Designation: C1131 − 10 (Reapproved 2015)

Standard Practice for Least Cost (Life Cycle) Analysis of Concrete Culvert, Storm Sewer, and Sanitary Sewer Systems[1]

This standard is issued under the fixed designation C1131; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice covers procedures for least cost (life cycle) analysis (LCA) of materials, systems, or structures proposed for use in the construction of concrete culvert, storm sewer, and sanitary sewer systems.

NOTE 1—As intended in this practice, examples of analyses include, but are not limited to the following: (*1*) materials-pipe linings and coatings, concrete wall thicknesses, cements, additives, etc.; (*2*) systems-circular pipe, box sections, multiple lines, force mains, etc.; and (*3*) structures-wet and dry wells, pump and lift stations, etc.

1.2 The LCA method includes costs associated with planning, engineering, construction (bid price), maintenance, rehabilitation, replacement, and cost deductions for any residual value at the end of the proposed project design life.

1.3 For each material, system, or structure, the LCA method determines in present value constant dollars, the total of all initial and future costs over the project design life, and deducts any residual value.

1.4 Major factors in the LCA method include project design life, service life, and relevant interest and inflation rates.

2. Terminology

2.1 *Definitions:*

2.1.1 *constant dollars*—dollars of uniform purchasing power exclusive of inflation or deflation.

2.1.1.1 *Discussion*—Constant dollars are costs stated at price levels for a specific reference year, usually the particular time that the LCA is being conducted.

2.1.2 *current dollars*—dollars of purchasing power in which actual prices are stated, including inflation or deflation.

2.1.2.1 *Discussion*—Current dollars are costs stated at price levels in effect whenever the costs are incurred. In the absence of inflation or deflation, current dollars are equal to constant dollars.

2.1.3 *direct costs*—the costs of excavation, removal, and disposal of existing materials, systems, or structures; installation and testing of replacements materials, systems, or structures; backfill; surface restoration, traffic rerouting, safety, utility relocations; and additional future costs required by new land uses, population growth.

2.1.4 *discount rate*—accounts for the time value of money and reflects the impartiality of paying or receiving a dollar now or at a future time.

2.1.4.1 *Discussion*—The discount rate is used to convert costs occurring at different times to equivalent costs at a common time. Discount rates may be expressed in nominal or real terms.

2.1.5 *future costs*—costs incurred after a project has been constructed and operating, such as maintenance, rehabilitation, and replacement costs.

2.1.6 *indirect costs*—the costs to the owner that users pay in terms of delayed time.

2.1.7 *inflation rate*—an increase in the volume of money and credit relative to available goods and services resulting in a continuing rise in the general price level.

2.1.7.1 *Discussion*—In this practice, inflation refers to yearly change in the Producer Price Index (**1**).[2]

2.1.8 *interest rate*—the cost of borrowed money.

2.1.9 *maintenance costs*—the annual or periodic direct and indirect costs of keeping a material, system, or structure functioning for the project design life; such maintenance does not extend the service life of the material, system, or structure.

2.1.10 *nominal discount rate*—a discount rate that takes into account both the effects of inflation and the real earning potential of money invested over time.

2.1.10.1 *Discussion*—When future costs and values are expressed in current dollars, after having been adjusted for inflation, a nominal discount rate is used to convert the future costs and values to present value constant dollars. Users of this practice should consult with their accountant or client to determine the appropriate discount rate for a given project.

2.1.11 *original costs*—costs incurred in planning, designing, and constructing a project.

[1] This practice is under the jurisdiction of ASTM Committee C13 on Concrete Pipe and is the direct responsibility of Subcommittee C13.05 on Special Projects.

Current edition approved Oct. 15, 2015. Published October 2015. Originally approved in 1995. Last previous edition approved in 2010 as C1131 – 10$^{\varepsilon 1}$. DOI: 10.1520/C1131–10R15.

[2] The boldface numbers refer to the list of references at the end of the standard.

2.1.12 *project design life*—the number of years of useful life the material, system, or structure must provide.

2.1.13 *real discount rate*—a discount rate that takes into account only the real earning potential of money over time and is the differential between the interest and inflation rates.

2.1.13.1 *Discussion*—When future costs and values are expressed in future constant dollars, a real discount rate is used to convert constant dollars to present value dollars. Life cycle economic analyses conducted in constant dollars and a real discount rate are often preferred to similar analyses conducted in current dollars using nominal discount rates because no forecast of the inflation rate is required.

2.1.14 *rehabilitation costs*—the direct and indirect costs of rehabilitating a material, system, or structure to extend the service life of the material, system, or structure.

2.1.15 *replacement costs*—the direct and indirect costs of replacing a material, system, or structure before the end of the project design life, so it will again function as originally intended.

2.1.16 *residual value*—the remaining value of the material, system, or structure at the end of the project design life.

