Cost-Effective Decision Models for Maintenance, Rehabilitation, and Replacement of Bridges

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ABSTRACT

Methodology has been developed to determine whether a deteriorated bridge should be rehabilitated or replaced based on minimum life-cycle costs. Mathematical models were developed from the generalized cash-flow diagrams to facilitate the conversions of cash flow to equivalent values. The equivalent alternative values (equivalent uniform annual costs) are compared by means of a parameter called the value management (VM) term. The sign of the VM term indicates the decision (rehabilitate or replace) and the magnitude of the cost savings. The true cost of long-term borrowing is considered in the interest rate. Inflation's opposite effects on receipts and disbursement are evaluated. Examples of the mathematical models are presented. A microcomputer program was developed to solve the mathematical model. It is a prompt-type program that asks for the input parameters and presents the results and the VM term.

Although highway conditions vary among the states, the national trend is toward deteriorating highway conditions and need for additional funding. Reflective of this trend is Pennsylvania's enormous bridge problem. Pennsylvania has approximately 54,500 bridges longer than 8 ft. About 7,200 of these bridges are structurally deficient or functionally obsolete or both. The cost of improving these structures has been estimated to be $3.0 billion (1). Pennsylvania's reaction to this staggering problem was the enactment of a $1.4 billion bridge program, but even with the implementation of this program a significant amount of bridge work will remain. In addition, of the 22,500 bridges in Pennsylvania that are 20 ft or longer, 400 (2 percent) become deficient each year (2). By 1990 the cost to repair the backlog of bridges after the billion-dollar program has been finished was estimated to be $4.6 billion (2). Therefore, a management tool that will optimize the use of available funds through cost-effective solutions is urgently needed. The purpose of this paper is to present a standardized methodology for cost-effectiveness comparisons in order to generate least-cost solutions to bridge work.

COST EFFECTIVENESS

Cost effectiveness can be achieved through a standardized methodology of comparison in order to generate least-cost solutions, which account for all of the costs incurred over the service life of a structure considering the time value of money. This is in fact the meaning of cost effectiveness. Decisions based on initial costs or individual events will generally not result in a least-cost solution.

Basis

By using standard engineering economic analysis procedures, cost effectiveness is based on comparison of alternatives. The alternatives are as follows:

1. Force-account rehabilitation of the existing structure followed by eventual replacement,
2. Contract rehabilitation of the existing structure followed by eventual replacement, and
3. Replacement of the structure immediately.

Because the rehabilitation alternatives (1 and 2) include eventual replacement, the replacement alternative (3) is evaluated first because it becomes an input parameter for the first two.

The rehabilitation alternatives are compared first, and the one that has the lowest cost is compared with the replacement alternative in the calculation of a parameter called the value management (VM) term, which is obtained by subtracting the equivalent structure rehabilitation cost from the equivalent structure replacement cost. The sign of the VM term indicates the decision (positive sign, rehabilitate; negative sign, replace) and the magnitude of the cost savings if the decision is rendered as indicated by the sign.

The equivalent values are determined as equivalent uniform annual costs (EUAC) for perpetual service. The choice of perpetual service is based on the long use of bridge sites (50 years or more), and the difference between equivalent values for 50 years or more and for infinity (perpetual service) is small in comparison with the uncertainties in predicting future cash flows. Note that the equivalent replacement and rehabilitation costs can be expressed in terms of capitalized cost (present worth of perpetual service) simply by multiplying by the reciprocal of the interest rate, which is, of course, the value for the uniform series present worth factor for infinite time.

Cost Data

Costs for rehabilitation and maintenance work by force account should include the following:

1. Maintenance overhead (equipment and facilities),
2. Design (personnel plus overhead),
3. Maintenance or rehabilitation work (personnel plus material and work contracted, if any),
4. Traffic maintenance and protection, and
5. Road user costs, if appropriate.

Rehabilitation and maintenance work performed by contract should include the following items:

1. Design (personnel plus overhead),
2. Contract administration,
3. Bid price,
4. Inspection costs (including overhead), and
5. Traffic maintenance and protection and road user costs, if applicable.

