expenditures at different intervals can be compared and the least cost design chosen on a present worth basis.

The technique is familiar to most engineers and engineering students. Anticipated future costs are discounted by using a present worth discount table and restated in terms of today's costs. Once discounted, all the costs for one project design can be added together and fairly compared to all of the costs for a competing project design.

Least cost analysis is well suited for comparing the competing bids for culvert and storm sewer projects when pipe material alternates such as corrugated steel (CSP) and reinforced concrete (RCP) are specified.

The least cost equations are fairly straightforward. Tables can be used to determine the various present worth factors of competing projects or numerous computer programs and hand held calculators are available to solve these problems.

The real difficulty with the method is making unbiased assumptions which produce fair comparisons of the alternate bids. The assumptions include project design life, project residual values at the end of its design life, material service life, rehabilitation costs and inflation and discount rates.

Design Life

Before any life cycle cost comparisons of materials can be made, the basic project design life must be established. In the case of some agencies it is already a matter of policy. For example, a 50 year design life for primary provincial highway culverts is common. The project design life has nothing directly to do with the various competitive materials available for the job. However, the least cost analysis of competitive materials is directly affected by the project design life.

There are two key factors that determine a proper project design life. One is probable obsolescence and the other is available funds. A design engineer may ignore these factors and select a design life based only on intuitive sense of logic. This mistake is particularly easy to make in the culvert and storm sewer field. Buried structures create a specter of excessive replacement costs; therefore, the tendency is to arbitrarily assign an excessive design life.

A rational determination of design life must consider obsolescence. How far in the future will the functional capacity be adequate? What is required in order to increase the capacity? Is a parallel line feasible? Does location dictate destruction of the old pipe to build a larger structure? All these questions and others must be considered and evaluated. Do you oversize now or not? If so, how much? It may require least cost analysis to evaluate the design capacity that is economically justified at this time to accommodate future requirements.

In addition to obsolescence in functional capacity, there is obsolescence in need. Will the basic facility be needed beyond some future date? The statistical probability that a specific facility will be totally abandoned after a certain period will set some upper limit of design life.

After rational study and economic analysis has determined a capacity (size), and a realistic design life for that capacity facility, there is still the question of available funds. Regardless of theoretical long-term economics, current resources will set practical limitations on building for future needs. Taxpayers and owners are not motivated to bear costs now which cannot possibly benefit them. This results in a limit on design life that could perhaps best be called political.

The result of obsolescence concerns and money factors is a practical limit on design life of 50 years for most public works projects. The taxpaying public can relate to a benefit to them in a 50 year life. Design lives exceeding 50 years are speculative at best.

Long span structure for grade separation.

Residual Values

The residual or salvage value should reflect the estimated value of the facility at the end of the project design life. Current experience on projects to increase drainage capacity indicate there is little probability of any salvage value for materials that must be removed to permit expansion. For new projects, the higher the likelihood of future functional obsolescence then the less likely there will be any salvage value. A residual value should not be assigned to account for any material whose estimated service life is greater than the project design life.

Material Service Life

After the design life of the facility (sewer, culvert) has been selected, the maintenance-free service life of the alternate pipe materials must be established. (Maintenance required of any type of pipe to maintain flow is not pertinent and is not the type referred to here.)

The validity of the least cost analysis will be no better than the estimated maintenance-free life (service life) selected. Unless this selection is given adequate effort and an objective evaluation, the least cost analysis will be only an exercise.

The average service life of various pipe materials varies with the environment, the effluent and the slope. Regional durability studies of culverts are available for most areas and can be used for storm drains, too. Additionally, numerous published reports by agencies and organizations are available, and in conjunction with simple jobsite tests of the environment and effluent, can develop material service life appropriate for that region and application. (See Chapter 8.)

Recurring Annual Costs

These are future costs such as inspection, cleaning, etc. that are expected to occur in about the same amount (in constant dollars) from year to year. These costs need not be included in the study if they are expected to be the same for each alternative. The present value (PV) for recurring annual costs can be calculated as:

$$PV = A_r \frac{(1 + d_r)^n - 1}{d_r (1 + d_r)^n}$$

Where: A_r = recurring annual amount
d_r = discount rate
n = number of years

Rehabilitation vs. Replacement

The end of average service life does not mean replacement of the pipe as is often assumed in many life cycle articles. It does mean expenditure of funds at that time for pipe material maintenance. Planned maintenance always reduces the cost of "neglect and replace" practices. This principle is entirely applicable to pipe culverts

Lifting box culvert into place.

and storm sewers. Currently there are several economical pipe rehab techniques being used. It is inevitable that easier and cheaper methods will be developed in the years between now and the end of a typical average service life period.

