Improving Transportation Investment Decision Through Life-Cycle Cost Analysis – Case Study on some Bridges in the North of Sweden

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ABSTRACT: The scope of this project is to perform Life Cycle Cost Analysis (LCCA) on different types of bridges, in order to learn which is most cost-efficient in a particular situation. A second scope is to study the impact of different cost items on the whole Life Cycle Cost. The work is performed to enable optimal strategic decisions regarding future investments.

Beam and Slab Bridges, Slab Bridges and Slab Frame Bridges are analyzed. The bridges are located in the north of Sweden, in the regions of Norrbotten and Västerbotten. All bridges have a total length of around 20 m, which is the most common length in Sweden and in Europe.

Furthermore, the analysis includes Timber and Soil-Steel bridges in order to understand the prospects for this types of bridges in Sweden. The analysis does not focus on a particular bridge but, based on information from some Swedish producers, it studies different scenarios.

The data collection covers initial investments, maintenance, repair and rehabilitation (MR&R) costs, user and demolition costs.

1 INTRODUCTION

Constant efforts of all bridge owners are to reduce the costs for the maintenance, repair and rehabilitation (MR&R) and disturbances for users of roads and bridges. One way to approach this goal is to collect information and gain knowledge about the previous maintenance costs and investment for different types of bridges and integrate these data with the future planning of MR&R. The data collected in this way will be used to perform the Life-Cycle Cost Analysis.

Furthermore, Life-Cycle Cost Analysis is a more and more recognized engineering tool used both in the planning phase and in the management of assets in order to take optimal decision. The background of this paper can be found in [Ditrani, 2009].

2 METHODOLOGY: THE LIFE-CYCLE COST ANALYSIS

LCCA is an engineering economic analysis tool that allows transportation officials to quantify the differential costs of alternative investment options for a given project. LCCA can be used to study a new construction project and to examine preservation strategies for existing transportation assets. LCCA considers all agencies expenditures and user costs throughout the life of an alternative, not only initial investments.

More than a simple cost comparison, LCCA offers sophisticated methods to determine and demonstrate the economical merits of the selected alternative in an analytical and fact-based manner.

Project teams using the LCCA process first define reasonable design or preservation strategy alternatives. For each proposed alternative, they identify initial construction or rehabilitation activities, and the timing for those activities. From this information, a schedule of activities is constructed for each project alternative.

Next, activity cost are estimated. Best practice LCCA include not only direct agency expenditures (for example, construction or maintenance activities) but also user costs. User costs are costs to the public resulting from work zone activities, including lost time and vehicle expenses. A predicted schedule of activities and their associated agency and user costs are combined to form a projected expenditure stream for each project alternative.

Once the expenditure streams have been determined for the different competing alternatives, the objective is to calculate the total Life Cycle Cost for each alternative. Because money spent at different times have different values to an investor, the projected activity costs for a project alternative cannot simply be added together to calculate total Life Cycle Cost. LCCA uses discounting to convert anticipated future costs to present money values [U.S. Department of Transportation, 1998].

2.1 Present Value for a single cash flow

The present value method is commonly used for discounting purposes. All past, present and future cash flows are discounted to a common point of time, the present, so as to account for the changes in money's purchasing power over time[Troive, 1998].

The present value of a future cash flow, expected to fall due n years later, may be calculated by:

$$B_o = \frac{B}{(1+r)^n} \tag{1}$$

Where B_o : the present value

B : cash flow, in constant money

r : real, inflation adjusted, discount rate for costing purposes

2.2 Present value for an annual cash flow

The present value for a future cash flow, expected to fall due every year during the time period n, may be calculated by [Troive, 1998]:

$$B_0 = B(1+r)^{-1} + B(1+r)^{-2} + \cdots + B(1+r)^{-n} = B\left[\frac{1}{1+r} + \frac{1}{(1+r)^2} + \cdots + \frac{1}{(1+r)^n}\right] =$$

$$= \frac{B}{(1+r)^n}[(1+r)^{n-1} + (1+r)^{n-2} + \cdots + (1+r)^0 \tag{2}$$

Which is a geometrical series that can be written as:

$$B_0 = \frac{B}{(1+r)^n}\sum_{i=0}^{n-1}(1+r)^i = B \cdot \frac{1-(1+r)^n}{(1+r)^n[1-(1+r)]} = B \cdot \frac{(1+r)^n - 1}{r(1+r)^n} \tag{3}$$

Dividing numerator and denominator by $(1+\mathrm{r})^{\mathrm{n}}$, the following equation is obtained:

$$B_0 = B \cdot \frac{1-(1+r)^{-n}}{r} \tag{4}$$

2.3 Present Value for a periodical cash flow

A future cash flow, expected to fall due periodically every p year during the n years, can be discounted to present value by:

$$B_0 = B(1+r)^{-p} + B(1+r)^{-2p} + \cdots + B(1+r)^{-mp} = B\left[\frac{1}{(1+r)^p} + \frac{1}{(1+r)^{2p}} + \cdots + \frac{1}{(1+r)^{mp}}\right] =$$

$$= \frac{B}{(1+r)^{mp}}[(1+r)^{m-1} + (1+r)^{m-2} + \cdots + (1+r)^0 \tag{5}$$

Where m is the number of times the cash flow is expected to fall due during the n years; $mp \leq n$.

