# USER COSTS IN A BRIDGE MANAGEMENT SYSTEM

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## ABSTRACT

A fundamental task of bridge management is to optimize fund allocations for the reconstruction, maintenance, repair and inspection of a bridge network under existing constraints. The first step in this process is to assume that all existing bridges are beneficial to the community of users. Thus a bridge is rebuilt, repaired or maintained according to its condition. Since all bridge management decisions are optimized under certain constraints, a bridge management system (BMS) provides a method for prioritizing work on structures according to selected criteria. A simple approach would involve addressing the bridges in the worst condition first. An improved system evaluates bridges according to the cost of the work needed. Intervention in the bridge deterioration process at an earlier stage is cost effective by comparison to allowing the bridge to depreciate and then replacing it. A further refinement considers the importance of the bridge to the users. Several factors can be used to reflect this consideration, such as average daily traffic, peak daily traffic, alternate routes, traffic accident count, and level of serviceability. Some of these factors can be treated as deterministic variables, while others are of a random nature. A detailed evaluation would assign certain value to the time lost by the users due to partial or full bridge closure. The study of bridge deck repair strategies by Llanos and Yanev (*1*) for instance assumed that bridges rated below three (3) provide 75 percent and bridges rated below two (2) provide 50 percent of the full bridge service. An accurate evaluation of this assumption would be of considerable benefit. An estimate of the effect of bridge conditions on traffic accidents and their respective cost would have to be made as well. Considering the above factors as variables allows one to observe their influence on bridge management strategies. Thus, it becomes possible to demonstrate critical levels of service that determine the optimal strategy for a bridge, e.g., to rebuild under partial or full closure, to demolish without replacement, or to rehabilitate. In the current practice such decisions are based on experience and engineering judgement. It would be helpful to compare these decisions with a model addressing an entire network, consisting of bridges of different size, importance and level of deterioration, such as the ones in New York City or even individual cases such as the East River crossings.

## INTRODUCTION

User costs or the benefits of a bridge to the community are hard to estimate. It is demonstrated that a bridge is needed when it is replaced. This is not always the case, for example when bridges are demolished and not replaced. In the general case when bridges are replaced, the cost of reconstruction is a lower estimate of their value over the useful life of the structure. The useful life, however is not uniquely defined for a bridge. Different designs can be expected to last over a variety of life-spans. In addition, the regular maintenance of the bridge can account for a variation in the life-span of a structure estimated at 30 to 120 years. Decisions related to bridge design and maintenance gain considerable significance when their implication to the life of the community is assessed. This is not easily quantified. The special case of a toll bridge provides a useful illustration of structural management with dedicated funding and, consequently, with a budget that lends itself to forecasting. In this instance it becomes possible to assess the benefits of the bridge to the users and to develop long range plans for maintenance and reconstruction such that these benefits are maximized. The George Washington Bridge in New York City is considered. The information about this structure was generously provided by the Port Authority of New York & New Jersey. A contrast with the above example is provided by the Williamsburg Bridge in New York City. This structure provides a similar service to the community but is owned by the City. Its maintenance is funded by the City expense budget while reconstruction is funded jointly with Federal and State funding. The bridge needs are well established by engineering studies, but the benefit to the community due to the bridge is not quantified. This has created significant drawbacks in the management of the structure over its 90 years existence.

## METHOD OF ANALYSIS

A large investment in a capital construction project is commonly evaluated by the present worth method. Essential to this method is the assumption of a discount rate for future investments and benefits. The discount rate is an estimate of the rate at which the investor loses interest in future benefits instead of immediate ones.

