Life Cycle Cost Analysis: Key Assumptions and Sensitivity of Results

THOMAS J. WONSIEWICZ

The growing use of life cycle cost techniques has brought to the surface some misconceptions and apparent conflicting approaches. Examined in this paper is the underlying basis for the two general approaches of selecting discount rates and dealing with inflation. The opportunity cost approach is endorsed as being the most effective in allocating resources. Suggestions are provided on how to evaluate the differential interest-inflation approaches being offered. Sensitivity analyses are used to show the relative insignificance of variations in design life, salvage value, and rehabilitation cost assumptions on results. By clarifying and putting these issues in a commonsense perspective, the reader should be able to use least cost analysis techniques with improved confidence.

Least cost analysis techniques are not new, although their use in the selection of economical project alternatives seems to be increasing. The approach, in general, is reasonably straightforward and provides a way to evaluate competing alternatives that have differing series of expenditures over the life of the project.

As simple as it all sounds, the practitioner can often be left bewildered by what seems to be conflicting information contained in articles on the subject and advice offered by energetic material suppliers.

The objective of this paper is to identify the more critical assumptions and to demonstrate the sensitivity of the results to variations in certain assumptions. This will put some of the more confusing issues into perspective and thereby result in improved confidence in the proper application and use of least cost analysis techniques.

TECHNIQUES

General

Mathematical formulas will not be presented in this paper. They are readily available in numerous texts on the subject. Inexpensive hand-held business or financial calculators are recommended as they readily handle the required computations.

The cost data used are intended to be realistic in their proportions, and represent typical competitive market conditions between corrugated steel pipe (CSP) and reinforced concrete pipe (RCP).

Lane Enterprises, Inc., 3705 Trindle Road, Camp Hill, Pa. 17011.

Base Information

The following data pertain to three alternative drainage structures intended to satisfy a 50-yr design life requirement.

1. Alternative *A*: Galvanized CSP with an initial cost of $195,000 and a projected service life of 40 yr, followed by invert maintenance at 25 percent of initial cost ($48,750) to satisfy required design life.
2. Alternative *B*: Asphalt-coated CSP with initial cost of $214,500.
3. Alternative *C*: Reinforced concrete pipe with an initial cost of $230,000.

Present Value

Of the three choices, only Alternative *A* needs to be analyzed to determine the present worth of the projected maintenance cost in Yr 40. The present value of Alternates *B* and *C* are equal to their first costs because there are no significant future expenditures.

In the case of *A*, at a discount rate of 9 percent, the present value is as shown in Table 1. The simple approach shows, for the assumptions used, that when ranked on a present value basis, Alternative *A* is the lowest cost alternative.

Average Annual Cost

This technique takes the present value calculation one step further. It is sometimes referred to as a sinking fund payment. In a way, it is similar to a mortgage payment. It represents the annual amount that would yield, over the project life, the total present value based on the stated discount rate. Accordingly, based on a 9 percent discount rate and a 50-yr project design life:

Cost ($)	*A*	*B*	*C*
Total current	243,750	214,500	230,000
Present value at 9 percent	196,550	215,500	230,000
Average annual (50 yr @ 9 percent)	17,930	19,660	20,980

Both the present value and average annual cost methods result in the same ranking of alternatives.

A potential error can occur if the material service life for each alternate is used to calculate the average annual cost. For the comparison to be fair, the project design life should

TABLE 1 PRESENT VALUE OF ALTERNATE *A* AT DISCOUNT RATE OF 9 PERCENT

Year	Current Dollars	Present Value at 9 Percent	
		Factor	Amount ($)
0, initial cost	195,000	1.0000	195,000
40, rehabilitation	48,750	.0318	1,550
Total	243,750		196,550

TABLE 2 PRESENT VALUE OF $1.00 EXPENDED AT VARIOUS INTERVALS AND DISCOUNT RATES

Year	Discount Rate (percent)		
	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

always be used so that all competing alternates are on an equal footing.

