COMPARISON OF BRIDGE DECK ALTERNATIVES USING LIFE CYCLE COSTS

T.R. Nathan and O.U. Onyemelukwe
University of Central Florida, Orlando, FL 32816
trn00158@hotmail.com

O.U. Onyemelukwe
University of Central Florida, Orlando, FL 32816
Onye@mail.ucf.edu

Abstract

This paper presents the Life Cycle Cost (LCC) study component of a bridge deck replacement alternatives for movable bridges. Life Cycle Cost analysis is done on an existing steel grid deck and a proposed Fiber Reinforced Polymer (FRP) deck based on maintanability and corrosobility. Three methodologies of LCC, Equivalent Uniform Annual Cost (EUAC), Benefit / Cost ratio, and the third method which does maximization of benefits less the costs instead of minimizing LCC, were selected. Since the cost of 'new material' FRP is uncertain, uncertainty analysis is also done on all the items of cost for FRP. For the same reason as above the service life of FRP deck could not be conclusively determined and hence a sensitivity analysis of service life on FRP deck is done. Cost data for the steel deck as well as the FRP deck was obtained from the Florida Department of Transportation and Strongwell Inc. respectively. The bridge deck that gave the least life-cycle cost was selected.

Introduction

Studies were done at the University of Central Florida on alternative bridge decks for the open steel deck grating on the Sunrise Boulevard Movable Bridge in Ft.Lauderdale,Florida. One solution proposed for the several problems of an open steel grid was the use of a lightweight movable FRP bridge deck system, Ballard (1997), consisting of a 4"x 4"x 1/4" tubes tied together with 1" thick flat sheets. The wear surface is SAFPLATE, a fiberglass gritted plate which is a unique combination of pultruded fiberglass plate and epoxied anti-skid grit surface.In this paper, LCC analysis is used to demonstrate the economic viability of the FRP deck.

Methodology

Method 1: Equivalent uniform annual cost (EUAC)

To facilitate the conversions of cash flows to equivalent values that can be compared, generalized models were developed, Cady, McClure, Weyers (1981). The generalized replacement model is presented in Equation (1) and the rehabilitation model in Equation (2).

Replacement Model:

$$EUAC_{Replace} = (A/P\ , i, N)\ [R + \sum_{m=1}^{l} G_m(P/G,i,h_m + 1)(P/F,i,g_m - 1)$$
$$+ \sum_{k=1}^{j} F_k(P/F,i,,n_k)] + C \qquad (1)$$

Rehabilitation model:

$$EUAC_{\ Rehab} = (EUAC_{Replace})\ (P/F,i,N') + i\ [D + C\ (P/A,i,N')$$
$$+ \sum_{m=1}^{l} G_m(P/G,i,h_m+1)\ (P/F,i,g_m - 1) + \sum_{k=1}^{j} F_k(P/F,i,n_k) \qquad (2\ )$$

F = single future expenditure (repairs), D = initial repair cost, N = life of bridge, N′ = time to require replacement, n = time to future expenditure, R = replacement structure first cost, C = annual maintenance cost, G = annual increase in maintenance cost due to progressive deterioration, Single payment present-worth factor (P/F,i percent,n) = $1/(1 + i)^n$,Gradient present-worth factor (P/G,i,n)= $(1/i)(\{[1 + i)^n\text{-}1]/i\ (1 + i)^n\}[n/(1 + i)^n])$ (P/A) = uniform series present worth factor = 1/(A/P) = $[(1 + i)^n - 1] / i\ (1 + i)^n$.

Single future expenditures (F_k) will be converted to present worth using the present worth factor (P/F). Corrosion maintenance costs (G_m) are gradient series costs, which the factor (P/G) converts to the present worth. The factor A/P determines the amount A (annual cost) for a series of present worths.

Method 2 : Maximizing Benefits

The optimization method maximizes the benefits minus the costs, instead of minimize the life cycle costs. The optimization problem is, Thoft-Christensen (1998)

$$W(T_R,N_R) = B(T_R,N_R) - C_R(T_R,N_R) \qquad (3)$$

where N_R expected number of repairs in the remaining lifetime and the time T_R of the first repair. W is the total expected benefits B minus costs C_R in the remaining lifetime of the bridge. The benefits are modeled by

$$B(T_R,N_R) = \sum_{i=[T0]+1}^{[T_L]} B_i\ (1 + r)^{\ T_0 - Tref}\ 1/(1 + r)^{Ti - T_0} \qquad (4)$$

Where [T] represents the integer part of T measured in years and B_i is the benefits in year i (time interval $[T_{i-1}, T_i]$). T_i is the time from the construction of the deck. The benefits in year i, B_i depends on the traffic volume per year and the average benefits for one vehicle passing the bridge. The expected repair costs capitalized to time t = 0 are modeled by

$$C_R(T_R,N_R) = \sum_{i=1}^{N_R} (1 - P_F^U(T_R)) C_R(T_R) \frac{1}{(1+r)^{T_R - T_0}} \tag{5}$$

$P_F^U(T_R)$ is the probability of failure in the time interval $[T_0, T_R]$. The factor $(1 - P_F^U(T_R))$ models the probability that the deck is not failed at the time of repair. r is the discount rate. $C_R(T_R)$ is the cost of repair. The repair cost depends on the duration of the repair in days, the number of lanes closed for the repairs, and the total number of lanes.

Method 3 : Benefit Cost Ratio method

In principle, this approach examines the extra benefits of advancing from one improvement level to the next divided by the corresponding extra costs, Xanthakos (1994). *Agency benefits* are defined as the present worth of future cost savings to the agency because of a bridge expenditure. In life cycle cost analysis, future costs must be discounted to a present worth before they are combined with present costs.