The major replacement cost items should include the following:

1. First cost (replacement structure cost, engineering, and contract administration);
2. Annual maintenance, rehabilitation, and repair costs (including the items previously listed);
3. Salvage values; and
4. Traffic maintenance and protection and road user costs, if applicable.

Interest Rate and Inflation

The interest rate is the expression of the time value of money in engineering economic evaluations. Prevailing lending rates are generally not appropriate because they include an inflation factor. The true cost of long-term borrowing is generally considered to be of the order of 4 to 6 percent (3).

Classical engineering economic evaluation methodology, for the most part, ignores the effects of inflation. The rationale for this posture is that if inflation affects all aspects of cash flow in the same manner, its net effect on economic decision making is nil. However, in the financing of highway maintenance and construction, this is not true. Funds for new construction, capital improvements, and maintenance of the nation's highways at both the state and federal levels are derived primarily from fixed cents-per-gallon motor fuel taxes. Revenues in the past increased as fuel consumption increased, and at relatively low inflation rates funding pretty well kept pace with costs. However, after the 1973 oil embargo a pronounced change occurred. Rapid increases in fuel costs resulted in marked reduction in fuel consumption because of economizing by motorists and the rapid changeover to smaller, more fuel-efficient automobiles. Also, in order to provide incentives for the development of alternative fuel sources, tax exemptions were provided for gasoline-alcohol blends. These factors produced a drastic reduction in the rate of growth in revenues. During the same period the costs increased sharply because of rapidly rising inflation rates. Although future rates may be tempered somewhat, there is every reason to believe that this trend will continue. Thus, we are faced with a scenario in which inflation affects receipts and disbursements oppositely, creating a situation in which engineering economic analysis must take into account the effects of inflation.

The true interest rate for the conditions described in the preceding paragraph is a function of three factors:

1. Prevailing interest rate,
2. Inflation rate, and
3. Rate of increase in funding.

It has been shown (4) that the applicable relationship is as follows:

$$i^* = \{[(1+i)(1+q)]/(i+f)\} - 1 \quad (1)$$

where

i^* = true interest rate,
i = prevailing interest rate,
f = inflation rate, and
q = rate of increase in funding.

(All rates are expressed in decimal form.) Note that when the effects of inflation are ignored, $i^* = i$.

Using data for the period 1970-1979 from a 1981 General Accounting Office report to the Congress (5), the following values for inflation and funding rates were determined:

1. Inflation rate for highway construction costs: 9.4 percent,
2. Inflation rate for highway maintenance costs: 7.4 percent, and
3. Increase in funding for highway maintenance and construction: 4.8 percent.

The Models

To facilitate the conversions of cash flows to equivalent values that can be compared and used in the VM term, generalized models were developed. The generalized replacement and rehabilitation models, in the form of cash-flow diagrams, are presented in Figures 1 and 2, respectively. The mathematical relationships follow.

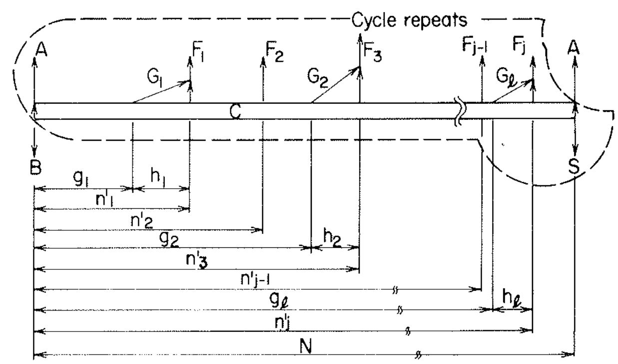

FIGURE 1 Replacement cash-flow diagram, mathematical model, and notation.

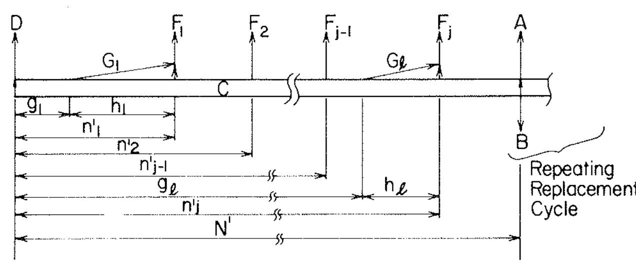

FIGURE 2 Rehabilitation cash-flow diagram, mathematical model, and notation.

