CHAPTER eleven

Value Engineering and Life Cycle Cost (LCC)

INTRODUCTION

This chapter deals with the important subject of cost efficiency. This requires a working understanding of both value engineering and life cycle cost. Value Engineering (VE) is the critical first step to insure that correct alternates are considered in the life cycle cost (LCC). Otherwise, the engineer may be comparing apples and oranges.

This chapter 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. The basic techniques of Value Engineering apply. 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, with savings of as much as 90% 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.

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.

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 alternative means to accomplish the function without any sacrifice of necessary quality.

By contrast, lack of information, wrong beliefs, habitual thinking, risk of personal loss, reluctance to seek advice, negative attitudes, over specifying and poor human relations represent barriers to cost-effectiveness.

Many VE recommendations or decisions are borne of necessity. Often, the limited availability of financial resources, equipment or material, or physical limitations of time and topography, limit the options available. These are the very reasons that Value Engineering came into being. It is a systematic process of obtaining the best result within the available resources. If the appropriate job plan is carefully followed, the alternative selected should be equal if not better, and capable of functioning within the stated limitations.

To be competitive, designers have to be production oriented and quickly prepare completed plans that are practical and economical. A simple technique to achieve efficiency and pursue maximum economy is for the project specifications to include a range of alternative materials, thereby engaging contractor creativity and experience. Of course, designers should always be open to Value Engineering change proposals.

The utility of Value Engineering as a cost control technique has long been recognized by the Federal Government. It was first used by the Navy in 1954. Subsequently, through the action of Congress and the Office of Management and Budget (OMB), virtually any federal agency with an annual budget in excess of $10 million was required to utilize VE analysis. AASHTO has the following position on Value Engineering:

To improve design excellence and achieve cost reduction and quality control, it is AASHTO's position that:

Each member state should establish an ongoing VE program.

- *The challenges of rising costs and diminished resources be addressed through the application of VE principles and practices in project development, construction, traffic operation, maintenance and other appropriate areas.*
- *Guidelines be provided to member organizations to promote and assist in broad acceptance and use of value engineering with the provision of flexibility to adapt to individual needs.*

Value Engineering has become a common practice in most transportation or highway departments in the US and among the federal agencies. It is recognized as an effective approach to obtain best results from limited taxpayer resources.

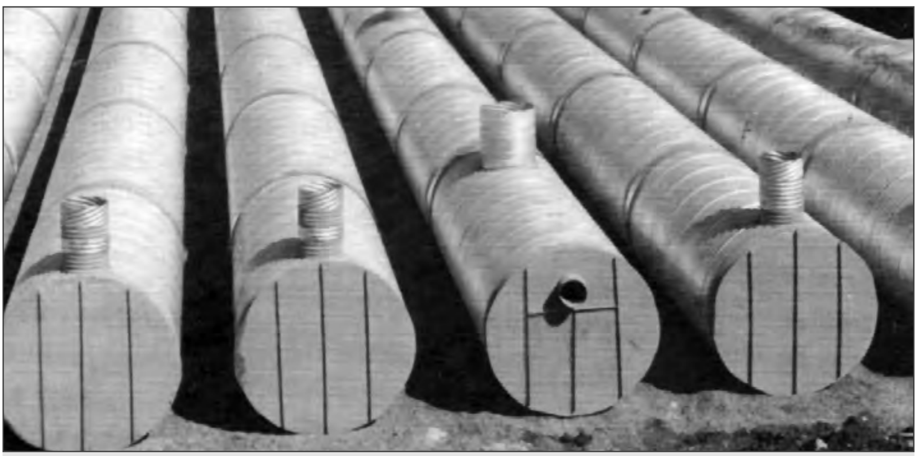


Figure 11.2 Seven lines of 96 inch CSP being installed to form an underground stormwater detention facility.

Inclusions of Alternative Materials in a Project Induce Lower Prices

The fundamental of a free market system is competition. By specifying as many alternative materials as possible, the owner of a project is assured of the most economic project possible since competition encourages lower pricing.

Value Engineering helps allow for competition of alternative materials because it provides a formalized approach that encourages creativity both during the design process and after the bid letting. During the design process it involves the consideration of both alternative 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 that would affect either the completion date or quality of the finished product.

