TECHNICAL BRIEF

# Life Cycle Cost Analysis in Drainage Projects

Concrete Pipe Association of Australasia

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## ABSTRACT

The introduction of Australian Accounting Standards by Local Governments has seen an increase in the use of Life Cycle Costing procedures into the material selection process in drainage projects.

The American Society for Testing Materials has developed and published a Standard of Practice for Least Cost (Life Cycle) Analysis of Concrete Culvert, Storm Sewer and Sanitary Sewer Systems.

The U.S. method is outlined in this technical bulletin.

### THE LOWEST BIDDER

*"It's unwise to pay too much, but it's worse to pay too little. When you pay too much, you lose a little money that is all. When you pay too little, you sometimes lose everything, because the thing you bought was incapable of doing the thing it was bought to do. The common law of business balance prohibits paying a little and getting a lot, it can't be done. If you deal with the lowest bidder, it is well to add something for the risk you run. And, if you do that, you will have enough to pay for sornething better."*

John Ruskin (1819-1900) – English writer, art critic and reformer, a dominant intellectual of the Victorian period.

# 1 Introduction

John Ruskin's observation published in 1849 is as valid today as it was a century and a half ago. In fact, with the billions of dollars required to upgrade, rehabilitate and maintain the nation's infrastructure, John Ruskin's basic economic statement takes on even more significance. In the 1994 *National Asset Management Manual* (1) published by the Institute of Municipal Engineering Australia, public infrastructure assets are valued at some $400 billion. It is estimated that federal, state and local authorities will need to invest $10 billion annually to ensure the condition and level of performance are maintained.

The changing role of local government and the recognition that the responsibility of Councillors will need to become similar to that of Directors under the Corporations Law together with the introduction of Australian Accounting Standard AAS 27 *Financial Reporting by Local Governments* has been the catalyst for the integration of technical and financial information into asset management systems.

Thus the application of least cost (life cycle) analysis to road and drainage projects has increased dramatically in recent years. Local and state governments have increasingly included some type of analysis in their material selection process.

The importance of considering the future of a facility during the design phase has been made clear by the multitude of problems many authorities are facing as our infrastructure wears out. In many instances, engineers and executive officers are having to repair and replace integral sections of infrastructure that have experienced premature degradation.

The transition from making decisions based on the lowest first or capital cost of a project to a more complex award process that involves prediction of interest and inflation rates for years into the future requires a major adjustment in philosophy of an awarding agency.

# 2 The U.S. Experience

The American Society for Testing and Materials (ASTM), Committee C-13 on Concrete Pipe, developed and published ASTM Standard of Practice C-1131-95 (2007) for Least Cost (Life Cycle) Analysis of Concrete Culvert, Storm Sewer and Sanitary Sewer Systems. The practice covers procedures for using life cycle analysis (LCA) techniques to evaluate alternative pipeline materials, structures or systems that satisfy the same functional requirement.

The LCA technique evaluates the present value constant dollar costs to install and maintain alternative drainage systems including planning, engineering, construction, maintenance, rehabilitation and replacement and cost deductions for any residual value at the end of the proposed project design life. The decision maker, using the results of the LCA can then readily identify the lalternative with the lowest total cost based on the present value of all initial and future costs.

ASTM Committee C-13 took nearly a decade to develop the original comprehensive LCA practice which eliminates unreliable assumptions, resulting in a readily usable and accurate design aid. The practice uses the well established economic principles of present value which has been used by economists and other professionals for decades. However, the method does require certain assumptions regarding future interest and

*Paying too little capital cost for pipe creates risks of failure*

inflation trends. Based on an article published in Consulting Engineering Magazine[2] the short term volatility of interest and inflation rates is eliminated in the analysis by utilising the relative stable long-term differential between the two rates.

## 3 Factors to be considered in LCA

The design and construction of pipelines, culverts and related drainage facilities are important areas of engineering, and like all engineering projects, decisions must be made regarding material and/or system selection. Material selection with development of appropriate design criteria is a very involved undertaking relating years of experience, usage and performance. The proper engineering design of any hydraulic structure requires consideration of the different but interrelated fields of:

- planning
- specification
- hydrology
- hydraulics
- structures
- installation
- durability
- economics.

The first six aspects of pipe and drainage design are fairly well established. However, the durability and economic aspects are generally not given proper consideration and for many projects, pipe materials or systems are selected on an initial (or capital) first cost basis only. However, lower captial cost does not necessarily mean the most economical product or system.