Replacement Model

$$EUAC_{Replace} = (A/P, i, N)\left[(A - S) + \sum_{m=1}^{\ell} G_m (P/G, i, h_m + 1)(P/F, i, g_m - 1) + \sum_{k=1}^{j} F_k (P/F, i, n'_k)\right] + (S - B)(i) + C \quad (2)$$

where

A = replacement structure first cost;
B = salvage value of present structure;
S = salvage value of replacement structure;
C = annual maintenance cost for cleaning deck, drainage system, and so on;
F = single future expenditures (e.g., deck overlay, abutment underpinning, painting);
N = life of replacement bridge;
G = annual increase in maintenance cost due to progressive deterioration (e.g., deck patching);
n' = time to single future expenditure;
g = time to beginning of increasing maintenance costs due to progressive deterioration;

h = duration of increasing maintenance costs due to progressive deterioration; and

i = interest rate;

$$(A/P) = \text{capital recovery factor } (A/P, i \text{ percent}, n) = i(1 + i)^n/[1 + i)^n - 1] \quad (3)$$

$$(P/F) = \text{single payment present-worth factor } (P/F, i \text{ percent}, n) = 1/(1 + i)^n \quad (4)$$

$$(P/G) = \text{gradient present-worth factor } (P/G, i, n) = (1/i)\left(\{[(1 + 1)^n - 1]/i(1 + i)^n\}\ [n/(1 + i)^n]\right) \quad (5)$$

Rehabilitation Model

$$EUAC_{Rehab} = (EUAC_{Replace})(P/F, i, N') + i\Bigg[D + C(P/A, i, N') + \sum_{m=1}^{\ell} G_m(P/G, i, h_m + 1)(P/F, i, g_m - 1) + \sum_{k=1}^{j} F_k(P/F, i, n'_k)\Bigg] \quad (6)$$

where

D = initial repair cost,

N' = time to require replacement, and

$$(P/A) = \text{uniform series present-worth factor} = (P/A, i, n) = 1/(A/P) = [(1 + i)^n - 1]/i(1 + i)^n \quad (7)$$

EXAMPLES

The manner in which the mathematical models are applied and the effects of inflation are accounted for in the selection of interest rate is illustrated in the two examples that follow. The values for the capital recovery factor (A/P, i percent, n), single payment present-worth factor (P/F, i percent, n), uniform series present-worth factor (P/A, i percent, n), and the gradient present-worth factor (P/G, i percent, n) used in the examples may be found in any engineering economy text or calculated from the formulas presented.

Example 1

The cash flows associated with replacement and rehabilitation (by force account and by contract) for a certain bridge are shown in Tables 1 and 2. The cost-effective approach is determined as follows:

1. Assume that the interest rate is the mean of the 4 to 6 percent usually considered to represent the range of the true interest values for long-term investments; that is, i = 5 percent.
2. Replace structure (see Figure 3):

```
                  0.05828
EUACReplace = (A/P,5%,40) {(45,000 - 1,500) +
                   5.101          0.5847
   [(100)(P/G,5%,3 + 1)(P/F,5%,12 - 1) + (100) x
      5.101          0.2812
   (P/G,5%,3 + 1)(P/F,5%,27 - 1)] + [(8,000) x
      0.4810                 0.3769
   (P/F,5%,15) + (1,500)(P/F,5%,20) + (6,000) x
      0.2314
   (P/F,5%,30)]} + (1,500 - 1,000)(0.05) +
   500 = $3,424/year.
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TABLE 1 Cash-Flow Table for Bridge Replacement: Example 1

End of Year	Cost ($)	Symbol	Item
0	45,000; 1,000	A, B	Replacement bridge minus salvage beams of current bridge
1-12	500	C	Annual maintenance and cleaning
13	500; 100	C, G_1	Annual maintenance and cleaning + deck patching
14	500; 200	$C2G_1$	Annual maintenance and cleaning + deck patching
15	500; 300; 8,000	C, $3G_1$, F_1	Annual maintenance and cleaning + deck patching + deck and drainage repair
16-19	500	C	Annual maintenance and cleaning
20	500; 1,500	C, F_2	Annual maintenance and cleaning + underpinning and bearing repair
21-27	500	C	Annual maintenance and cleaning
28	500; 100	C, G_2	Annual maintenance and cleaning and deck patching
29	500; 200	C, G_2	Annual maintenance and cleaning and deck patching
30	500; 300; 6,000	C, $3G_2$, F_3	Annual maintenance and cleaning + deck patching + deck and abutment repair
31-39	500	C	Annual maintenance and cleaning
40	500;1,500	C, S	Annual maintenance and cleaning minus salvage value of railings and beams

Note: Bridge replaced after 40 years.

TABLE 2 Cash-Flow Table for Rehabilitation of Current Structure: Example 1

End of Year	Force Account[a]			Contract[b]		
	Cost ($)	Symbol	Item	Cost ($)	Symbol	Item
0	7,500	D	Point abutment, repairing wings, widening and patching deck, treating railing, and painting beams	12,000	D	Point abutment, replacing wings, deck, and railings
1-5	300	C	Annual maintenance and cleaning	200	C	Annual maintenance and cleaning
6	300, 100	C, G_1	Annual maintenance and cleaning + deck patching	200	C	Annual maintenance and cleaning
7	300; 200	C, $2G_1$	Annual maintenance and cleaning + deck patching	200	C	Annual maintenance and cleaning
8	300; 300	C, $3G_1$	Annual maintenance and cleaning + deck patching	200	C	Annual maintenance and cleaning
9	300; 400	C, $4G_1$	Annual maintenance and cleaning + deck patching	200	C	Annual maintenance and cleaning
10	300; 500; 1,200	C, $5G_1$, F	Annual maintenance and cleaning + deck patching + underpinning wings and abutment and painting beams	200; 1,000	C, F_1	Annual maintenance and cleaning + painting
11-15	300	C	Annual maintenance and cleaning	200	C	Annual maintenance and cleaning
16-19				200	C	Annual maintenance and cleaning
20				200; 1,000	C, F_2	Annual maintenance and cleaning + painting
21-25				200	C	Annual maintenance and cleaning

[a]Bridge replaced after 15 years.
[b]Bridge replaced after 25 years.

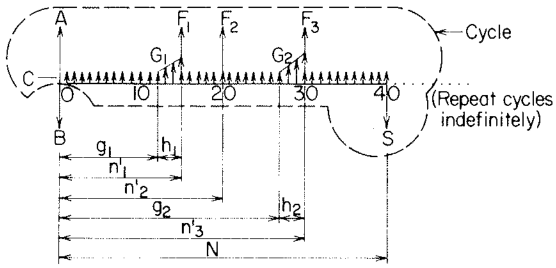

FIGURE 3 Example 1: replacement model.

3. Rehabilitate structure (force account) (see Figure 4) by using the rehabilitation model:

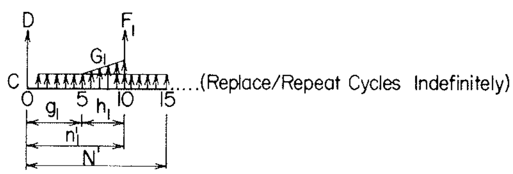

FIGURE 4 Example 1: force-account rehabilitation model.

$$EUAC_{Rehab} = (3,424)\underset{}{\overset{0.4810}{(P/F,5\%,15)}} + (0.05) \times$$

$$[7,500 + (300)\overset{10.3796}{(P/A,5\%,15)} + (100)\overset{11.966}{(P/G,5\%,6)} \times \overset{0.8227}{(P/F,5\%,4)} + (1,200)\overset{0.6139}{(P/F,5\%,10)}] = \$2,264/\text{year}.$$

4. Rehabilitate structure (contract) (see Figure 5):