Differential Cash Flow Comparisons

Although not widely used in engineering assessments, this technique is frequently used in private industry to evaluate capital expenditure decisions. Essentially, it compares the cash flow of competing alternatives, and solves for an interest rate. It is often referred to as a discounted cash flow analysis that results in an internal rate of return. The magnitude of the resulting interest rate is used to judge the relative attractiveness of spending a higher sum initially to avoid future expenditures. Expenditures that do not meet some specified minimum rate of return are usually avoided. Generally, cost of capital is considered to be at least 10 percent.

A comparison of Alternates *A* and *C* results in the following:

Cash Flow ($)	*C*	*A*	*Difference (C–A)*
Year 0	230,000	195,000	35,000
Year 40	–	48,750	(48,750)
Total	230,000	243,750	(13,750)

The internal rate of return in this case is 0.83 percent, or less than 1 percent. This represents the discount rate at which the $48,750 of future expenditures avoided are equal to the $35,000 increased initial cost. Said another way, the added $35,000 investment to avoid a $48,750 future cost results in less than a 1 percent return on investment—by any measure, a poor return.

Because the results of a discounted cash flow comparison can be directly interpreted as a return on investment percentage, it serves as a useful way to gauge the significance of difference in present value amounts.

INTEREST AND INFLATION

General

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 that go on at length about whether to inflate or not, by how much, and what should be used for interest 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?

Why Are Results So Sensitive?

The answer lies in gaining an understanding of how the results are affected over a range of discount rates. In general, greater significance is given to future spending at low discount rates and less significance at high discount rates, as shown in Table 2 and Figure 1.

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

In practical terms, if an alternate were to require a future expenditure equal to the initial investment some time between Yrs 25 and 50, that expenditure would represent a much more significant portion of total present value at a 3 percent discount rate, and much less at 9 percent.

Discount Rate (%)	*Significance of Future Expenditure as Percent of Total Present Value*	
	Year 25	*Year 50*
3	32	19
9	11	1

Generally, those who promote the recognition of inflation in least cost analysis wind up using relatively low discount rates, and those who exclude inflation use higher rates. So who is correct?

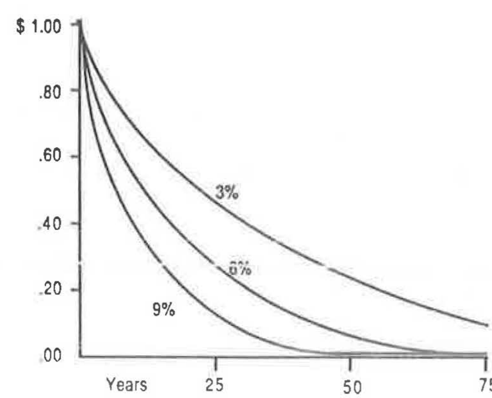

FIGURE 1 Graph of present value of $1.00 expended at various intervals and discount rates.

To Inflate or Not To Inflate

Recognition of inflation is a matter of policy. Strong arguments can be made for both techniques. As will be seen, the results of each approach require different interpretations.

In actual practice, both approaches are used. The Water Resources Council of the U.S. Department of the Interior in a report entitled, *Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies* (*1*), established evaluation principles to be followed by the Corps of Engineers, Bureau of Reclamation, Tennessee Valley Authority, and the Soil Conservation Service for water resource project plans. The report states that all costs are to be at a constant price level and at the same price level at the time of the analysis and as used for the computation of benefits [Section XII 2.12.4 (*b*) and (*i*)].

Similarly, Department of the Army Technical Manual, TM 5-802-1, *Economic Studies for Military Design—Applications* (*2*), indicates that the rate of inflation of the economy as a whole will be neglected in all least cost calculations. Although provisions are made to recognize differential cost growth (where particular costs or benefits are expected to change at rates different from the economy as a whole), it concludes that, in general, the differential growth rate will be assumed to be 0 (Chapter 2–2.b.(7)–*C*).