This is an indicator of the investor's preference to postpone expenditures on activities, such as maintenance. Generally, the discount rate determines not only the rate of the investor's interest in the future but also the range of time that is significant to planning. The basic relationships of the method are shown below:

For r>0,

$$a \sum_{k=1}^{n} \frac{1}{(1+r)^k} = a\,(1+\frac{1}{r})\,[1-\frac{1}{(1+r)^n}]$$

For n = ∞,

$$a \sum_{k=1}^{n} \frac{1}{(1+r)^k} = a\,(1+\frac{1}{r})$$

where,

$r$ equals the discount rate, $\frac{a}{(1+r)^n}$ equals the present worth of an amount $a$ considered $n$ years in the future,

and $a \sum_{k=1}^{n} \frac{1}{(1+r)^k}$ equals the present worth of a sum of annual increments $a$ over $n$ years. The period beyond which financial planning becomes insignificant can be determined by computing the sum of the convergent series of annual increments when the period tends to infinity. Here, the limit is defined by a sum of annual increments within $x$ percent of the sum of the infinite series, which is determined by

$$\sum_{k=1}^{n} / \sum_{k=1}^{\infty} = [1-\frac{1}{(1+r)^n}] = 1-x$$

where, $n = -\frac{\ln(x)}{\ln(1+r)}$ .

Table I lists the limits imposed on long-range planning for a variety of discount rates and values of the selected roundoff error $x$. Also listed are the factors by which a constant annual increment is multiplied for an infinite series. The assumed discount rate is extremely significant to the period over which planning can be extended. Lower discount rates indicate a confidence in the economy and allow for a long-range planning. High discount rates suggest that an investment should be recovered as soon as possible (Figure 1). The implication of the present worth method is that at high discount rates it is preferable to avoid annual expenditures such as maintenance in favor of maximizing annual profit. Since a civilian bridge is usually built on the assumption that the need for it will grow with time, the question arises if the present worth method applies to such an investment at all. An additional difficulty in applying the method is due to the lack of hard estimates showing the benefit from the bridge to society. If it is assumed that the benefits are known, it becomes possible to plan over a range defined by the discount rate. A general pattern of initial and annual investments and benefits is shown on Figure 2. Significant stages in the life of the bridge are:

TABLE I LIMITS OF LONG RANGE PLANNING DUE TO DISCOUNT RATES

| $r$, % | $1 + 1/r$ | $n$, years | |
|---|---|---|---|
| | | $x$ = 5% | $x$ = 2% |
| 3 | 34.33 | 101 | 132 |
| 4 | 26.00 | 76 | 100 |
| 6 | 17.67 | 51 | 67 |
| 8 | 13.50 | 39 | 51 |
| 10 | 11.00 | 31 | 41 |
| 12 | 9.33 | 26 | 35 |

$T_1$ = the recovery period for the original investment, and
$T_2$ = the period over which annual maintenance and annual benefits remain approximately constant.

The end of the latter stage is the one that should be anticipated, based on engineering knowledge, experience, etc. An intervention such as structural repair, rehabilitation or replacement should be planned to prevent the bridge level of service from declining. The two principal alternatives available to the bridge manager can be defined as follows:

*A* - Annual expenditures (such as maintenance) are minimized. It is assumed that this option will result in the shortest possible useful life for the bridge at full traffic capacity.

*B* - Annual expenditures are optimized to provide a maximum useful life of the structure at full traffic capacity. The life of the structure may easily extend