If the cash flow is some kind of maintenance, repair or rehabilitation cost, the cash flow at year n is not relevant and should therefore not be counted for.

The number of times the cash flow is expected to fall due, m, may then be calculated by:

$$m = trunk\left(\frac{n-1}{p}\right) \tag{6}$$

The equation of the present value above is a geometrical series that can be rewritten as

$$B_0 = \frac{B}{[(1+r)^p]^m} \cdot \sum_{i=0}^{m-1}[(1+r)^p]^i = B \cdot \frac{1-[(1+r)^p]^m}{(1+r)^{mp}[1-(1+r)^p]} =$$

$$= B \cdot \frac{(1+r)^{mp}-1}{(1+r)^{mp}[(1+r)^p-1]} \tag{7}$$

By dividing numerator and denominator by $(1+\mathrm{r})^{\mathrm{mp}}$, the following equation is achieved:

$$B_0 = B \cdot \frac{1-(1+r)^{-mp}}{(1+r)^p-1} \tag{8}$$

2.4 Annuity Cost

When expected service lifes differ, the investments may preferably be compared on an annual equivalent basis. The annuity cost is the inverse of the present value for annual costs [Troive]:

$$A = B_0 F_A = B_0 \frac{r}{1-(1+r)^L} \tag{9}$$

Where B_o : the present value
F_A : annuity factor
L : service life
r : real, inflation adjusted, discount rate for costing purposes

2.5 User Costs

Because an infrastructure like a bridge is built for the society, and not for a single private owner, the users have to be taken in high consideration during the management operations. When a bridge needs to be inspected, an element has to be replaced or maintained, all of these operations affect the users, because they affect the regular traffic flow on the bridge. Time lost by the users, through rerouting or delay of commercial and non-commercial traffic has a cost, that can be calculated. In this project, the user costs have been estimated by an application available in BatMan, the National Database of Vägverket (Figure 1).

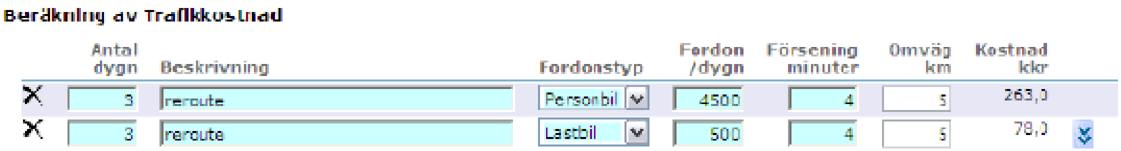

Figure 1. BaTMan tool to calculate user costs

In the first box is asked the number of days for the operation, then if the user cost that has to be calculated is referred to regular cars or trucks, then the amount of traffic and the expected length of the delay is requested. In the white box it is possible to feed the length of the rerouting if this is the case. All the parameters concerning commercial and non-commercial hourly cost are implemented in the tool. The result is the cost for the users shown on the right, in kkr (Kilo-SEK).

A weak point of this tool, is the fact that the future growth of the traffic is not taken in consideration.One way to do it, and make the analysis more reliable, is to estimate the future traffic using the traffic model SAMPERS, the Swedish national traffic model, implemented in a software [Ditrani, 2009].

2.6 Historical Traffic Data and Forecasting Calculation

A function for the traffic during the whole service life of the bridge is needed in order to calculate the cost for users. First, the historical data on traffic have been collected for each of the roads the different bridges are located in. This was possible with the help of a web application, in use in Vägverket, through which is possible to look at all the surveys in the whole Sweden approximately from 1989 to 2008. The data available are ‘total traffic’, ‘cars’ and ‘trucks’, presented as number of vehicles but also as ‘pair of axis’. We should notice that the most reliable data is the ‘pair of axis’ but the tool implemented in BaTMan use ‘cars’ and ‘trucks’ in order to calculate the costs for users, so an approximation has been necessary.

Then, with the help of the software that implement the SAMPERS traffic model, it was possible to get information on the traffic forecast. The forecast is given for a specific area, and different forecasts are given for cars and trucks. The first forecast is given for the year 2020 and a second one for the year 2040. Then a linear extrapolation has been considered to forecast the traffic data until the end of the service life.