The normal type of rehabilitation required for a corrugated steel pipe line is invert repair. The typical pipe can be repaired and made serviceable for another "life cycle" with relatively modest invert treatment. Inspections, even on only a 10 year frequency, will permit timely repair to be made while it is still inexpensive.

The soundness and need for such inspections is essential to all infrastructure and must be done regardless of the materials involved. Such inspections allow a low cost, planned invert maintenance. Actual rehab cost will vary with the pipe size and the timeliness of the repair.

Based on prior and continuing technical advances, rehabilitation should be no more than 25% of original pipe cost. Higher costs would apply to rehabilitation of pipes not maintained at the end of their average service life. In those cases, however, many more years of service squeezed out of the structure offset some of that cost. For further information on pipe maintenance and rehabilitation see Chapter 10.

Discount Rates and Inflation

The method of handling these two components probably contributes to most of the confusion in developing least cost comparisons. There are many articles and texts which go on at length about whether to inflate or not, by how much, and what should be used for discount rates. The logic for each seems coherent and yet, depending on the approach used, the calculations often result in completely different choices appearing to have the lowest cost. How can that be?

The answer lies in gaining an understanding of how the present value is affected over a range of discount rates. Present value is developed by $1/(1+d_r)^n$ where d_r = the discount rate, and n = number of years until a future expenditure occurs. In general, greater significance is given to future spending at low discount rates, and less significance at high discount rates, as shown in the following Table 9.1 and Figure 9.1.

Table 9.1

Present value of $1.00 expended at various intervals and discount rates

Number of Years, n	Discount Rate, d_r		
	3%	6%	9%
0	1.00	1.00	1.00
25	.48	.23	.12
50	.23	.05	.01
75	.11	.01	.01

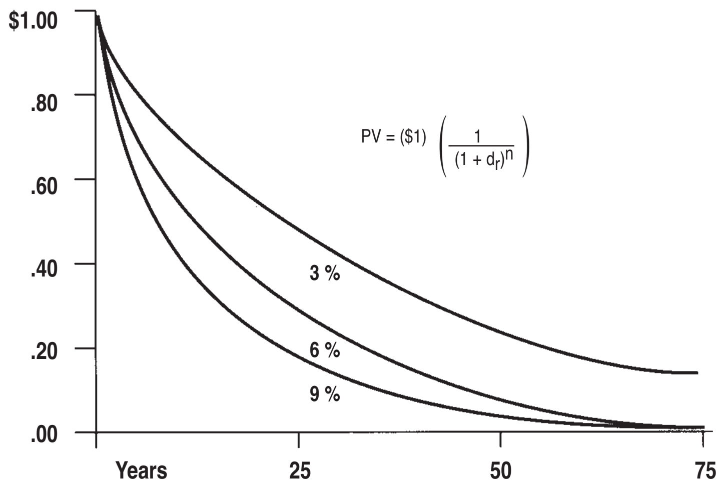

Figure 9.1 Present value of $1.00 expended at various intervals and discount rates.

In contrast to the three times increase in discount rates from 3% to 9%, there is a 23 times decrease in the significance in the present values of expenditures occurring in year 50 (0.23 vs. 0.01). Also, since present value factors behave exponentially, a 3 point difference at higher rates (9% vs. 6%) has less of a present value significance than the same 3 point difference at low rates (3% vs. 6%).

The shape of the present value curves indicate that the significance of future expenditures diminishes as time increases and as the discount rate increases.

Discount Rates

The discount rate is used to convert costs occurring at different times to equivalent costs at a common point in time. The rate selected should reflect the owner's time value of money. That is, the rate should represent the rate of interest that makes the owner indifferent between paying or receiving a dollar now or at some future point in time.

There is no single correct discount rate for all owners in either the public or private sector. Rate selection should be guided by the value of money to the owner. In the private sector, this is usually influenced by the rate of return the owner can achieve on projects that have comparable risk. This is sometimes referred to as the owner's "opportunity cost of capital."

In the public sector, discount rates are often mandated by policy or legislation. The U.S. Office of Management and Budget in Circular A-94 requires that federal projects use, in most cases, a discount rate of 10%. These guidelines are further amplified in practices developed by the U.S. Water Resources Council and the Department of the Army (see bibliography). Some, but not all, states have established their own values for discount rates.

Borrowing Rates

There is a tendency in the public sector to use the cost to borrow money (interest rate) as the discount rate. This is incorrect. The interest rate on bond financing represents a "cost" to the project and does not reflect the "value" of money used on the projects.