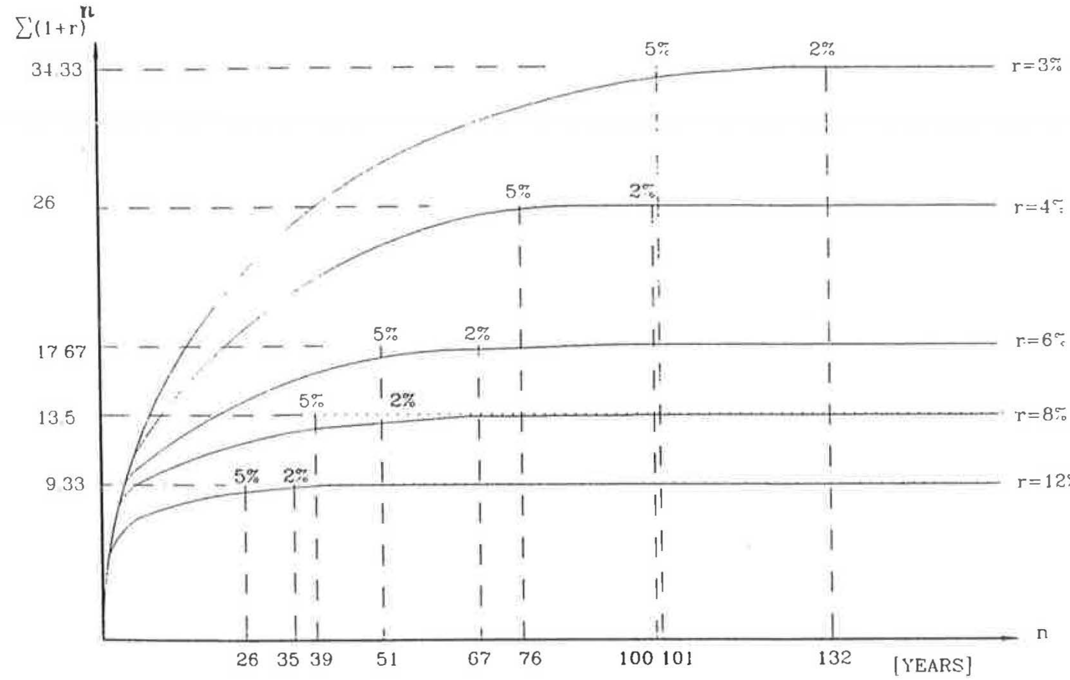


FIGURE 1 Effect of varying discount rates.

beyond the range defined as significant by the selected discount rate. It may be practical to divide the structural life-span into periods of 30 to 40 years and plan to arrive at the end of each period with the best capability to provide service, i.e., to maintain traffic at the least expense.

Two Present Worth methods for comparing the alternatives, *A* and *B*, are considered:

- A simple way to compare the two alternatives, *A* and *B*, is to consider both of them over the same number of years. The options can be compared as follows:

$$m\,(1+\frac{1}{r})\,[1-\frac{1}{(1+r)^n}] + \frac{C_m}{(1+r)^n} \Longleftrightarrow \frac{C_o}{(1+r)^n}$$

or

$$m\,(1+\frac{1}{r})\,[(1+r)^n-1] \Longleftrightarrow C_o-C_m$$

or

$$B \Longleftrightarrow A$$

where,

*n* = number of years under consideration,
*m* = annual maintenance expenditure,
$C_m$ = reconstruction cost after *n* years at *m* maintenance,
$C_o$ = reconstruction cost after *n* years at zero (0) maintenance, and
*r* = discount rate.

The equations can be construed as a relationship between alternatives *A* and *B*, such that if *B* is smaller, Option *B* is the more economical one and vice versa. In this simplified analysis additional costs due to the traffic constraints during construction are included in $C_m$ and $C_o$ respectively. Both traffic and maintenance are assumed constant over the period under consideration.

- The second approach distinguishes between structural life with and without maintenance, while the eventual reconstruction is assumed to have the same magnitude. Comparing the two alternatives *A* and *B* on those terms is expressed as follows:

$$m\,(1+\frac{1}{r})\,[1-\frac{1}{(1+r)}]^n + \frac{C}{(1+r)^n} \Longleftrightarrow \frac{C}{(1+r)^{n_o}} + \frac{C}{(1+r)^{2n_o}} + \ldots + \frac{C}{(1+r)^n}$$

where,
$n$ = number of years until reconstruction with maintenance $m$,
$no$ = number of years until reconstruction without maintenance,
$C$ = cost of reconstruction, and
$n > no$, since maintenance extends the life of the structure.

The inequality states that alternative $A$ reconstructs the bridge every $no$ years without maintenance, while alternative $B$ maintains the bridge annually at an amount $m$ and reconstructs it at the end of $n$ years. Intermediate minor reconstruction also can be incorporated in alternative $B$, since this would better represent actual practice.

In the case when maintenance doubles the life of the structure ($n = 2no$) the above relationship obtains the form:

$$m\ (1+\frac{1}{r})\ [(1+r)^{no} - (1+r)^{-no}] \Longleftrightarrow C$$

Both methods show certain limitations. The case when $A = B$, the two alternatives are comparable. In reality however, alternative $A$ is to entail full traffic closures for more comprehensive or frequent reconstructions. A partial closure may put a strain on the life of the community and reduce local business activities, while a complete closure may extinguish these activities permanently.