Although the foregoing suggests that inflation is not considered at the federal level, practice at the state level is mixed. Based on the 20 states and provinces that responded to the Transportation Research Board survey, *National Cooperative Highway Research Program Synthesis of Highway Practice 122, Procedures for Selecting Pavement Design Alternatives*, (*3*) and that provided meaningful descriptions of their techniques, eight states recognized inflation in their life cycle cost evaluations.

Opportunity Value or Cost of Money

The previously mentioned Department of the Army Technical Manual describes the "opportunity value" basis for evaluation (*2*). It states: [Chapter 2.–2.b.(4)] "The prescribed annual discount rate of 10 percent should be viewed as the minimum 'real' rate of return—i.e., the net rate of return, over and above the rate of inflation—to be achieved by public sector investments. The Office of Management and Budget, at the recommendation of the Joint Economic Committees of Congress, has determined that withdrawal of investment capital from the private sector by taxation can be justified only when the capital is used to finance public sector investments for which the real rate of return is at least equal to that achievable on the average in the private sector (estimated to be 10 percent)."

This position is fairly close to that commonly used in industry. That is, money has value and the competing demands for its use exceed the supply. Using a minimum rate of return screens out the poorer prospects. At the same time, inflation is not expressly calculated because it is believed that both costs and benefits are similarly influenced.

Another commonly held position is to use a discount rate that is related to the cost of borrowing. Typically, the interest rate associated with long-term federal, state, or municipal securities is used. This approach makes the choice between alternatives only on the basis of the cost of borrowing. However, the cost of borrowing a given sum is not necessarily the best measure to determine whether an additional sum for a higher cost alternate is warranted.

The difference between the concepts of opportunity value and the cost of borrowing is fundamental and requires the user to make a policy choice. As noted earlier, when the discount rates are high enough, there is generally little difference in the resulting answer for most drainage projects. In other words, if an agency has a 9 percent borrowing rate, it would come to the same choice of alternates as it would if it used the Department of the Army's 10 percent discount rate.

Inflation

Those who do recognize inflation in their calculations are generally concerned that the savings from an alternate with a lower initial cost may not be sufficient to cover the actual costs incurred in the future. A common approach is to assume an across-the-board inflation factor, project future costs, and then discount the resulting cash flows to their present value. Some formulas require specific assumptions on inflation and discount rates; others deal only with the differential between the two rates. The end result is aimed at identifying the alternative with the lowest real cost.

Although the concept is sensible, its application can be troublesome, especially for projects with long design lives. The first comes with rate selection. Aside from the basic choices of discount rates (opportunity or borrowing costs) what do you use for inflation? How do you apply it? Should a flat rate be used across the board or should different elements (e.g., labor, materials, energy) be treated independently (*4*, *5*)? How do you predict it? If nothing else, the analysis becomes much more complex.

Another major problem is the determination of an acceptable real rate. Whereas most decision makers would be comfortable accepting a 9 or 10 percent return on their investment, how would they feel about accepting a 2 percent real rate of return? For that matter, how about 2 percent or 3 percent? Simply put, most people do not have a practical feel for using real discount rates.

Rate Selection

For long-life projects, rate selection should be a matter of policy similar to the basic choice between using opportunity costs as compared with borrowing costs. Historical trends are useful, but should be viewed for what they are: a guide. Certainly, recent history and economic projections should be given higher weighting than data from 3 or 4 decades in the past.

Above all, common sense should prevail. Some techniques being promoted sound logical but do not make sense. For example, one published approach recommends that inflation should be recognized, and used the differential rate approach. The calculation was based on the long-term relationship of municipal bond rates to the consumer price index of 0.9953. If a long-term municipal bond rate of 8 percent is used in conjunction with this ratio, it implies a long-term inflation rate of 7.96 percent. By difference, the real value of money is only 0.04 percent. This just does not make sense. No investor or taxpayer would agree to such a small value, real or otherwise.