2.1.17 *service life*—the number of years of service a material, system, or structure will provide before rehabilitation or replacement is required.

2.1.17.1 *Discussion*—Project design life and service life are usually established by the owner or controlling agency.

3. Significance and Use

3.1 The significance of the LCA method is that it is a comprehensive technique for taking into account all relevant monetary values over the project design life and provides a measure of the total cost of the material, system, or structure.

3.2 The LCA method can be effectively applied in both the preconstruction and bid stages of projects. After bids are taken, real costs can be used instead of estimates.

4. Procedures

4.1 The procedures for determining the LCA of a material, system, or structure can be summarized in five basic steps.

4.1.1 *Identify Objective, Alternatives, and Constraints.*

4.1.2 *Establish Basic Criteria.*

4.1.3 *Compile Data.*

4.1.4 *Compute LCA for Each Material, System, or Structure.*

4.1.5 *Evaluate Results.*

4.2 *Objectives, Alternatives, and Constraints*—Establish the specific objectives of the project and identify alternative ways of accomplishing the objectives. For example, alternatives for a sanitary sewer system may include a gravity flow system versus a gravity flow system with life stations versus a single force main. Identify constraints, such as maximum culvert head or tail water, maximum and minimum slopes and depths of burial, installation methods, etc.

4.3 *Criteria*—Establish basic criteria that should be followed in applying the LCA method, including project design life; the material, system, or structure service life; direct and indirect costs and timing of maintenance, rehabilitation and replacement; real or nominal discount rate; and the comprehensiveness of the LCA evaluation.

4.4 *Compile Data*—Compile basic data required to compute the LCA of potential alternatives, including costs of planning, design, engineering and construction; maintenance costs; rehabilitation costs; replacement costs; residual values; and the time periods for all future costs.

4.5 *Compute LCA*—The LCA of a material, system, or structure can be formulated in simple terms with all costs and values in present value constant dollars:

$$LCA = C - S + \sum (M + N + R) \quad (1)$$

where:

C = original cost,
S = residual value,
M = maintenance cost,
N = rehabilitation cost, and
R = direct and indirect replacement cost.

4.5.1 *Original Cost*—Original cost is defined in Section 2 and is normally developed from the engineer's estimate or is the actual bid price. A material, system, or structure may have a service life longer than the project design life and, consequently, would have a residual future current dollar value, which must be discounted back to a present constant dollar value, and subtracted from the original cost. Since maintenance, rehabilitation, and replacement costs may be incurred several times during the life of the project, the future current dollar value of each occurrence must be discounted back to a present constant dollar value and the values summed.

4.5.2 *Future Costs*—Future costs are normally estimated in constant dollar values, which are then converted to future current dollar values by an inflation factor and then discounted back to present constant dollar values by an interest factor:

$$FV = A(1 + I)^n \quad (2)$$

where:

FV = future current dollar value,
A = constant dollar value,
I = inflation rate, and
n = number of years in the future at which costs are incurred.

$$PV = \frac{FV}{(1 + i)^n} \quad (3)$$

where:

PV = present constant dollar value, and
I = interest or nominal discount rate.

Combining Eq 2 and Eq 3:

$$PV = A\left(\frac{1 + I}{1 + i}\right)^n \quad (4)$$

Eq 4 is usable, but requires assumptions of both interest and inflation rates. Although interest and inflation rates can vary widely, historical records indicate that the differential between interest and inflation rates has been relatively stable over the long term. Therefore, by defining an inflation/interest factor, F, as:

$$F = \left(\frac{1+I}{1+i}\right) \quad (5)$$

where:

F = inflation/interest factor.

Restating Eq 4:

$$PV = A(F)^{n} \quad (6)$$

The inflation/interest factor is virtually constant for specific differentials between interest and inflation rates. Therefore, utilizing the inflation/interest factor in present value calculations eliminates the uncertainties and distortions due to selection of possibly incompatible individual interest and inflation rates (**2**).

NOTE 2—Table X1.1 presents the inflation/interest factor for a range of inflation rates from 4 through 18 % and differentials between interest and inflation rates of 1 through 5 %. For different sources of financing, the differential between interest and inflation rates significant in construction over a 30-year period is presented in Table X1.2.

4.5.3 *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 and subtracted from the original cost. Using a straight-line depreciation, the present value of the residual value is:

$$S = C(F)^{n_p}\left(\frac{n_s}{n}\right) \quad (7)$$

where:

S = residual value,
C = present constant dollar cost,
n_s = number of years the material, system, or structure service life exceeds the project design life,
n = service life, and
n_p = project design life.

With a lack of data to determine the residual value, a salvage value or cash value may be substituted or the term neglected. If accounting practices dictate, another depreciation method, other than straight-line, may be used.