Thus, 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 Alternative Designs

In addition to the savings resulting in allowing pipe alternatives 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 that 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, which can be hazardous during flood conditions, and instead store the flood waters underground in large corrugated steel pipe detention chambers as shown in Figure 11.2.

Another excellent example of the application of value engineering principles in a real situation is 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, the Abilene District of the Texas DOT developed an innovative approach.

Utilizing 96 inch diameter pipe at one location and 112 inch x 75 inch 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

Rehabilitate with CSP

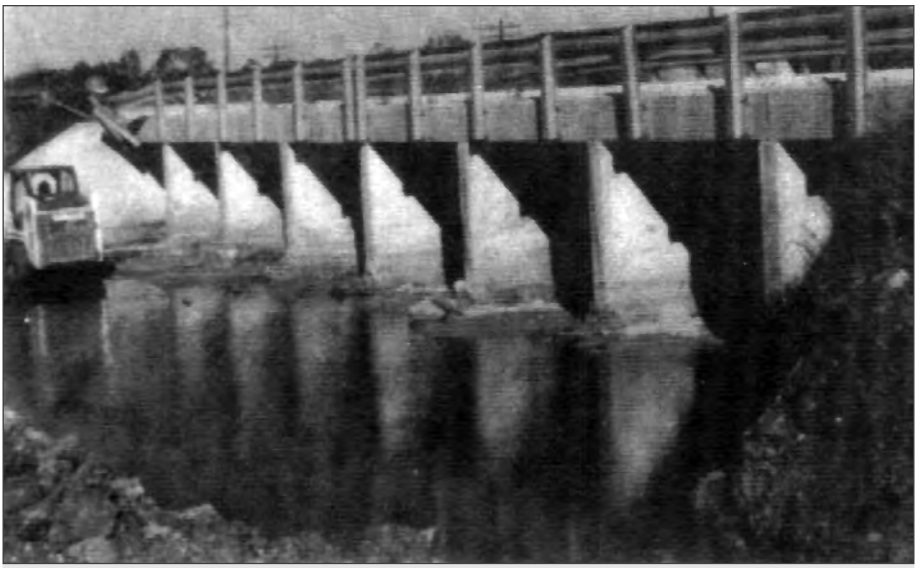
Class A Concrete	$99,550
Corrugated Steel Pipe	78,200
Flowable Fill	7,174
Riprap	2,278
Total Actual Cost	$187,202

Cost Savings

Amount	$193,998
Percent	51%

In addition to the lower cost, the CSP alternative did not impede traffic flow and thus public safety was not compromised.

No detours were necessary, the roadway was widened, and the load carrying capacity was increased. The following photos show how CSP solved the problem.



■ **Figure 11.3** Texas DOT bridge replacement project. Before...

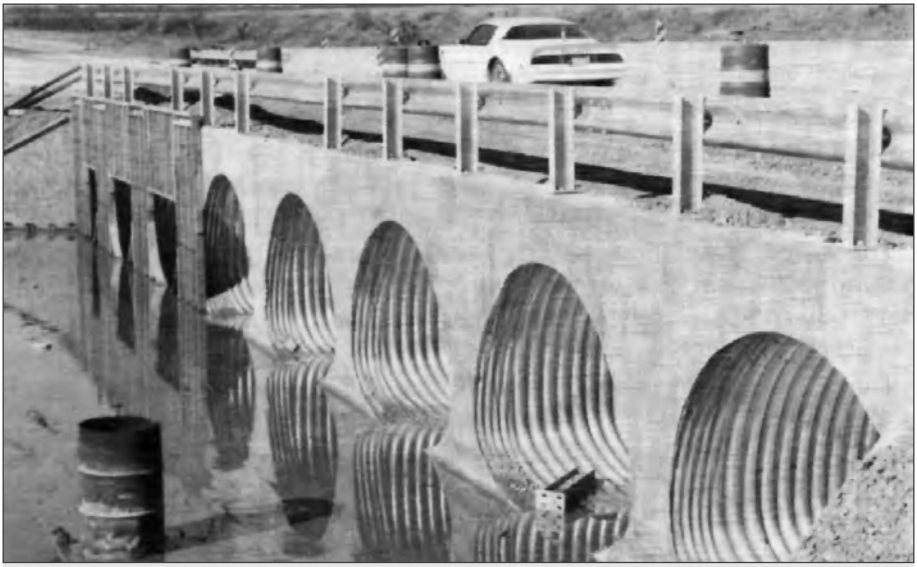


Figure 11.4 Texas DOT bridge replacement project. After...