Recommendations

The National Corrugated Steel Pipe Association (*6*) agrees with the general approach used by the Department of the Army and, similarly, that of the Department of the Interior. The Association recommends using a 9 percent discount rate and excluding adjustments for future inflation.

For those who, by policy, must specifically identify inflation, a rate of 5 percent in conjunction with the 9 percent discount rate is recommended.

DESIGN LIFE

General

Least cost analysis techniques require that some period of time be selected. However, there is uncertainty as to how long the period should be. In many cases, policy controls. Fifty yr is commonly used for primary state highway culverts.

The choice of design life should be independent of the materials available. Two practical parameters that should be considered are the risk of obsolescence and the availability of funds. The future likelihood of needing increased capacity, the options available to increase capacity in the future, and a risk of complete facility abandonment will serve to place an upper limit on design life. Similarly, fiscal limitations often dictate the limit of spending and therefore influence design life. You cannot spend what you do not have.

In the case of drainage pipe, the exact number of years the pipe is required to perform is less important than a reasonable estimate of the timing and magnitude of future expenditures. For example, even in the situation where invert repair is projected, the resulting extension in service life can normally be expected to go well beyond the 50-yr mark. From the point of view of the calculation, the year of rehabilitation and cost are the only data needed.

Material Life

Some methodologies impose a symmetry of lives position in computing present value. That is, the longest life material governs, and the shorter material life must be replaced as many times as necessary to be equal.

The primary flaw with this approach is that the project design life should determine the calculation period, not the material life. Material life in excess of the design life is immaterial. Materials with shorter life spans need to be either replaced or rehabilitated.

In the case of CSP, invert repairs can extend serviceability for another life cycle at a cost far lower than complete replacement. Prudent inspection programs, even at only a 10-yr frequency, will permit timely repairs while they are still inexpensive.

Residual-Salvage Value

Salvage value is usually taken to mean the benefit of being able to use a given material at the end of a project. In practice, it occurs fairly infrequently with drainage pipe. When it does, the extra cost associated with careful removal has to be weighed against the value of the material. An objective review of current practices on replacement projects shows that the probability of salvage is low.

In contrast, residual value is sometimes taken to mean the calculated value associated with a material that can continue to provide service beyond the project design life. To be valid, either the capacity requirements at the end of the original design life will not need to be changed or, if an increase is necessary, the existing line can continue to provide service without any effect on adding the increased capacity. The mathematics used by some to calculate residual value should be approached with caution. One published example uses a design life of 50 yr, a 100-yr material life, a 7 percent interest rate, and a 5 percent inflation rate. It concludes that the 50 yr of remaining service life at the end of the 50-yr project design life represents an "immediate 19 percent benefit" to the owner that results in a life cycle cost of 81 percent of the actual bid price. Although the mathematics are internally consistent, most owners would not agree with this conclusion. A possible savings 50 yr down the road would not be considered as "immediate".

Whereas salvage or residual values may have significance in short-life projects, which have unusual once-and-done requirements (temporary pumps, generators, etc.), they usually have little significance when applied to long-life drainage projects.

SENSITIVITY EXAMPLES

General

The information contained in this section is intended to provide a perspective on the sensitivity of the present value to variations in certain assumptions. The basic information pertaining to Alternates *A* and *C*, introduced earlier, will be used throughout. Data will be shown using a 9 percent discount rate and no inflation, as recommended in this paper, as well as for an inflation-interest combination of 5 percent and 9 percent, respectively.