To determine the most economical choice, the principles of economics must be applied through a life cycle cost analysis.

In such analyses all factors affecting the cost effectiveness must be evaluated.

The ASTM standard practice includes the following factors:

- project design life
- material service life
- capital cost
- interest (discount) rate
- inflation rate
- maintenance cost
- rehabilitation cost
- replacement cost
- residual value.

'Capital cost' is only one of the nine factors which influence a proper economic analysis and 'capital cost' is probably the least important factor if there are high maintenance costs or if the pipe material or system ever has to be replaced during the design life of the project.

### Project Design Life

In regard to 'project design life', a review of all published culvert surveys, and current (USA) state practices published in the National Cooperative Highway Research Program Synthesis of Highway Practice titled *Durability of Drainage Pipe,* defines service life by the number of years of relatively maintenance-free performance and states that a high level of maintenance may justify replacement before failure occurs.

The synthesis also offers guidelines to determine required project service lives for culverts under primary and secondary highways. Based on the guide recommendations, up to 50 years of relatively maintenance-free performance should be required for culverts on secondary road facilities and up to 100 years for higher-type facilities, such as primary and interstate highways and all storm and sanitary sewers. Project design life is similar to the concept of useful life defined in the *National Asset Management Manual* and the recommended design lives are consistent with Australian and New Zealand standards and practice.

### Material Service Life

Once the 'project design life' is established the proven service life of the pipe material or system must be evaluated.

Service life is the number of years of service a material, system or structure will provide before rehabilitation or replacement is required. Numerous culvert condition surveys dating back more than 75 years have been conducted in the United States by major, impartial specifying agencies such as the Federal Highway Administration, Soil Conservation Service, Bureau of Reclamation, Corp of Engineers and several state Departments of Transport. Sewer condition surveys have also been conducted by local jurisdictions, municipalities, consulting engineers and

*Proper analysis of all factors results in a pipeline which economically meets the design criteria*

universities. A bibliography has been published by the American Concrete Pipe Association[3]. Several reports in the bibliography include predictive equations and/or charts for a given set of environmental conditions to accurately predict service life. Project design life and service life must be established by the principal or owner.

## Capital Cost

Capital cost is the original cost incurred in planning, designing and constructing a project including the direct cost, removal and disposal of existing materials, systems or structures, mobilisation, administration, clearing and grubbing, excavation, pipe material and placement, bedding and back filling, surface restoration, traffic maintenance, engineering and contingencies. The actual tender prices can be used for many of the capital cost items.

## Inflation/Interest Factor

The general expression for the compounding of interest or the inflating of a future cost is:

$S = P\,(1 + i)^n$ or $S = P\,(1 + I)^n$

where

$S$ = Future sum of money or cost
$P$ = Present sum of money or cost
$i$ = Interest rate
$I$ = Inflation rate
$n$ = Number of periods

Present Worth is simply the reciprocal of the compound amount and is given by the expression.

$$P = S\left[\frac{1}{(1 + i)^n}\right] \quad \text{or} \quad P = S\left[\frac{1}{(1 + I)^n}\right]$$

Evaluation of cash flows over a period of time must recognise inflation, defined as:
*an increase in the price level creating a decrease in the purchasing power of the monetary unit.*

The least cost of a project is the lump sum of money that would have to be set aside at one time (usually at the beginning of the project) to cover all expenditures during the entire life cycle of the project. The amount of money that must be set aside to cover a future expendiure is affected by both interest rates and inflation rates. Interest may be earned on the money set aside but inflation will increase the amount of the final expenditure. Thus the effects of interest and inflation rates tend to offset each other and the net effect on the life cycle cost is essentially due to the difference in these two rates.

It is not necessary to try to forecast what interest rates or inflation rates will be in the future overa 20, 50 or 100 year period because life cycle costs analysis is affected by the difference in the two rates – and based on substantial historical data this difference remains relatively constant[2].

Using an annual inflation rate 'I', a current expenditure of 'P' will, at 'n' years, cost: $P\,(1 + I)^n$. With an annual interest rate of 'i', the discounted value of this cost at the present is:

$$P\,(1 + I)^n \times \frac{1}{(1 + i)^n} = P\left[\frac{1 + I}{1 + i}\right]^n$$

The term within the brackets is the Inflation/Interest Fact 'F'. The intest rate of a period of time will always be greater than the inflation rate, usually by at least 1 or 2 percentage points. Therefore the Inflation/Interest Factor will always be less than one.