Agency Benefits

Figure 3. Replacement alternative, LCC_0

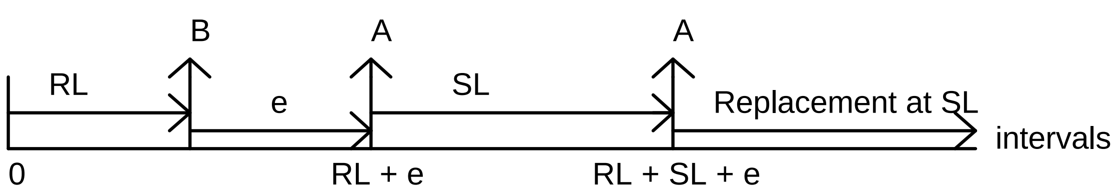


Figure 4. Calculating agency benefits, Extended life alternative, LCC_1

where A = Replacement cost; B = Rehabilitation cost; RL = Remaining life; e = Extended life; SL = Service life. In order to determine agency benefits two life cycle cost scenarios are constructed as shown in Figure 3 and Figure 4. The first assumes no improvement is made to extend service life, and hence replacement occurs at the end of the remaining life of the deck. The second assumes that an expenditure B extends the remaining life of the deck by e years. According to the cost profiles shown in Figure 3 and Figure 4,

$$\text{Agency benefits} = A(pwf_{SL})(pwf_{RL}) - A(pwf_{SL})(pwf_{RL})(pwf_{e}) \qquad (6)$$

$pwf\ (n) = (1+i)^n / (1+i)^n - 1$ and $pwf\ (n) = (1+i)^{-n}$ where n is the number of years.

Results

Method 1: Equivalent uniform annual cost (EUAC)

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 (40 years or more for the steel deck).

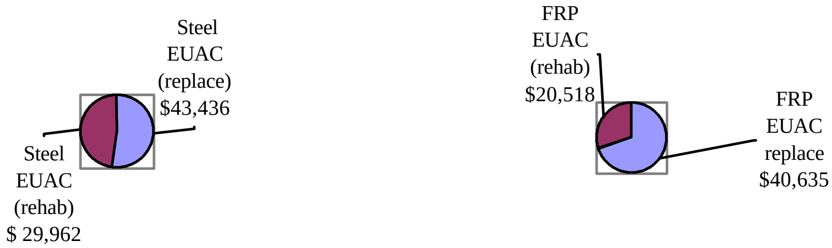
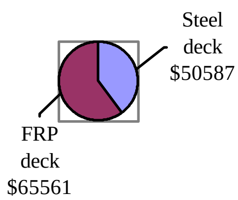


Figure 5. EUAC replace and rehab

Compare cost from Figure 5:
1.Rehabilitation for steel ($29,962) is 43 % more than FRP deck ($20,518) alternative
2.Replacement cost for steel ($43,436) is 7% more than FRP deck ($40,635). This analysis suggests that in the long term FRP deck is cost effective.

Method 2: Maximising Benefits



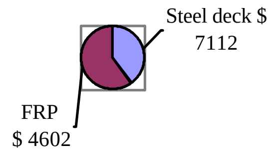


Figure 6. Benefits for steel and FRP deck **Figure 7. Repair costs for steel and FRP deck**

The following observations can be made:
1.The benefits of FRP ($ 65,651) is 35 % more than that of steel deck ($ 50,587).
2.The repair costs for steel deck ($ 7112) is 58 % more than FRP deck ($ 4602).

Method 3:Benefit Cost Ratio

In order to compare the cost of all alternatives, the costs for steel and FRP are discounted to the base year (year 0). The results are tabulated in Table 1.

Alternative	Cost $	Present worth factor pwf	Discounted cost $
Steel deck	733,684	0.2313	169,701
FRP deck	863,321	0.14204	122,626

Table 1. Discount rehabilitation cost

Table 2 shows in tabulated form the benefits, costs, benefit / cost (B/C) ratios for the two alternatives of steel and FRP.

Alternative	Net Benefits $	Cost $	Benefits $	B / C
Steel deck	141,516	169,701	311,217	1.8
FRP deck	86,657	122,626	209,283	1.7

Table 2. Agency benefit / cost ratios

The above result shows the difference in B/C ratio for both decks (steel 1.8 and FRP 1.7) is only 5 %. The results will be more comparable with availability of historical data for ′new material′ FRP.

Computer programs that simulate the mathematical models presented in the three methods were written in Visual Basic. These are user friendly prompt type programs that asks for input parameters. Since service life of FRP was uncertain the programs were used to conduct sensitivity analysis on service life of FRP deck. Also the cost of new construction materials such as FRP is uncertain and does not follow a normal distribution. Therefore any LCC method must address this uncertainty. One method of uncertainty analysis requiring no mathematical representation for the distribution was used. The expected value is the sum of the product of the distributed estimated cost and the probability of occurrence.

Conclusion

The values above are for deck life of 40 years for steel and 50 years for FRP with a discount rate of 2 % provided by the Florida Department of Transportation. According to the analysis the FRP deck is the least cost alternative. With reliable input data, the methodologies described offers the potential for integrating economic issues in structural design. Concluding, it should be mentioned that this study serves as an initial base on which to develop improved life cycle cost. These models can be modified to include additional issues such as inspection costs, and user costs. The essence of the LCC approach is to obtain, record and use data on current activities but for the benefit of future decisions. A major difficulty encountered for this study was the lack of extensive historic data of costs for different actions such as maintenance, repair, rehabilitation, and replacement of the bridge element, as well as costs borne by the bridge users. Concern should be in collecting, validating, analyzing and presenting data for LCC purposes and in monitoring progress.

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