4.5.4 *Maintenance Costs*—The present value of maintenance costs is calculated by determining the future value of each cost occurrence, discounting each to a present value, and summing all the values. Maintenance costs may be on an annual basis or estimated as a total for a periodic cycle or covering a certain number of years, which reduces the number of computations. The total present value of all maintenance costs is:

$$M = C_M \sum \left(Fn + F^{2n} \ldots + F^{mn} \right) \quad (8)$$

where:

M = total present value of all maintenance costs,
C_M = constant dollar cost of a maintenance cycle,
n = number of years in maintenance cycle, and
m = number of maintenance cycles in project design life.

If a maintenance cycle ends in a year in which rehabilitation or replacement work is scheduled, then the total present value of maintenance costs should be refined by omitting the costs of that maintenance cycle. Where future maintenance costs are on an annual basis, the total present value of all maintenance costs can be determined by:

$$M = C_M \left[\frac{1-(F)^{mn}}{1/F-1} \right] \quad (9)$$

4.5.5 *Rehabilitation Costs*—If a material, system, or structure has durability or structural problems before the end of the project design life, it may be possible to extend its service life by rehabilitation repairs. If the extended service life does not equal or exceed the project design life, the material, system, or structure would probably require replacement at the end of the extended service life. A material, system, or structure may require rehabilitation or replacement several times during the project design life. The present value of rehabilitation costs is calculated by determining the future value of each cost occurrence, discounting each to a present value and summing all values:

$$N = \sum C_N F^n \quad (10)$$

where:

N = present value of rehabilitation costs,
C_N = constant dollar cost estimated for a rehabilitation project,
n = number of years after the project is completed that rehabilitation costs will be incurred.

4.5.6 *Replacement Costs:*

4.5.6.1 The present value of replacement costs is zero for a material, system, or structure with a service life equal to or greater than the project design life.

4.5.6.2 The present value of replacement costs for a material, system, or structure with a service life less than the project design life is calculated by determining the future value of each replacement, discounting each to a present value, and summing all values:

$$R = \sum C_R F^n \quad (11)$$

where:

R = present value of replacement costs,
C_R = constant dollar cost of direct and indirect replacement, and
n = number of years after the project is completed that replacement costs are estimated to occur.

4.5.6.3 The future value of indirect replacement costs for a material, system, or structure with a service life less than the project design life is calculated by determining user delays during construction (**3**):

$$C_{R_i} = \text{AADT} \times t \times d \left(c_p \times v_p \times v_{of} + c_f \times v_f \right) \quad (12)$$

where:

$AADT$ = Annual Average Daily Traffic of the roadway which the culvert is being installed,
t = the average increase in delay to each vehicle per day, in hours,
d = the number of days the project will take,
c_p = the average rate of person-delay, in dollars per hour (**4**),
v_p = the percentage of passenger vehicle traffic,

v_{of} = the vehicle occupancy factor,
c_f = the average rate of freight-delay, in dollars per hour (**5**), and
v_f = the percentage of truck traffic.

5. Keywords

5.1 acceptance criteria; concrete; costs; culvert; inflation rate; interest rate; least cost analysis; life cycle analysis; pipe; procedures; project design life; sanitary sewer; service life; storm sewer

APPENDIXES

(Nonmandatory Information)

X1. INFLATION/INTEREST FACTOR

X1.1 *History*—The use of the inflation/interest factor to simplify life-cycle cost estimation was first proposed by the Jet Propulsion Laboratory of California Institute of Technology under a contract with the National Aeronautics and Space Administration (**2**). Kerr/Ryan proposed the concept for pipeline installations (**6, 7**), and developed the concept that the differential 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. Subsequently, the American Concrete Pipe Association sponsored development of a comprehensive LCA microcomputer program, which is available from McTrans (**8**). The rehabilitation and replacement sections of LCA were developed primarily from Federal Highway Administration information on risk analysis, accidents, injuries, and deaths related to such projects (**9, 10**).

X1.2 *Inflation/Interest Factor Values:*

X1.2.1 Table X1.1 presents the maximum, minimum, and average values for the inflation/interest factor, F, as defined by Eq 5, for inflation rates ranging from 4 through 18 % and differentials between interest and inflation rates ranging from 1 through 5 %. The calculations show that the inflation/interest factor is virtually constant for specific differentials between the rates. Values for inflation rates or differentials not shown in the table can be easily calculated.

TABLE X1.1 Inflation/Interest Factor Values

$(i - I)$ %	$F = (1 + I)/(1 + i)$		
	Maximum	Minimum	Average
1	0.9916	0.9905	0.991
2	0.9833	0.9811	0.982
3	0.9752	0.9720	0.974
4	0.9672	0.9630	0.965
5	0.9593	0.9541	0.957

X1.2.2 Table X1.2 presents 30-year averages of the inflation/interest factor and corresponding interest/inflation rate differential for municipal bonds, treasury bills, and the prime rate (**7**). Users of this practice can prepare similar tables as desired to update the factors, extend the 30-year period, or use indicators rather than municipal bonds, treasury bills, or the prime rate.