CSP Products for VE Application

The following list indicates the possible VE applications where the various CSP products can provide a cost-effective solution.

Product	Possible VE Application
All CSP products	Storm Sewers Underground Detention Systems Bridges
Spiral Rib CSP	Hydraulic Storm Sewers Rehabilitation / Reline
Double Wall CSP	Hydraulic Storm Sewers Rehabilitation / Reline
Concrete Lined CSP	Hydraulic Storm Sewers Rehabilitation / Reline
Slotted Drain CSP	Sheet Flow Capture vs. Inlets
Structural Plate	Bridges Stream Enclosures Golf Cart Crossings / Underpasses Underground Detention Systems Special Foundations / Piling

LIFE CYCLE COST

Life Cycle Cost 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 that have differing cost expenditures at different intervals can be compared and the lower 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 factor 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.

Life Cycle Cost is well suited for comparing the competing bids for culvert and storm sewer projects when pipe material alternatives such as corrugated steel (CSP) and reinforced concrete (RCP) are specified.

The life cycle 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 that produce fair comparisons of the alternate bids. The assumptions include project design life, material service life, project residual values at the end of its design life, recurring annual costs, 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 state highway culverts is common. The project design life has nothing directly to do with the various competitive materials available for the job. However, the life cycle 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 (the longer the design life chosen the greater the risk of probable project obsolescence) and the other is available funds. A design engineer may ignore these factors and select a design life based only on his 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 adjacent development will take place? What future environmental regulations will require retrofit at the project site? What is required 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 life cycle 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 that cannot possibly benefit them. This results in a limit on design life that could perhaps best be called political.

The result of these obsolescence 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.

Material Service Life

After the design life of the facility (sewer, culvert) has been selected, the service life of the alternative pipe materials must be established. The validity of the life cycle cost analysis will be no better than the estimated service life selected. Unless this selection is given adequate effort and an objective evaluation, the life cycle cost analysis will be only a mathematical 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. In conjunction with simple jobsite tests of the environment and effluent, such reports can develop material service life appropriate for that region and application.

Refer to Chapter 9, Durability, for comprehensive guidance in determining service life for CSP.

Residual Values

Residual or salvage value reflects estimated economic value of the drainage facility at the end of project design life. While a used piece of construction equipment can be sold at auction at the end of its service life, drainage pipe—be it metal, concrete or plastic—is of little economic value. Often, projects to increase drainage capacity require that existing materials be removed before the end of their service life to permit expansion. The higher the likelihood of future *functional obsolescence,* the less likely there will be any salvage value. Concrete pipe proponents suggest that economic credit should be given when their estimated pipe service life exceeds the project design life (100 year pipe life vs 50 year project design life). Such calculations make it appear as if only one-half the cost of the pipe should apply to the project. This is inappropriate economic logic.

Recurring Annual Costs

All underground pipe systems require periodic inspection and maintenance. Typically, the costs for these preventative maintenance functions can be 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 pipe alternative. The present value (PV) for recurring annual costs can be calculated as:

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

Where: A_r = Recurring Annual Amount
d = 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. 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 infrastructures and must be done regardless of the materials involved. Such inspections allow low cost, planned maintenance. Actual rehabilitation cost will vary with the pipe size and the timeliness of the repair. This principle is entirely applicable to pipe culverts and storm sewers.

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.

Based on prior and continuing technical advances, rehabilitation should be about 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 12.

■ **Figure 11.5** There are many economical pipe rehabilitation techniques being used. One method employs the use of CSP to slip line distressed reinforced concrete pipe.