The Present Worth method becomes increasingly inaccurate with time, as shown on Figure 1. Consequently, public facilities or any other capital investment that runs to infinity should be analyzed by the Annual Rate of Return method instead. With these reservations, it is useful to apply the Present Worth method to actual bridges to discern patterns in their management history.

## GEORGE WASHINGTON BRIDGE

Construction, reconstruction and maintenance historical data for the George Washington Bridge is listed in Tables II-IV. The historic data are a valuable source of information on the management of the World's longest bridge of its time that played a significant part in the life of the World's largest city.

The toll information can be used for several significant estimates as follows:

TABLE II CONSTRUCTION OF THE GEORGE WASHINGTON BRIDGE

| Construction Activity | Year(s) | Cost, $ Million |
|---|---|---|
| Ordinal span and approaches (8 lanes) | 1928-31 | 59.0 |
| Lower level and approaches (6 lanes) | 1957-62 | 76.0 |
| Capital Rehabilitation | 1992 | 20.7 |
| Capital Rehabilitation | 1993 | 15.5 |

TABLE III MAINTENANCE FOR THE GEORGE WASHINGTON BRIDGE

| Maintenance Costs in $ Millions | Year | |
|---|---|---|
| | 1992 | 1993 (Estimate) |
| Construction | 5.4 | 6.0 |
| Facility Maintenance | 7.4 | 8.3 |
| Total | 12.8 | 14.3 |

TABLE IV ANNUAL TRAFFIC, TOLL COST, AND ANNUAL REVENUE FOR THE GEORGE WASHINGTON BRIDGE

| Year | Annual Traffic (East Bound), Vehicles | Average Toll, $ | Annual Revenue, $ Million |
|---|---|---|---|
| 1932 | 10,500,000 | 0.50 | 5.25 |
| 1991 | 47,952,700 | 4.30 | 207.78 |
| 1992 | 47,764,900 | 4.70 | 223.76 |

- The worth of the bridge to the community is equal to or greater than the amount generated in tolls. This assumption may provide a lower limit of the actual worth of the bridge to the community, since it is not exactly known what traffic reduction results from a specific toll increase. The relationship between the number of users of a public facility of this kind and the toll they are willing to pay can be represented by a