The use of the Inflation/Interest Factor to simplify lifecycle cost estimation was first proposed by the Jet Propulsion Labor atory of California Institute of Technology under a contract with the National Aeronautic and Space Administration. Kerry/Ryan[2] proposed the concept for pipeline installations, and developed the concept that the differential meets the design criteria. between interest and inflation rates for projects involving state or local funding should be determined using the municipal bond rate average; projects involving federal funding should be determined by the treasury bill rate average; and projects involving private funding should be determined by the prime lending rate. Equivalent bond and lending rates are readily available for Australia and New Zealand.

## Maintenance, Rehabilitation and Replacement Cost

The Inflation/Interest factor to the 'nth' power is used as a multiplier to inflate future maintenance, rehabilitation and replacement costs and then discount these future costs back to present constant dollar values. The 'n' term is the number of years in the future at which the costs are incurred.

## Residual Value

If a material, system or structure has a service life greater than the project design life, it would have a residual future current dollar value, which should be discounted back to a present constant dollar value utilising the Inflation/Interest factor and subtracted from the original cost.

# 4 The ASTM Procedure

The ASTM Standard of Practice adopts a 5-step procedure:

1. Identify Objective, Alternatives and Constraints
2. Establish Basic Criteria
3. Compile Data
4. Compute LCA for each Material, System or Structure
5. Evaluate Results.

## Objectives, Alternatives and Constraints

It is important that the specific objectives be established to enable alternative means of accomplishing them to be identified. For example, alternatives for a road drainage system may include a pipe culvert, box culvert or a bridge. Constraints may include head and tailwater levels, maximum and minimum grades, access requirements, etc.

## Criteria

The basic criteria have been discussed earlier but should include:

- project design life
- material, system or structure service life
- first or capital cost
- maintenance, rehabilitation and replacement costs
- residual costs.

Consideration should also be given to the comprehensiveness of the LCA evaluation.

## Data

The necessary data to calculate the LCA of the potential alternative must be collected.

## Calculation or Computation

Cost categories to be considered include:

- capital cost
- maintenance and operating cost
- rehabilitation or repair cost
- replacement cost.

If there is a residual value at the end of the project design life, this value should be discounted back to a present value and subtracted from the original cost.

The present value of all future costs is determined by multiplying each cost by the appropriate Inflation/Interest factor. As illustrated in **Figure 1**, the Inflation/Interest factor inflates a cost into the future by an inflation rate and then discounts the inflated cost back to the present using the discount rate.

Present values will always be less than future values since a present sum could be invested at the discount rate which is larger than the inflation rate. Consequently, the more distant a sum of money is to the present, the less its present value and the greater the discount rate the less a future sum of money is worth at the present.

To illustrate this concept assume a discount rate of 7% and an inflation rate of 5% for a cost to be incurred at 25 and 50 years into the future. The Inflation/ Interest factors for 25 and 50 years are $(1+0.05/1+0.07)^{25}$ = 0.624 and $(1+0.05/1+0.07)^{50}$ = 0.389.

As shown in **Figure 2,** \$0.624 must be invested today at 7% interest (discount rate) to have a 5% inflated sum of money of \$3.39, 25 years into the future. Whereas, only \$0.389 must be invested at 7% interest (discount rate) to have a 5% inflated sum of money of \$11.47, 50 years into the future.

Using the same 5% inflation and 25 and 50 year future times, but increasing the discount rate from 7 to 9% **(Figure 3)** results in Inflation/Interest factors for 25 and 50 years of $(1.05/1.09)^{25}$ = 0.393 and $(1.05/1.09)^{50}$ = 0.154.

Thus increasing the discount rate from 7 to 9% reduces the present value from \$0.624 to \$0.393 at 25 years and \$0.389 to \$0.1 54 at 50 years.

