Life Cycle Costs for Heavy Infrastructure

By Peter Davis

Utilization of life cycle cost analysis may identify opportunities to reduce the costs of owning and operating heavy infrastructure. While this approach may be used for all types of heavy infrastructure, a vertical lift bridge will be used as an example. Life cycle costs are defined as:

> *"The sum of all recurring and one time (nonrecurring) costs over the full life span or specified period of a good, service, structure or system. It includes purchase price, installation costs, operating costs, maintenance costs and upgrade costs, and remaining (residual or salvage) value at the end of ownership or useful life." – Merrill Lynch*

Application of this concept is realized by defining the expected rehabilitation work, and estimating the operating and ongoing maintenance costs for the structure. Each of these elements contributes to the overall cost of ownership. The challenge for most public owners is that these costs are spread across different department budgets and are defined as either capital or operating (discretionary) expenses; therefore, it is difficult to understand the total costs associated with any particular structure. Various costs are estimated based upon experience and actual values for the example structure. The expected capital rehabilitation projects, the ongoing maintenance expenses, and the costs to operate the structure will be evaluated.

Movable bridges come in three basic designs: the bascule, swing or vertical lift. There are approximately 3500 of these bridges in the continental Unites States; they represent over $175 Billion of infrastructure, and cost approximately $2.0 Billion annually to operate and maintain. On average, these structures have a 75 year life.

Unlike fixed bridges, movable bridges require mechanical and electrical systems to provide their functionality and maintain safety for the travelling public. These systems require ongoing maintenance (as does any heavy equipment) and require human operation. The maintenance and operational costs become a significant expense beyond what a typical fixed bridge requires. A vertical lift bridge is used as a test case to investigate life cycle costs and identify opportunities for savings.

The bridge used for this analysis carries highway traffic across a navigable waterway, and has a movable span that provides 300 feet of horizontal clearance and 110 feet of vertical clearance. The

Table 1: Structure Elements.

Time period (year)	Substructure	Fenders	Superstructure	Deck and Joints	M&E	Total $
0	40,000,000	15,000,000	60,000,000	15,000,000	25,000,000	155,000,000
5						
10						
15				1,000,000[1]		1,000,000
20		1,500,000[2]				
25						
30				5,000,000[3]		5,000,000
35	3,000,000[4]		7,500,000[5]		2,000,000[6]	12,500,000
40		2,500,000[2]				2,500,000
45					8,500,000[7]	8,500,000
50			30,000,000[8]	10,000,000[9]	5,000,000[10]	45,000,000
55						
60	3,000,000[4]	1,500,000[2]				4,500,000
65				1,000,000[1]	2,000,000[6]	3,000,000
70			5,000,000[5]			5,000,000
75						

1 – Minor joint and deck surface repairs
2 – Replacement of pile/whalers/walkways/navigation lights/cable and conduits
3 – Major deck repairs including stringer steel repairs/new wearing surface
4 – Misc concrete and crack repairs
5 – Misc steel repairs and minor painting
6 – Instrument support repairs/limit switch and controls upgrades/ generator
7 – Major electrical system upgrade/cable & conduits/emergency power/ operator desk/drives
8 – Structural steel repairs and painting
9 – Major deck repairs/stringer replacement/new deck
10 – Counterweight cable replacement

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For more on Predictive Maintenance Programs, see *Reliability Centered Maintenance*, 2nd edition, Industrial Press.

Table 2: Annual Costs.

Annual Expense	Cost $
Maintenance General MB Specific	 12,000 250,000
Operating Costs Utility Bridge Operators	 7,800 228,000
Total Annual Expenses	497,800

overall structure is approximately 980 feet long. The bridge is opened approximately 3500 times per year and is operated on a 24 x 7 basis. The marine traffic requiring span openings range from local sightseeing craft to large ocean going vessels. The bridge carries two lanes of vehicular traffic and has two sidewalks. The specific bridge is slated to be rebuilt such that it will have a new service life of 75 years. Based upon the assumption that the bridge is effectively new, the first step performed for the analysis was to identify rehabilitation requirements over the life of the structure.

Capitalized Rehabilitation Projects

The *Table 1* identifies the rehabilitation projects along with the expected cost (current $) and timing.

The year 0 costs represent the structure's construction cost. As the structure ages, various maintenance and rehabilitation repairs are assumed based upon first year constant dollars. From the example above, the deck will be rehabilitated in years 15, 30, 50 and 65. These rehabilitation projects are typical for a vertical lift bridge located in the Northeast United States.

Maintenance Costs

The ongoing general maintenance costs for any bridge include rubbish removal, snow plowing, guard rail repairs, minor deck/sidewalk repairs, joint repairs, lighting repairs, etc. Based upon actual annual costs, a rate of $0.40 per square foot of bridge deck was used. This rate per square foot is derived from actual costs for the referenced structure. This cost is approximately $12,000 per year. Please note that this cost is applicable for both fixed and movable bridges. For items which are specific for movable bridges only, we have developed a cost for standard maintenance items such as: Traffic Gate Arm Repairs, Navigation and/or Aviation Light Repairs, monthly lubrication, minor electrical system repairs, standby generator service, etc. Monthly lubrication requires a team of maintenance staff to spend approximately one day per month lubricating the bridge, plus the cost of materials. These minor repair and maintenance costs are estimated to be approximately $250,000 per year.