Salvage-Residual Value

The information in Table 3 gives an indication of the effect of a broad range of salvage value assumptions. It can be noted from this table that salvage value is not a significant factor. Even under the most extreme condition (30 percent of original cost) it represents a value that is less than 5 percent of the initial cost:

	Sensitivity of Present Value of Salvage as A Percent of Initial Cost		
Interest (%)	*10*	*20*	*30*
9	0.1	0.3	0.4
5/9	1.6	3.1	4.6

TABLE 3 EFFECT OF BROAD RANGE OF SALVAGE VALUE ASSUMPTIONS

Year	Alternate *A* ($)	Alternate *C* Salvage Value ($) at % of Initial Cost		
		10	20	30
0	195,000	230,000	230,000	230,000
40[a]	48,750	–	–	–
50[b]	–	(23,000)	(46,000)	(69,000)
Total	243,750	207,000	184,000	161,000
Present value				
At 9 percent	196,600	229,700	229,400	229,100
At 5 percent/9 percent	205,900	226,400	222,900	219,400

[a] Rehabilitation cost.
[b] Salvage value.

TABLE 4 SIGNIFICANCE OF TIMING OF FUTURE REPAIR COSTS RELATIVE TO INITIAL COST

Year	Alternate *A* Invert Repair Cost ($) at Year	
	40	25
0	195,000	195,000
25	–	48,750
40	48,750	–
Total	243,750	243,750
Present value		
At 9 percent	196,600	200,700
At 5 percent/9 percent	205,900	214,100

Rehabilitation Costs: Timing

The significance of the timing of future repair costs relative to the initial cost is shown in Table 4. It should be noted that, despite a significant acceleration in the assumption about invert repair, the effect on the present value is less than 5 percent:

Interest (%)	*Sensitivity Difference in Present Value as* A *Percent of Initial Cost 25 Versus 40 Yr (%)*
9	2.1
5/9	4.2

Rehabilitation Costs: Magnitude

The example given in Table 5 portrays the significance of an increase in rehabilitation costs from the base assumption of 25 percent of original costs to 40 percent. Similar to the previous example, even this significant increase in rehabilitation cost results in less than a 4 percent increase in present value in relation to the initial cost:

Interest (%)	*Sensitivity Difference in Present Value as* A *Percent of Initial Cost 40 Versus 25 Yr (%)*
9	0.5
5/9	3.4

TABLE 5 SIGNIFICANCE OF INCREASE IN REHABILITATION COSTS FROM 25 TO 40 PERCENT OF ORIGINAL COSTS

Year	Alternate *A* Invert Repair Costs ($) at % of Initial Cost	
	25	40
0	195,000	195,000
40	48,750	78,000
Total	243,750	273,000
Present value		
At 9 percent	196,600	197,500
At 5 percent/9 percent	205,900	212,500

SUMMARY

Least cost analysis techniques are a front-line tool to aid in the selection of alternatives and to see that limited financial resources are spent prudently. Because some of the approaches being promoted appear to be contradictory, the user must be on guard. The most crucial assumption is the basis for the proposed discount rate. Low rates should be rejected on a commonsense basis. Additionally, the sensitivity calculations show that for long-life drainage projects, variations in design life, salvage value, rehabilitation costs, and timing have only a small effect on total present value.

REFERENCES

1. *Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies.* PB 84-199405, U.S. Water Resources Council, U.S. Department of the Interior, Feb. 3, 1983.
2. *Economic Studies for Military Construction Design—Applications.* TM 5-802-1, Department of the Army, Washington, D.C., Dec. 31, 1986.
3. *NCHRP Synthesis of Highway Practice 122. Life Cycle Cost Analysis of Pavements.* Transportation Research Board, National Research Council, Washington, D.C., Dec. 1985.
4. E. L. Grant and W. G. Ireson. *Principles of Engineering Economy*, 5th ed. The Roland Press Company, New York, 1970.
5. H. L. Beenhakker. *Handbook for the Analysis of Capital Investments.* Greenwood Press, Westport, Conn., 1976.
6. J. K. Leason and R. Standley. *Least Cost Analysis.* National Corrugated Steel Pipe Association, Washington, D.C., March 1986.

Publication of this paper sponsored by Committee on Culverts and Hydraulic Structures.