The distinction between cost and value is subtle but important. Borrowed money does not pay for the project, taxpayers do. Borrowed funds are repaid, over time, with taxes collected from taxpayers. Therefore, the discount rates used for public projects should be based on the time value of money to the taxpayer, which will always be greater than the interest rate on public bonds. It is that logic that led the federal government to inflation.

Inflation

Several approaches can be used in the treatment of inflation. First, the analyst should determine whether any legislated or mandated policy applies to the project under consideration. If not, several choices are possible. If it is assumed that future inflation will affect all costs and/or benefits in a uniform manner over the life of the project, then a straight forward approach can be used. All costs, both present and future, can be estimated in base year or current year dollars and discounted back to the present using a "real" discount rate (excluding inflation). The real discount rate (d_r) and its corresponding nominal discount rate (d_n) are related as follows:

$$d_r = \frac{(1 + d_n)}{(1 + I)} - 1 \quad \text{or} \qquad d_n = (1 + d_r)\,(1 + I) - 1$$

where I = the general rate of inflation. The real discount rate can be calculated based on a user selected nominal discount rate and general rate of inflation. For example, a 10% nominal discount rate and a 5% inflation rate results in a real discount rate of 4.76% (Note: This is a slightly different result than the arithmetic difference between 10% and 5%).

A less direct approach, but one yielding the same results, is for the analyst to make specific projections of future costs. Future costs can be projected by multiplying the estimated cost expressed in base year or current cost dollars by the inflation factor (l+I)n where I is the general rate of inflation and "n" is the number of years into the future.

A third method is to apply inflation selectively to certain elements of cost. For example, some federal agencies are required to recognize inflation on energy costs only; general inflation is to be ignored. Dealing with inflation incrementally adds to the computational complexity.

Recommendations

The analyst must first determine if the project owner has or is subject to any policy that specifies the treatment of discount rates and inflation. In the absence of specific guidance, it is recommended that a minimum nominal discount rate of 10% be used. Long term price inflation should be limited to no more than 5%.

Calculations

The following example is presented to illustrate the comparison on two drainage pipe alternatives.

Basic Assumptions

Project Design Life: 50 years

Owner Selected

Discount Rate (d_n) 10% (nominal)

Inflation Rate (I): 5%

Corrugated Steel Pipe

Initial Cost: $150,000

Service Life: 40 Years

Current Cost of Invert Rehab at 25% of Initial Cost: $37,500

Salvage Value: None

Annual Maintenance Cost: $500

Concrete Pipe

Initial Cost: $180,000

Service Life: 75 Years

Salvage Value: None

Annual Maintenance Cost: $500.

Since the $500 annual maintenance costs affect both cases equally, they can be excluded from the analysis. The next step is to calculate the real discount rate where:

$$d_r = \frac{(1 + d_n)}{(1 + I)} - 1 = \frac{1.10}{1.05} - 1 = 0.0476$$

The present value for the CSP alternative is then determined as:

$$\text{Initial Cost} = \$150{,}000$$

$$\text{Rehab Cost} = (37{,}500)\left[\frac{1}{(1 + 0.0476)^{40}}\right] = \$5{,}800$$

$$\text{Total Present Value} = \$155{,}800$$

Since the concrete pipe alternative is estimated not to require future expenditures, its present value is equal to its original cost of $ 180,000. Accordingly, the CSP alternate has a lower present value and therefore, represents the least cost alternative.

	Present Value
Concrete Pipe	$180,000
Corrugated Steel Pipe	155,800
CSP Advantage	$ 24,200

Sensitivity of Results

A sensitivity analysis can be used to determine how variations in key assumptions affect the outcome of the least cost analysis. This can be particularly helpful when the present value of alternatives are close or there is uncertainty regarding certain assumptions.

In general, the factors having the greatest influence on the ranking of alternatives are the magnitude of the discount rate and the differential in initial costs. The significance of future expenditures is lessened when higher discount rates are assumed and increased at lower discount rates. Reasonable variations in the magnitude and timing of future expenditures usually have only a small effect on the results. Based on the proceeding example, Table 9.2 illustrates how reasonable variations in assumptions affect the $24,200 difference in present value.

Table 9.2
Sensitivity analysis for example problem

Basic Assumption	Variation	Increase / (Decrease) in $24,200 Present Value Differential
10 % Discount Rate	9 % 11 %	$(2,600) 1,800
Rehab in 40 Years	35 Years 45 Years	(1,600) 1,200
25% Rehab Cost	20 % 30 %	1,200 (1,200)

SUMMARY

The principles of value engineering are essential in a cost effective approach to design. Least cost analysis is an especially effective method to compare alternatives that are characterized by different cash flows over the project life. The method requires objective and realistic assumptions concerning project design life, material service life, future expenditures, the owner’s time value of money (discount rate), and future inflation.

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