$$EUAC_{Rehab} = (3,424)\overset{0.2953}{(P/F,5\%,25)} + (0.05) \times$$

$$[12,000 + (200)\overset{14.094}{(P/A,5\%,25)} + (1,000)\overset{0.6139}{(P/F,5\%,10)} + (1,000)\overset{0.3769}{(P/F,5\%,20)}] = \$1,802/\text{year}.$$

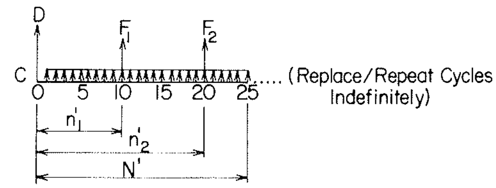

FIGURE 5 Example 1: contract rehabilitation model.

5. Compare rehabilitation methods:

\$1,802/year < \$2,264/year.

Therefore, contract repair would be chosen.

6. Compare repair versus replacement cost:

VM = \$3,424/year - \$1,802/year = +\$1,622/year.

Therefore, the structure should be rehabilitated (by contract). The annual saving is \$1,622/year and the capitalized saving is \$1,622/0.05 = \$32,440.

Example 2

The cash flows associated with replacement and rehabilitation (by force account and by contract) for a certain bridge are shown in Tables 3 and 4. The most cost-effective approach is determined as follows:

1. Assume that the interest rate is based on the technique that takes into account rates of inflation and funding. As previously discussed, the historical rates for the 1970s are 9.4 percent inflation rate for highway construction costs, 7.4 percent inflation rate for highway maintenance costs, and 4.8 percent increase in funding for highway maintenance and construction. Because it is not practical to use two interest rates in the same analysis, assume that the combined inflation rate is the average of the rates for construction and maintenance costs; i.e., f = (9.4 + 7.4)/2 = 8.4 percent. Assume that the prevailing interest rate for long-term public financing during the period is 10 percent. There-

TABLE 3 Cash-Flow Table for Bridge Replacement: Example 2

End of Year	Cost (\$)	Symbol	Item
0	44,000; 2,000	A, B	Replacement of bridge minus salvage beams of current bridge
1-11	500	C	Annual maintenance and cleaning
12	500; 50	C, G_1	Annual maintenance and cleaning and deck patching
13	500; 100	C, $2G_1$	Annual maintenance and cleaning and deck patching
14	500; 150	C, $3G_1$	Annual maintenance and cleaning and deck patching
15	500; 200	C, $4G_1$	Annual maintenance and cleaning and deck patching
16	500; 250	C, $5G_1$	Annual maintenance and cleaning and deck patching
17	500; 300	C, $6G_1$	Annual maintenance and cleaning and deck patching
18	500; 350	C, $7G_1$	Annual maintenance and cleaning and deck patching
19	500; 400	C, $8G_1$	Annual maintenance and cleaning and deck patching
20	500; 450; 8,800	C, $9G_1$, F_1	Annual maintenance and cleaning and deck patching + deck overlay
21-29	500	C	Annual maintenance and cleaning
30	500; 1,030	C, F_2	Annual maintenance and cleaning + underpin abutment and cleaning channel
31	500; 50	C, G_2	Annual maintenance and cleaning and deck patching
32	500; 100	C, $2G_2$	Annual maintenance and cleaning and deck patching
33	500; 150	C, $3G_2$	Annual maintenance and cleaning and deck patching
34	500; 200	C, $4G_2$	Annual maintenance and cleaning and deck patching
35	500; 250, 10,000	C, $5G_2$, F_3	Annual maintenance and cleaning and deck patching and deck overlay
36-39	500	C	Annual maintenance and cleaning
40	500; 900	C, F_4	Annual maintenance and cleaning and repair bearing areas
41-49	500	C	Annual maintenance and cleaning
50	400; 4,000	C, S	Annual maintenance and cleaning minus salvage value of beams and railings

Note: Bridge replaced after 50 years.

TABLE 4 Cash-Flow Table for Rehabilitation of Current Structure: Example 2

End of Year	Cost ($) Force Account	Contract	Symbol	Item
0	20,000	26,000	D	Underpin and pressure point abutments
1	600	500	C	Annual maintenance and cleaning
2	600; 50	600; 50	C, G_1	Annual maintenance and cleaning and deck patching
3	600; 100	600; 100	C, $2G_1$	
4	600; 150	600, 150	C, $3G_1$	