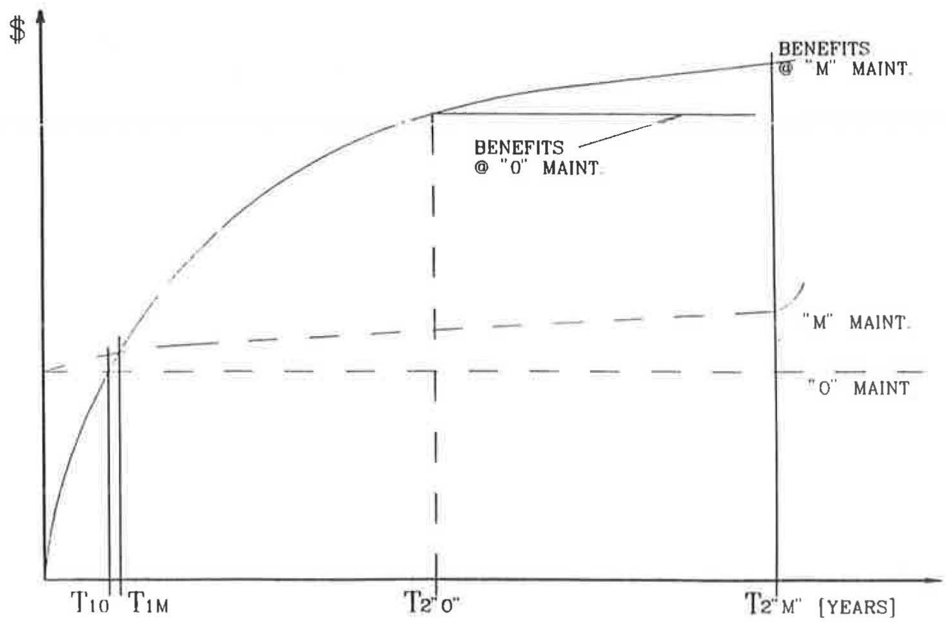


**FIGURE 2** General pattern of initial and annual investments and benefits.

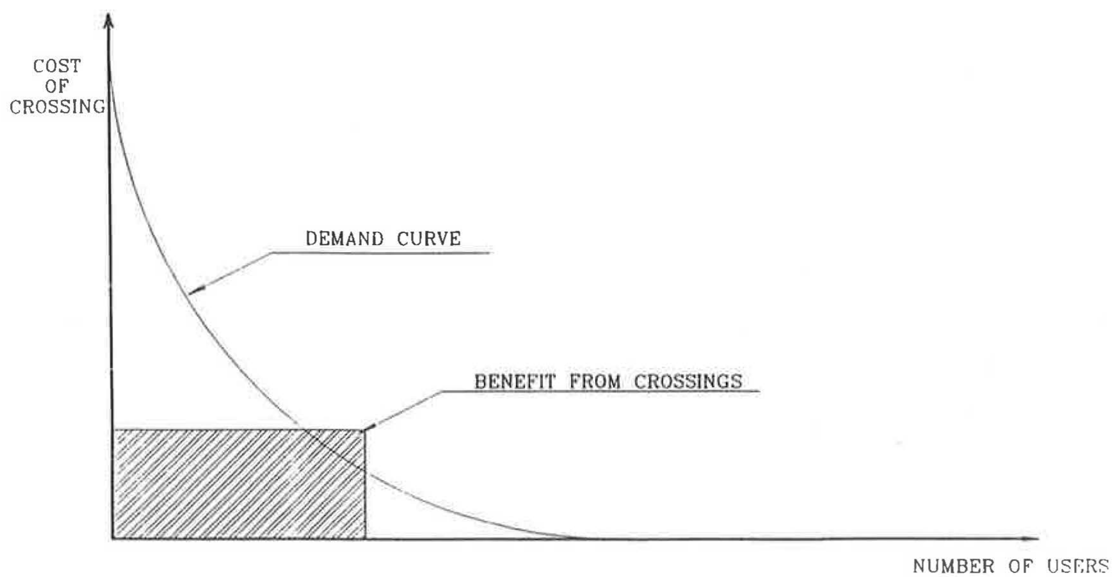


**FIGURE 3** Relationship between users of a public facitlity and toll rate.

graph as shown on Figure 3 (*2*). The exact shape of the curve is not uniquely defined. Consequently, the optimal toll that would maximize the revenues (and the service rendered to the community according to the assumption above) is only tentatively established.

- The rate of inflation over the period under consideration can be estimated. If a period of 60 years (1932-92) is considered, assuming a uniform inflation rate and considering the average toll increase yields:

$$\$0.5\ (1 + i)^{60} = \$4.68$$

Hence, i = 3.8% is the average uniform inflation rate. At 3.8 percent the inflation rate over the 60 years of the bridge useful life to date is half of the discount rate of 8 percent, proposed for the present worth analysis. This is realistic, considering the usual difference between the expectations for future investments and actual record. This difference may be an important source of the well-known trend to neglect future investments in maintenance in favor of other activities, while also professing bewilderment at the reluctance of past managers to spend money on maintenance. The two strategies correspond to the curves for a discount rate of 4 percent and 8 percent of Figure 1. The future is usually assessed at 8 percent, while the past may be reviewed at 4 percent. As a result short range vision is proven faulty only in retrospect.

The data of Tables II-IV is used as follows. The capital expenditures for the bridge are brought back to the year of original completion at the inflation rate of 3.8 percent with the following result. For annual maintenance:

1932 @ 8 traffic lanes, 10.5M vehicles East bound: $\$(5.4 + 7.4) * (8/14) / (1.038)^{60} = \$(0.33 + 0.45)M$
1992 @ 14 traffic lanes, 47.8M vehicles East bound: $\$(5.4 + 7.4) = \$12.8M$.