Operating Costs

Operating costs include the cost of the dedicated staff and utility costs for the structure. The utility costs include electricity for the bridge drive and lighting. In addition, most bridges have standby diesel generators, so the cost of fuel must be included. Relative to the other costs, utility costs are almost negligible and should not be considered as a source of savings. The electric power costs are calculated using $0.15 per kilowatt hour, the number of openings (assume 5 minutes of operation) and the lighting loads over a one year period equal approximately $6,000. The cost of diesel fuel, assuming the generator is operated at least monthly for 30 minutes and once per year for 4 hours, equates to approximately $1,800 per year.

The largest operating cost for a movable bridge is the operators. In order to provide 24 x 7 coverage, four full-time operators are required. An hourly rate of $18/hour, with benefit costs of approximately 45%, is assumed. The annual cost for the operators is approximately $228,000 per year. The annual costs to maintain and operate the structure (not including capital costs) are listed in *Table 2*.

Life Cycle Cost Analysis

With an understanding of the costs that will be incurred over the life of the structure, these costs can be put into the context of life cycle. For the purpose of this exercise, an annual inflation rate of 5% and an interest rate of 6% is assumed. These rates will be used to calculate the value of the services provided over the life of the structure in current dollars (first cost equivalent dollars).

The capitalized rehabilitation projects performed over the 75 year period are considered,

Table 3: Capitalized Rehabilitation Costs.

	Substructure	Fenders	Superstructure	Deck and Joints	M&E
First Costs	40,000,000	15,000,000	60,000,000	15,000,000	25,000,000
Present Value of Rehabilitation	3,851,728	3,801,445	26,634,054	11,395,434	11,176,603
Life Cycle Cost	43,851,728	18,801,445	86,634,054	26,395,434	36,176,603

Table 4: Operating and Maintenance Costs.

	Maintenance	Operations
Annual Cost (year 0 $)	262,000	235,800
Life Cycle Cost	16,068,000	14,462,000

for the purpose of the analysis, as one time costs (nonrecurring). Each of these projects will have their cost projected to the end of the period and then, as an aggregate, the net present value is calculated. The combination of the first cost and the present value of the ongoing costs is the life cycle cost (*Table 3*).

The operating and maintenance costs are ongoing (recurring) and will be adjusted for inflation, and then as an aggregate calculated for net present value (*Table 4*).

By combining the cost for the required rehabilitation work along with the operating and maintenance costs, the total life cycle costs for the structure are calculated and shown in *Table 5*.

Opportunities for Cost Savings

The total life cycle cost for this bridge in current year dollars is approximately 56% greater than the construction value. Based upon this finding, the design and construction of the bridge can impact the life cycle costs with a positive result. It is no surprise that the Deck and Joints are a major element where life cycle cost are high due to anticipated maintenance, as are the M&E systems. The bridge maintenance and operation are directly linked to the M&E systems and should be considered together as opportunities for savings are investigated. The M&E systems for the bridge should receive special scrutiny to identify opportunities for savings.

Specific opportunities to reduce M&E system costs are:

1) Consider remotely operating several movable bridges from a central location. From this analysis, every bridge has a life cycle cost of $14.4 million.
2) Implement a predictive maintenance program (reduces ongoing maintenance and M&E rehabilitation costs by approximately 70%) for a savings of $19.1 million.

Remote operation of a movable bridge is very common for railroad bridges and has been implemented on selected highway bridges for over 15 years. The installation of closed circuit television and channel sensing equipment allows several bridges to be operated by a single individual. As indicated above, consolidation of two separate bridge crews into one crew has a net present value of $14.4 million, while the cost to implement a remote operation system is generally less than $1.0 million. Recent practice for railroad bridges includes three or four structures operated by the same individual, resulting in substantial savings.

In accordance with requirements of the Federal Highway Administration's *National Bridge Inspection Standards* (NBIS), structures are required to be inspected every other year as a minimum. These safety inspections are structural in nature; however, many movable bridge owners include the M&E systems in the biennial inspections. The results of these inspections often are not acted upon unless a safety issue is identified. Experience shows that performing minor repairs on an ongoing basis has a dramatic impact on the timing of major repairs, which in turn can reduce life cycle cost.

Conclusions and Recommendations

By identifying where costs are incurred in the ownership of a movable bridge, the design team can concentrate on design details which will significantly reduce maintenance. In addition, decisions can be made to eliminate certain costs altogether. As a planning tool, a life cycle cost analysis can be performed for each major structure within an owner's inventory. This analysis allows the owner to understand which structures have high costs, and what the source of those costs are.▪

Table 5: Total Life Cycle Costs.

	First Cost	Life Cycle Cost	% increase
Substructure	40,000,000	43,851,728	10%
Fender System	15,000,000	18,801,445	25%
Superstructure	60,000,000	86,634,054	44%
Deck and Joints	15,000,000	26,395,434	76%
M&E Systems	25,000,000	36,176,603	45%
Maintenance	0	16,068,000	
Operations	0	14,462,000	
Total	155,000,000	242,389,264	56%