5	600; 200; 28,000	600; 200; 25,000	C, $4G_1$, F_1	Annual maintenance and cleaning and deck patching and deck replacing and adding more stringers
6-14	600	600	C	Annual maintenance and cleaning
15	600, 3,000	600, 3,500	C, F_2	Annual maintenance and cleaning + painting
16-24	600	600	C	Annual maintenance and cleaning
25	600; 3,000	600; 3,500	C, F_3	Annual maintenance and cleaning + painting
26-30	600	600	C	Annual maintenance and cleaning

Note: Bridge replaced after 30 years.

fore, the true interest rate is calculated as follows:

$i^* = \{[(1 + i)(1 + q)]/(1 + f)\} - 1$
$= \{[(1 + 0.10)(1 + 0.048)]/(1 + 0.084)\} - 1$
$= 0.063 = 6.3$ percent.

a. Replace structure (see Figure 6) by using the replacement model:

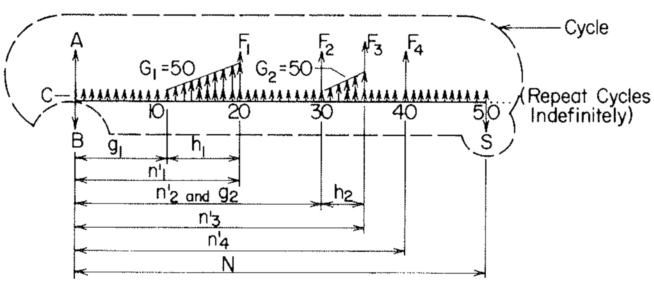

FIGURE 6 Example 2: replacement model.

0.06612
$EUAC_{Replace}$ = (A/P,6.3%,50) {(44,000 - 4,000) +
29.020 0.5428 11.312
[(50)(P/G,6.3%,10)(P/F,6.3%,10) + (50)(P/G,6.3%,6)
0.1700 0.2947
x (P/F,6.3%,29)] + [(8,880)(P/F,6.3%,20) + (1,030)
0.1600 0.1179
x (P/F,6.3%,30) + (10,000)(P/F,6.3%,35) + (900) x
0.0868
(P/F,6.3%,40)]} + (4,000 - 2,000)(0.063) + 500
= $3,595/year.

b. Rehabilitate structure (see Figure 7) (same cash-flow diagram applies to force-account and contract repairs in this case; only values of factors are different):

(1) Force account by using the rehabilitation model:

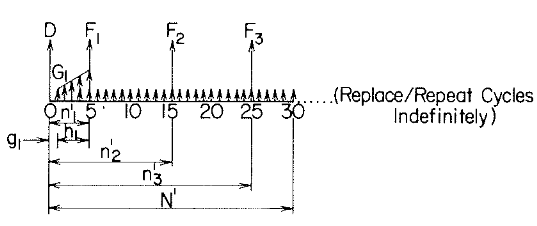

FIGURE 7 Example 2: force-account and contract rehabilitation model.

0.1600
$EUAC_{Rehab}$ = (3,595)(P/F,6.3%,30) + 0.063 x
13.3340 7.847
{20,000 + (600)(P/A,6.3%,30) + (50)(P/G,6.3%,5)
1.000
x (P/F,6.3%,0) + [(28,000) x
0.7368 0.4000
(P/F,6.3%,5) + (3,000)(P/F,6.3%,15) + (3,000) x
0.2171
(P/F,6.3%,25)]} = $3,780/year.

(2) Contract by using the rehabilitation model:

0.1600
$EUAC_{Rehab}$ = (3,595)(P/F,6.3%,30) + (0.063) x
13.3340 7.847
{26,000 + (600)(P/A,6.3%,30) + (50)(P/G,6.3%,5)
1.000 0.7368
x (P/F,6.3%,0) + [(25,000)(P/F,6.3%,5) +
0.4000 0.2171
(3,500)(P/F,6.3%,15) + (3,500)(P/F,6.3%,25)]}
= $4,038/year.

c. Compare cost:
(1) Rehabilitation by force account: $3,780/year.
(2) Rehabilitation by contract: $4,038/year.
(3) Replacement: $3,595/year.

Therefore, the structure should be replaced.

2. In the same situation as that just described but without considering inflation (f = q and therefore i* = i = 10 percent), the calculations are exactly the same as those in the immediately preceding case except that the interest rate is 10 percent. The results will be as follows:
a. Rehabilitation by force account: $4,722/year.
b. Rehabilitation by contract: $5,152/year.
c. Replacement: $4,958/year.

Therefore, the structure should be rehabilitated by force account.

3. In the same situation as that just described, ignoring inflation changes the choice of alternative from replacement to rehabilitation (by force account) and has an effect on the magnitude of the real present value. Because the relationship used in accounting for inflation is based on the real present value of inflated future costs, comparisons will have to be based on present worth.

The EUAC computed by using the model are for perpetual service. The present worth for perpetual service, also called the capitalized cost, is EUAC divided by the interest rate (expressed as a decimal). Therefore, the capitalized cost for the choice when taking inflation into account (replacement) is calculated as follows:

$\$3,595/i^* = \$3,595/0.063 = \$57,063.$

And the capitalized cost for the choice when inflation is ignored (rehabilitate by force account) is calculated as follows:

$\$4,722/i = \$4,722/0.100 = \$47,220.$

Therefore, if inflation is ignored in this case, the real present value for the least-cost alternative is understated by nearly $10,000 (17.2 percent).