The above equation assumes that maintenance expenditures have remained constant per traffic lane over the 60 years. If the relationship were corrected to reflect the traffic increase from 10.5M to 47.8M vehicles (East bound) annually, one obtains:

$\$(5.4 * (5.4 + 7.4) (10.5/ 47.8) / 1.038^{60} = \$(0.127 + 0.173)M = \$0.3M$

Forecasting the bridge revenues is based on a traffic forecast. The bridge capacity was increased by 75 percent in 1962 (from eight to 14 lanes). As shown the traffic during the life of the bridge has increased approximately 4.5 times. A linear traffic increase over the 60 years under consideration is assumed. Thus, the annual traffic increase per East bound lane is 0.035M vehicles per lane (1992 @ 47.8M vehicles/14 lanes = 3.4, 1932 @ 10.5M vehicles/8 lanes = 1.3). The ratio of annual revenue to annual maintenance expenditures remains near constant over the life of the structure to date as shown in Table V. The Preventive Maintenance Manual for the New York City Bridges (*3*) recommends a minimum of annual maintenance of 0.5 percent of the replacement value of the bridge. If $0.3M is assumed to have been the original maintenance amount, this results in 0.3 / 59 = 0.51 percent. The original construction cost of $59M and the reconstruction costs of 1957-62, 92, 93 corrected by an inflation rate of 3.8 percent for the present amount roughly to:

$$59*1.038^{60} + 76*1.038^{30} + 20.7 + 15.5 = \$822M.$$

TABLE V RATIO OF ANNUAL REVENUE TO ANNUAL MAINTENANCE EXPENDITURES

| YEAR | MAINTENANCE, % |
|---|---|
| 1932 | (0.3 / 5.25)*100 = 5.7% |
| 1992 | (12.8 / 223.8)*100 = 5.7% |

This suggests that a 3.8 percent inflation rate is below the true value. A bridge of this magnitude would cost over $1 Billion if built today. Depending on the replacement cost, the current total annual maintenance of $12.8M is near 1 percent. The annual structural maintenance amounts to approximately 0.5 percent of the replacement cost.

The reconstruction expenditures of 1957-62 and 1992-93 are discounted to 1932 at the inflation rate of 3.8 percent as shown in Table VI. With these expenditures expressed in 1932 currency, one can examine the future management of the bridge from the year it was opened. This is done at a discount rate of 8 percent, which is an average value common for such studies. Under the above conditions the management of

TABLE VI RECONSTRUCTION COSTS DISCOUNTED TO 1931 (INFLATION RATE = 3.8%)

| Year | Construction Cost, $M | 1931 Equivalent Cost, $M |
|---|---|---|
| 1957 | 12.67 | 4.8 |
| 1958 | 12.67 | 4.6 |
| 1959 | 12.67 | 4.5 |
| 1960 | 12.67 | 4.3 |
| 1961 | 12.67 | 4.1 |
| 1962 | 12.67 | 4.0 |
| Total | 76.00 | 26.3 |
| 1992 | 20.7 | 2.1 |
| 1993 | 15.5 | 1.5 |

the bridge over the first 30 years appears to have followed a sound strategy of increasing service and revenue under growing demand. The second deck with additional traffic lanes (or possibly a rapid transit line) was anticipated and incorporated in the original design. The reconstruction was done when the demand had developed and the revenues had accumulated. Significantly, the assumed discount rate (8 percent) also suggests a 30-year span for long range planning. This coincides with the behavior of structural components, for instance decks, which exhibit a need for rehabilitations at a roughly 30-year cycle as demonstrated in many studies (*1*).

The comparison of the options *A* (no maintenance) and *B* (optimal maintenance) described above can be applied to the case of the George Washington bridge as follows:

$$0.127(1 + 1/0.08)(1.08^{30} - 1) + 26.3 <====> C_o$$

$$15.5 + 26.3 = \$41.8M \text{ (1932 currency)}$$

This equation assumes that the facility maintenance that included toll collection at $0.173M annually could not have been eliminated but the construction maintenance of $0.127M could have been. In 1932 the construction of the bridge had recently been completed at $59M. It is therefore indicated that full maintenance and reconstruction cost in 30 years are preferable to a new construction of the above magnitude at the end of that period. If it is assumed that $n = 2no = 60$ years, the method yields the following relationship ($r = 8$ percent):