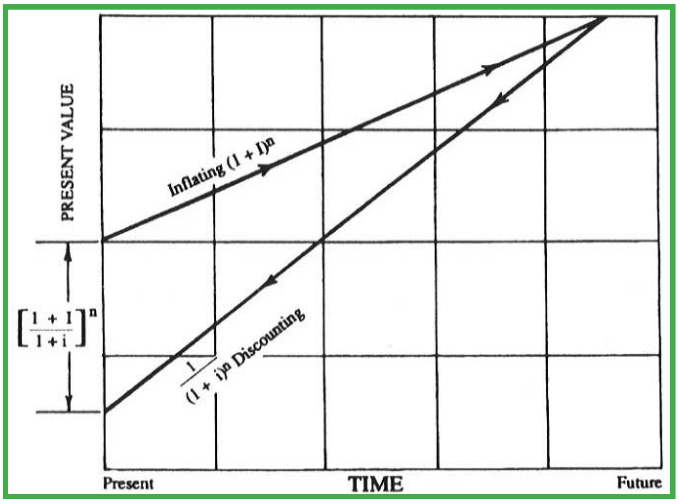


**Figure 1: Inflation/Interest Factor**

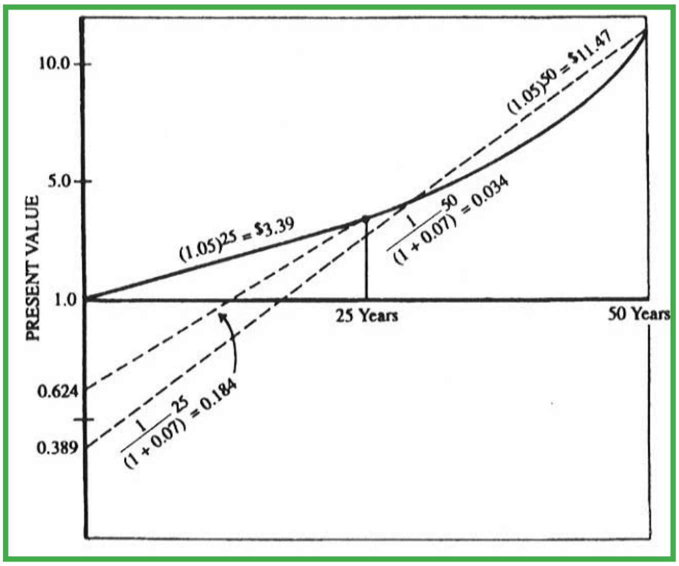


**Figure 2: I = 5% i = 7%**

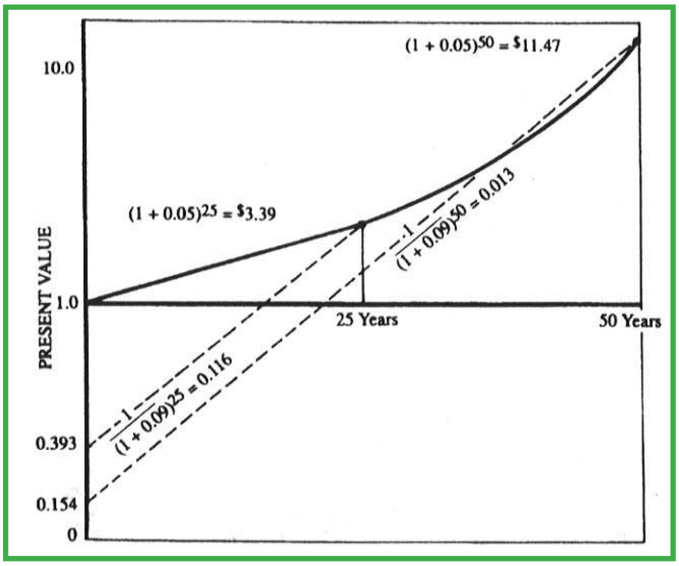


**Figure 3: I = 5% i = 9%**

ASTM C-113 presents the following formula for the LCA calculation:

$$LCA = C - S + \Sigma(M + N + R)$$

where

LCA = least cost (life cycle) analysis
C = original cost
S = residual value
M = maintenance cost
N = rehabilitation cost
R = replacement cost

Using straight line depreciation present value of the residual value is further defined as:

$$S = C(F)^{n_p} \left[\frac{n_s}{n}\right]$$

where

S = residual value
C = present constant dollar factor
F = inflation/interest factor
$n_s$ = number of years of service life exceeds design life
n = service life
$n_p$ = project design life.

The present value of maintenance costs can be determined by applying the inflaction/interest factor to each cost occurrence and summing all values.

If maintenance costs are established on an annual basis the following equation can be used with a nominal discount rate.

$$M = C_m \frac{(1/F)^n - 1}{(i - I/1 + I)\ (1/F)^n}$$

where

$C_m$ = annual maintenance cost
i = nominal discount rate
I = inflation rate
F = inflation/interest factor
n = number of years requiring annual maintenance.

# 5 Example

The following example is presented to demonstrate applicaton of the ASTM method.

### Given:

The 75-year design life has been assigned to a road drainage project to be constructed for a private subdivision. Alternative pipe systems of different materials are included in the tender documents.