TABLE X1.2 Inflation/Interest Factor 30-Year Averages

Funding Source (User)	$F = (1 + I)/(1 + i)$	Differential $(i – I)$ %
Municipal Bonds (State and Local)	0.9953	0.52
Treasury Bills (Federal Agency)	0.9853	1.66
Prime Rate (Private Investment)	0.9749	2.86

X2. EXAMPLE CALCULATIONS

X2.1 *Given*—A 75-year design life has been assigned to a storm sewer project with an AADT of 10 000 vehicles. Two alternative pipe materials are included in the bid documents.

X2.1.1 Material A, with an "in ground" cost of $300 000, has been assigned a 50-year service life with an annual maintenance cost of $6000/year. To meet the project design life, a replacement cost will have to be incurred at the end of the 50-year service life. Estimated lane closures will occur for 60 days with delays of 30 min on average.

X2.1.2 Material B has an "in ground" cost of $345 000 with a 100-year projected service life. The annual maintenance cost has been estimated at $5000/year. Planning and design costs applicable to all alternatives are $150 000. Based on historical data, a 5% inflation rate and 7.15% interest (discount) rate is appropriate for this project.

X2.2 *Find*—The most cost effective material with the lowest LCA.

X2.3 *Solution—Summary:*

General	Material A	Material B
Project Design Life — 75 years	Service Life — 50 years	Service Life — 100 years
Inflation Rate — 5%	Bid Price — $300 000	Bid Price — $345 000
Interest (Discount Rate) — 7.15%	Replace Cost — $300 000 + indirect	Replace Cost — $0
Inflation/Interest Factor — 1.05/1.0715 = 0.98	Maintenance Cost — $6000/year	Maintenance Cost — $5000/year

Table X2.1 summarizes the calculations and costs.

TABLE X2.1 Calculations and Costs

Material A	Description and Calculations	Material B
$150 000	Planning and Design Cost	$150 000
$300 000	Bid Price	$345 000
$229 390 (6000)/year	Maintenance Cost† $M = C_M \dfrac{1 - F^n}{\dfrac{1}{F} - 1} = \dfrac{1 - 0.98^{75}}{\dfrac{1}{0.98} - 1}$	$191 158 (5000)/year
$2 923 066	Replacement Cost Direct $= C_{R_D} F^n = \$300\,000 \times 0.98^{50} = \$109\,251$ Indirect $= C_{R_I} F^n = [\text{AADT} \times t \times d\,(c_p \times v_p \times v_{of} + c_f \times v_f)]F^n$ $C_{R_I} = [10\,000 \times 0.5 \times 60\,(18.62 \times 0.97 \times 1.2 + 52.86 \times 0.03)] \times 0.98^{50}$ $C_{R_I} = \$2\,813\,815$	$0
$0	Residual Value† $S = C\,(F^{n_p})\left(\dfrac{n_s}{n}\right) = 345\,000 \times 0.98^{75}\left(\dfrac{25}{100}\right) = 18\,955$	($18 955)
$3 602 456	Total Cost	$667 203

Answer: Material B is more cost effective since the present value is almost $3 million less than Material A.

†Editorially corrected.

REFERENCES

(1) *Producer Price Index, Annual Averages*, U.S. Department of Labor, Bureau of Labor Statistics.

(2) "Simplified Life-Cycle Cost Estimation," National Aeronautics and Space Administration, NASA Tech Brief, Vol 7, No. 1, Item 88, January 1983.

(3) Perrin, J. Jr., and Jhaveri, C., "The Economic Costs of Culvert Failures, " prepared for the Transportation Research Board, November 2003.

(4) Bureau of Labor Statistics (BLS), Consumer Price Index, All Urban Consumers—(CPI-U).

(5) National Compensation Survey: Occupational Wages in the United States, Department Labor Statistics, United States Department of Labor, July 2002.

(6) Kerr, W. O., and Young, A., *Interest and Inflation Factors in Least Cost Analysis*, published by American Concrete Pipe Association, Vienna, VA, 1985.

(7) Kerr, W., and Ryan, B. A., "Taking the Guesswork Out of Least Cost Analysis," *Consulting Engineer*, March 1986.

(8) LCA diskette, User Manual and Supplemental Documentation, McTrans, University of Florida, Center for Microcomputers in Transportation, Gainesville, FL 36210.

(9) "The Design of Encroachments on Flood Plains Using Risk Analysis," Federal Highway Administration, HEC No. 17, 1980.

(10) "Sensitivity of Resource Allocation Models to Discount Rate and Unreported Accidents," Federal Highway Administration, FHWA/RD-85/092, July 1985.