$$0.127(1 + 1/0.08)(1.08^{30} - 1.08^{-30}) + 26.3 + 2.1 + 1.5 = \$47M$$

Again the cost of maintenance and the added reconstruction fall below the $59M of constructing the new bridge. This analysis does not include the added benefit of expanding the bridge to 175 percent of its original capacity at the end of the 30-year period. This benefit is only possible if the structure has been designed accordingly and maintained in good condition. Furthermore, the good condition of the original structure makes it possible to add new lanes while maintaining traffic. The annual revenue of 1932 is $5.25M. Thirty years later, discounted at $r = 8$ percent, a traffic closure of a 6-year duration amounts to a $3.2M in 1932, to be added to $C_o$. The Present Worth premise fails over a period of $n = 2no = 120$, i.e., reconstruction in 120 years with maintenance and in 60 years without. In this case,

$$0.127(1 + 1/0.08)(1.08^{60} - 1.08^{60}) + 29.9 = \$203.5M$$

This amount relative to the year of construction would suggest a bridge that could provide service for 60 years without maintenance should be left well enough alone over that period and then replaced. This conclusion stems from the fact that a construction expenditure removed 60 years into the future loses most significance at a discount rate of 8 percent (Figure 1). It is for this reason that the Annual Rate of Return method is better suited for such analyses. The next case provides a clearer illustration of the same point since it deals with a bridge built 90 years ago and without a means for clearly showing its benefits.

## WILLIAMSBURG BRIDGE

The Williamsburg Bridge was constructed in 1903. The bridge carries (8) eight vehicular traffic lanes, two subway tracks and pedestrian walkways. The number of people crossing daily has fluctuated over the years as shown in Table VII.

TABLE VII WILLIAMSBURG BRIDGE

| Year | Number of People Crossing | |
|---|---|---|
| | Daily | Annually |
| 1910 | 227,000 | 81,720,000 |
| 1924 | 505,000 | 181,800,000 |
| 1988* | 240,000 | 86,760,000 |

* Closed for 2 months in Summer of 1988.

The deterioration of the bridge due to lack of maintenance led to its full closure for two months in 1988. Traffic was eventually resumed but serious consideration was given to the complete replacement of the bridge. Also considered was the option of partial replacement and/or rehabilitation, once it was determined that the structural condition allows for such an alternative. The value of the bridge to the community was aptly stressed by its closure. Yet, without tolls there is no quantified measure of the annual benefits due to the service of the bridge.

Assuming a toll equal to that of the George Washington Bridge, i.e., $4.7 (one way) and an average daily traffic of 150,000 vehicles (as opposed to the 260,000 on the George Washington Bridge) would result in an annual revenue of $128.6M. Applying this value to a full closure of the bridge for five years (deemed necessary for a full replacement) has the following present worth at 8 percent discount:

TABLE VIII CONSTRUCTION AND MAINTENANCE COSTS OVER THE BRIDGE USEFUL LIFE AT A 4.5% INTEREST RATE

| Year | Construction, $ | Maintenance, $, 0.5% of replacement cost |
|---|---|---|
| 1903 | $1{,}000 / 1.045^{90} = 19M$ | 0.1M |
| 1993 | 1,000M | 5.0M |

TABLE IX WILLIAMSBURG BRIDGE REPLACEMENT VS. REHABILITATION (8% DISCOUNT RATE)

| | Replacement, $M | Rehabilitation, $M | Percent |
|---|---|---|---|
| Construction, Lump Sum | 1,000 | 400 | 40 |
| Distributed Over 5 Years | 863 | - | |
| Distributed Over 10 Years | - | 290 | 34 |
| Traffic Interruption - 100% During 5 Years | 555 | - | |
| Traffic Interruption - 50% During 10 Years | - | 466 | |
| Total | 1,418 | 756 | 53 |

$$\$128.6\ (1 + 1/0.08)(1 - 1/1.08^{5}) = \$555M$$

A 50 percent closure over 10 years costs:

$$\$0.5 * 128.6\ (1 + 1/0.08)(1 - 1/1.08^{10}) = \$466M$$

The cost of new construction was estimated at roughly $1 Billion. Uniformly distributed over a five-year period and discounted as above this yields the following present worth:

$$\$200M\ (1 + 1/0.08)(1 - 1/1.08^{5}) = \$863M$$

Rehabilitation with partial replacement was estimated at roughly $400M. Uniformly distributed over 10 years this has the following present worth:

$$\$40M\ (1 + 1/0.08)(1 - 1/1.08^{10}) = \$290M$$

Thus the total present worth of the new construction costs amounts to $1.418B, while the rehabilitation costs are estimated at $756M. The estimated costs are summarized in Table IX. Significantly, the rehabilitation cost considered as a lump sum represents 40 percent of the full replacement. If the same costs are distributed over 10 years for the rehabilitation and five years for the replacement, the former represents 34 percent of the latter, i.e., it becomes even more attractive. After adding the estimated costs to the community, however, the ratio changes to 53 percent. In this estimate, comparing quantitatively 50 percent and 100 percent closures is deceptive. A full closure may entirely extinguish certain activities while reduced traffic may cause hardship but no permanent consequences. This is an important limitation of the demonstrated analysis.

The alternative option of regularly maintaining the bridge at a level of expenditure comparable to that of the George Washington bridge is considered. A maintenance of 0.5 percent of full replacement cost of $1 Billion would amount to $5M annually. At a constant inflation rate of 4.5 percent over the bridge useful life one obtains the following values for the year of original completion as shown in Table VIII. The construction cost for the bridge is reported at $14.2M with an additional land cost of $9.1M. Consequently, the $19M appears to confirm the assumed 4.5 percent inflation rate. Within a period of 50 years the discounted sum of the annual maintenance accumulates to such amounts that new construction at no maintenance becomes attractive. This reasoning may have contributed to the neglect of the bridge, thus bringing it close to complete replacement. Neglected in the process are the benefits of the bridge to the community. If, as with the George Washington Bridge, the maintenance was to represent 5.7 percent of the annual revenues due to the structure, a different light is cast on the decision making process.

## CONCLUSIONS

The parallel between a tolled and a publicly owned bridge is used to illustrate certain points, such as:

- User costs or benefits to the community from a public facility, such as a bridge, significantly influence the assessment of bridge management strategies.
- The Present Worth method is limited by the assumed discount rate to a period shorter than the life of a large structure, such as a suspension bridge. While the effect of the discount rate on the long-range planning for a bridge is obvious, it is less apparent how the overall condition of bridges affects the economy and, therefore, discount rates. It is generally agreed that the economy drives the bridge condition. The reverse effect however does exist within limits not clearly determined. A mechanical application of the Present Worth method to the bridge management problem may be partly responsible for the following two negative effects: 1) planning tends to ignore developments beyond the limit set by the discount rate, and 2) structural design seeks to accomplish a useful life, limited by the range provided by the discount rate and thus, shorter than the optimal.
- Any method for the assessment of bridge management alternatives must be modified to reflect the reduction of traffic due to structural deterioration and the added costs due to the corresponding increase in the probability of accidents.
- The annual rate of return method can be applied successfully to the bridge management problem if the means exist for quantifying the benefits due to the bridge. For a non-toll bridge, it is helpful to draw a parallel to a toll structure that provides comparable service. An established strategy in annual rate of return optimization is to opt for the higher initial investment when alternative projects have comparable rates of return. Under the fiscal constraints of capital reconstruction programs this strategy has yielded to the lowest first cost requirement for new bridge design. It is inevitable that structures built under such a requirement will not maximize the benefits they were designed.
- Most methods of economic analysis tacitly assume that any funding withheld from the structural annual maintenance is profitably invested elsewhere (at the discount rate) and available when optimally needed. This assumption is rarely true and the least so for a non-toll bridge.
- All quantitative methods of evaluating a bridge worth to the community suffer from limitations. An alternative approach is to consider the bridge as necessary and to minimize its costs while maximizing service. For a toll bridge, service is equivalent to revenue and the strategy is obvious. For a non-toll bridge the priorities are harder to discern, but should be recognized. A bridge is regarded as irreplaceable in the rare case when it happens to be a landmark. Here the replacement value of the bridge is infinite and any amount of annual maintenance always remains the economical alternative. It is not purely coincidental that the Brooklyn Bridge in New York City, a World famous landmark, is the oldest of the East River crossings and has the least traffic capacity but currently enjoys the best condition of the four bridges.

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