Discount Rates and Inflation

The method of handling these two economic values contributes to most of the confusion in developing life cycle cost comparisons. There are many articles and texts which debate whether to inflate or not, by how much, and what value to use for the discount rate. 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 calculated as:

$$PV = A\left[\frac{1}{1+d}\right]^n$$

where A = Amount
d = Discount rate
n = Number of years until 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:

Present Value of $1.00
Expended at Various Intervals and Discount Rates

	Discount Rate		
Year	**3%**	**6%**	**9%**
0	1.00	1.00	1.00
25	0.48	0.23	0.12
50	0.23	0.05	0.01
75	0.11	0.01	0.01

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 (.23 vs. .01). Also, since present value factors behave exponentially, a 3 point difference at higher rates (9% vs. 6%) has less present value significance than the same 3 point difference at low rates (3% vs. 6%).

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 financially indifferent between paying or receiving a dollar now or at some future 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 Office of Management and Budget in Circular A-94 requires that federal projects use, in most cases, *a real discount rate* (net of inflation) of 7%.

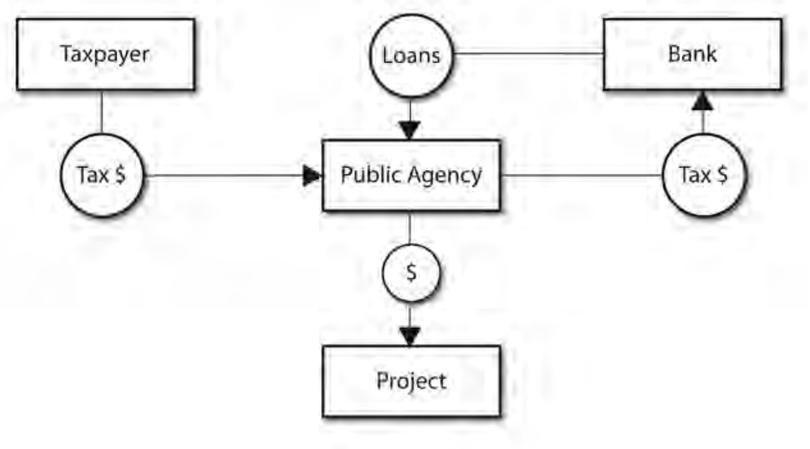
OMB recognizes that public investments displace both private capital and consumption. The use of a real discount rate of 7% …*approximates the marginal pretax rate of return on an average investment in the private sector*…" The U.S. Water Resources Council, Department of the Army and some, but not all, states have established guidelines and values for discount rates.

Borrowing Rates

There is a tendency in the public sector to base the discount rate on the cost to borrow money (interest rate on bonds). 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.

The following diagram shows the financial relationship between taxpayers, public agencies and bank borrowing.



In the end, taxpayers pay for public projects. Therefore, it is never appropriate to use the interest rate on borrowed money for the discount rate. A common sense test of any proposed discount rate is whether you would want your pension to be invested at that rate. In that perspective the 7% (real) discount rate prescribed in A-94 is realistic.

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, 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 (net of inflation). This approach is the most commonly used and eliminates the complications that are associated with making future projections of inflation.

The real discount rate (d_r) and its corresponding nominal discount rate (d_n) are related as follows:

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

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 3% inflation rate results in a real discount rate of 6.8% (Note: This is slightly different result than the arithmetic difference between 10% and 3%).

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 $(1+I)^n$ 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. Those interested in this approach should consult TM 5-802-1 listed in the bibliography for practical application of this technique.

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, consistent with OMB A94, that a *real* discount rate of 7% be used and all costs estimated in current period dollars. If a requirement exists to recognize inflation, then use a *nominal* discount rate of 10% and a long term inflation rate of no more than 3%.