MICROCOMPUTER PROGRAM

A microcomputer program that simulates the mathematical models presented in this paper and outputs the least-cost solution was written for the Apple IIe. It is a user-friendly prompt-type program that asks for the input parameters (interest rate, if inflation is to be considered; maintenance and rehabilitation costs; time parameters; etc.). The program is available on request from Richard Weyers or Philip D. Cady.

SUMMARY

A standardized cost-effectiveness solution to whether a bridge should be rehabilitated or replaced has been developed. The alternatives were evaluated by means of appropriate mathematical models that have been developed from generalized cash-flow diagrams. Inflation's opposite effects on receipts and disbursements were evaluated and illustrated by an example. The example showed that if inflation is ignored, the wrong decision can be reached and the real cost will be significantly understated. The standardized methodology presented for cost-effectiveness comparison of alternatives for bridge operations should aid in optimizing the use of limited available funds.

ACKNOWLEDGMENT

The authors wish to acknowledge the support of the Pennsylvania Department of Transportation and FHWA in funding the work described here as part of a larger project. The authors also wish to acknowledge and thank Knud E. Hermansen, instructor of civil engineering at Pennsylvania State University, for developing the computer program discussed here.

REFERENCES

1. R.M. McClure, C.L. Brodeur, and S.W. Marquiss. Bridge Problems and Policies in Pennsylvania. PTI 8301. Pennsylvania Transportation Institute, Pennsylvania State University, University Park, May 1983, 246 pp.
2. Bridges 83: An Economic Analysis. Pennsylvania Economy League, Western Division, Pittsburgh, April 1983, 101 pp.
3. J.R. Craig, D.S. O'Conner, and J.J. Ahlskog. Economics of Bridge Deck Protection Methods. Presented at National Association of Corrosion Engineers Annual Convention, March 22-26, 1982, (Paper 82).
4. P.D. Cady. Inflation and Highway Economic Analysis. Journal of Transportation Engineering of ASCE, Vol. 109, No. 5, Sept. 1983, pp. 631-639.
5. Deteriorating Highways and Lagging Revenues: A Need to Reassess the Federal Highway Program. Report CED-81-42. General Accounting Office, March 5, 1981, 90 pp.

Publication of this paper sponsored by Committee on Structures Maintenance.

The authors are responsible for the accuracy of the data and the conclusions and opinions.

Economic and Performance Considerations for Short-Span Bridge Replacement Structures

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ABSTRACT

Bridges with span lengths up to 100 ft often can be replaced with many different types of structures. This paper is based on a study covering economic and performance aspects of 3,692 bridge replacements in Minnesota during the period 1973 to 1983. Initial and subsequent costs as well as performance problems and considerations for different types of concrete, steel, and timber structures are discussed.

During the past decade new bridge construction and reconstruction activities in the United States have increased significantly. Many different types of structures have been and are being built to replace a large number of deteriorated and deficient bridges. This paper is based on a study that covers 3,692 bridge replacement structures constructed in Minnesota during 1973 to 1983. For the purposes of this study, bridges with main-span lengths of up to 100 ft are considered as short-span structures. Table 1 indicates different types and numbers of bridge replacement structures included in this