***Material A*** with a project capital cost of $325,000 has been assigned to a 50-year service life with an annual maintenance cost of $6,000/year. To meet the project design life, a $75 000 rehabilitation cost will have to be incurred at the end of the 50-year service life.

***Material B*** has an "in ground" cost of $310 000 with a 25-year projected service life. The annual maintenance cost has been estimated at $6000/year. Rehabilitation costs of $100,000 will be incured at the end of the 25-year service life and again after 50 years.

***Material C*** has an estimated capital cost of $300,000, a 15-year projected service life and annual maintenance costs of $7000/year. Rehabilitation costs will be $120,000 after each 15 year period.

***Material D*** with a project tender price of $345,000 has been assigned a 100-year service life with an annual maintenance cost of $5000/year.

Planning and design costs applicable to all alternatives are $150,000.

Based on historical data, a 4% inflation rate and 8% interest (discount) rate is appropriate for this project.

### Find:

The most cost effective material with the lowest LCA.

### Summary:

| | |
|---|---|
| Project Design Life | 100 years |
| ***Material A:*** | |
| Service Life | 50 years |
| Capital Cost | $325,000 |
| Rehab Cost | $75,000 |
| Maintenance Cost | $6,000/year |
| ***Material B:*** | |
| Service Life | 25 years |
| Capital Cost | $310,000 |
| Rehab Cost | $100,000 |
| Maintenance Cost | $6,000/year |
| ***Material C:*** | |
| Service Life | 15 years |
| Capital Cost | $300,000 |
| Rehab Cost | $120,000 |
| Maintenance Cost | $7,000/year |
| ***Material D:*** | |
| Service Life | 100 years |
| Capital Cost | $345,000 |
| Rehab Cost | $0 |
| Maintenance Cost | $5,000/year |
| ***Planning and Design*** | |
| Cost | $150,000 |
| Inflation Rate | 4% |
| Nominal Discount Rate | 8% |
| Inflation/Interest Factor | 1.04/1.08 = 0.96 |

To illustrate the sensitivity of the discount rate relative to the inflation rate, the discount rate will be increased from 8 to 12% in the above example, resulting in a significantly large difference of 8% between discount rate and inflation rate. The Inflation/Interest factor F = 1.04/1.12 = 0.93. By increasing the discount-inflation differential from a realistic 4% to an artificial high 8% reversed the LCA results such that the shorter service life alternatives start to become more cost effective than the longer service life alternative.

This emphasises the importance of properly evaluating interest (discount) rates relative to inflation rates. **The determination of these two rates should be based on historical data of appropriate economic indicators rather than arbitrary assumptions.**

**Solution 1:** The following table summarises the calculations and costs for a 4% inflation rate and 8% nominal discount rate.

| ELEMENT | MATERIAL A | MATERIAL B | MATERIAL C | MATERIAL D |
|---|---|---|---|---|
| Planning and design cost | $150,000 | $150,000 | $150,000 | $150,000 |
| Installed capital cost | $325,000 | $310,000 | $300,000 | $345,000 |
| Present value of maintenance cost | $148,698 | $148,698 | $173,480 | $123,915 |
| Present value of rehabilitation cost | $9,741 | $49,029 | $129,791 | $0 |
| Present value of residual value | $0 | $0 | $0 | ($4,037) |
| **Total costs** | **$633,439** | **$657,727** | **$753,271** | **$614,878** |
| Answer: Material D is more cost effective since the LCA is $18,561 less than Material A. | | | | |

**Solution 2:** The following table summarises the calculations and costs for a 4% inflation rate and 12% nominal discount rate.

| ELEMENT | MATERIAL A | MATERIAL B | MATERIAL C | MATERIAL D |
|---|---|---|---|---|
| Planning and design cost | $150,000 | $150,000 | $150,000 | $150,000 |
| Installed capital cost | $325,000 | $310,000 | $300,000 | $345,000 |
| Present value of maintenance cost | $77,662 | $77,662 | $90,606 | $64,719 |
| Present value of rehabilitation cost | $1,991 | $18,952 | $59,131 | $0 |
| Present value of residual value | $0 | $0 | $0 | ($373) |
| **Total costs** | **$554,653** | **$556,614** | **$599,737** | **$559,346** |
| Answer: Material A and B are marginally more cost effective than Material D | | | | |

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3. *Bibliography - Pipe Material Durability,* Buried Fact No.9, American Concrete Pipe Association, September 1991.



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