Calculations

The following example is presented to illustrate the comparison on two drainage pipe alternatives. Results are based on calculations carried to the fifth decimal, rounded as shown

- Basic Assumptions
  - Project Design Life: 50years
  - Owner Selected
    - Discount Rate (d_n) 10% (nominal)
    - Inflation Rate (I): 3%
- Corrugated Steel Pipe
  - Initial Cost: $150,000
  - Service Life: 40 Years
  - Current Cost of Invert Rehabilitation at 25% of Initial Cost: $37,500
  - Salvage Value: None
  - Annual Maintenance Cost: $500
- Concrete Pipe
  - Initial Cost: $180,000
  - Service Life: 60 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:

$$d_r = \frac{1 + d_n}{1 + I} - 1$$

$$= \frac{1.10}{1.03} - 1 = \textbf{.068 or 6.8\% real discount rate}$$

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

Initial Cost	$150,000
Rehabilitation Cost	
$37,500 x 0.0721* =	2,703
Total Present Value	$152,703

$$* = \frac{1}{(1 + .068)^{40}} = 0.0721$$

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, CSP has a lower present value and therefore, represents the lower cost alternative.

	Present Value
Concrete Pipe	$180,000
Corrugated Steel Pipe	152,703
CSP Advantage	$ 27,297

Sensitivity of Assumptions

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

In general, the two 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 at higher discount rates 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, the following table illustrates how reasonable variations in assumptions affect the $27,297 difference in present value.

Basic Assumption	Variation	Approximate Increase/ (Decrease) in $27,297 Present Value Differential
6.8% Real Discount Rate	4.8% 8.8%	$(3,000) 1,400
Rehabilitate in 40 Years	35 years 45 years	(1,000) 800
25% rehabilitation cost	20% 50%	500 (2,700)

Computer Program

The National Corrugated Steel Pipe Association has developed a computer spreadsheet template designed to evaluate up to three alternatives simultaneously. User selected input can be easily modified to perform sensitivity analysis. Output can be reviewed on screen or printed. To obtain the program, visit the NCSPA website at www.NCSPA.org.

Summary

The principles of value engineering are essential in a cost-effective approach to design. Life cycle cost 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, residual values, future expenditures, the owner's time value of money (discount rate) and future inflation.

Nested and stacked CSP.

BIBLIOGRAPHY

ASTM, "Standard Practice for Life-Cycle Cost Analysis of Corrugated Metal Pipe Used for Culverts, Storm Sewers, and other Buried Conduits," A930, Annual Book of Standards, Vol. 01.06. American Society for Testing and Material, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959.

Anon, "Economic Studies for Military Construction Design-Applications," TM 5-802-1, Department of the Army, Washington, D.C., December 31, 1986.

Beenhakker, H.L., *Handbook for the Analysis of Capital Investments*, Greenwood Press, Westport, Connecticut, 1976.

Grant, E.L., and Ireson, W.G., *Principles of Engineering Economy*, 5th ed., The Roland Press Co., New York, 1970.

Jacobs, K.M., "Culvert Life Study," Technical Publication 74-1, Maine Department of Transportation, January 1974.

Leason, J.K., and Standley, R.S., "Least Cost Analysis," National Corrugated Steel Pipe Association, Dallas, TX, March 1986.

Lindley, B.R., "Bridge Replacement Alternate Design," Texas Department of Highways and Public Transportation, May 1991.

Mikesell, Raymond F., "The Rule of Discount for Evaluating Public Projects," American Enterprise Institute, Washington, D.C., 1977.

NCSPA, "CSP Durability Guide," National Corrugated Steel Pipe Association, Dallas, TX, May 2000.

OMB, "Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs," Circular A-94, Office of Management and Budget, Washington, D.C., October, 29, 1992.

Potter, J.C., "Life Cycle Costs for Drainage Structures," Technical Report GL-87, U.S. Army Corps of Engineers, Washington, D.C.

TRB, "Life Cycle Cost Analysis of Pavements," Transportation Research Board, National Research Council, National Cooperative Highway Research Program Synthesis of Highway Practice No. 122, Washington, D.C., December 1985.

Wonsiewicz, T.J., "Life Cycle Cost Analysis-Key Assumptions and Sensitivity of Results," Transportation Research Board, Washington, D.C., January 1988.

Wonsiewicz, T.J., "Life Cycle Cost Analysis Discount Rates and Inflation," Proceedings, International Conference on Pipeline Design and Installation, ASCE, March 1990.

WRC, "Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies," PB 84-1999405, U.S. Water Resources Council, Department of the Interior, Washington, D.C., February 3, 1983.

Rehabilitation & extended concrete box.