2.6 Dealing with inflation – choice of the parameters

One of the parameters that most influence the result of a LCC Analysis is the interest rate. The analysis can be performed at different degrees of accuracy. It is possible to consider the interest rate as a constant, without any influence of inflation. In this case, the cost that is planned today is going to be the same in the future and the Present Value will end up to be a cost that is less than the real one. When the inflation is considered, taking into account the fact that goods today cost, probably, less than tomorrow, the result may be seen as more accurate. The inflation rate can be approximately chosen constant. In this case, it is possible to consider a unique parameter, "V", which is the ratio between 1+j and 1+i, where j and i are respectively the inflation and the interest rate. A third way to perform the Life Cycle Cost Analysis is to consider a constant interest rate and constant inflation rates, that change depending on the good that is considered. In this report this third solution is adopted. The motivations that has driven to this choice are based, for what concern the choice to consider interest and inflation rate in an unique parameter, on a study made in the USA where it is shown the stability in a LCCA of the parameter V during the years 1950 – 1976 [Eisenberg, 1976], and for what concern the choice of different 'inflations' on the reality of economy. The cost of a good will increase in a different manner compared to the cost of the time of the users for example.

The table that follow shows the different 'V-parameters' used in the analysis. The values are an average, in fact one of the further development of LCCA would be to find out more accurate values or functions (of time) for these parameters [Ditrani, 2009].

Table 1. "V" parameters

V parameters calculation
$V_{users} = \frac{1,05}{1,04} = 1.00962$
$V_{MR\&R} = \frac{1,015}{1,04} = 0.97596$
$V_{investment} = \frac{1}{1,04} = 0.96154$
$V_{planning\&deisgn} = \frac{1,02}{1,04} = 0.98077$
$V_{dismantle} = \frac{1,03}{1,04} = 0.990384615$

This choice reflect the way the different items in the LCCA will decrease or increase comparing to the cost of money.

3 SYSTEM LIMITATIONS

Sweden has a very well organized system of archives spread all over the country, in which lots of data concerning investments, technical reports, drawings are stored. Unfortunately, not the totality of the data are kept over the years, so that in many cases it was not possible to have the information on initial investment. Just for a few bridges (in the regions analyzed, Norrbotten and Västerbotten) it was possible to find this information. Another kind of information that was almost impossible to find has been the 'TBb' document, in which is registered the technical service life of the bridge. It was possible to suppose the service life according to the internal regulations of Vägverket [Ditrani, 2009].

4 RESULTS

4.1 Comparative LCCA of Bridges in Norrbottens and Västerbottens Län.

Table 2. List of the bridges analyzed sorted by type

n°	type n°	Construction Type	Material	Code (BaTMan)
1	I	Beam and Slab Bridge (balkbro fritt upplagd)	Steel	24-1790-1
2	II	Slab Bridge (Plattbro)	Concrete	24-1861-1
3		Slab Bridge (Plattbro fritt upplagd)	Concrete	24-1497-1
4		Plattbro fritt upplagd	Concrete	24-1753-1
5		Plattbro fritt upplagd	Concrete	24-1876-1
6	III	Slab Frame Bridge (Plattram 2-leds)	Concrete	24-417-1
7		Slab Frame Bridge (Plattram 2-leds)	Concrete	24-471-1
8		Slab Frame Bridge (Plattram 2-leds)	Concrete	25-1432-1
9		Slab Frame Bridge (Plattram 2-leds)	Concrete	25-1674-1
10		Slab Frame Bridge (Plattram 2-leds)	Concrete	25-1888-1
11		Slab Frame Bridge (Plattram 2-leds)	Concrete	25-780-1

Table 3. Comparison of the results obtained from the LCCA of bridges in Norrbotten and Västerbotten

	PV 2009 [SEK]							
				Impact of different cost items on total LCC				
N°	***Bridge code***	***Total LCC***	***Annuity Cost***	***Initial investment***	***MR&R***	***User costs***	***Planning & design***	***Dismantle***
1	24-1790-1	8 629 534	11 752	6 787 171 (78,7 %)	1 137 440 (13,2 %)	446 316 (5,2 %)	112 357 (1,3 %)	146 250 (1,7 %)
2	24-1861-1	4 989 279	6 777	4 201 102 (84,4 %)	498 110 (10 %)	28 443 (0,6 %)	110 196 (2,2 %)	151 427 (3 %)
3	24-1497-1	5 204 830	12 033	3 872 389 (74,4 %)	671 110 (12,9 %)	301 823 (5,8 %)	144 621 (2,8 %)	214 888 (4,1 %)
4	24-1753-1	9 628 595	11 712	4 892 634 (50,8 %)	624 851 (6,5 %)	3 733 373 (38,8 %)	116 806 (1,2 %)	260 931 (2,7 %)
5	24-1876-1	19 951 560	27 170	9 439 589 (47,3 %)	800 880 (4 %)	9 319 372 (46,7 %)	108 077 (0,5 %)	283 642 (1,4 %)
6	24-417-1	6 705 193	20 371	3 063 579 (45,7)	931 728 (13,9 %)	2 220 913 (33,1 %)	165 677 (2,5 %)	323 296 (4,8 %)
7	24-471-1	6 908 271	15 971	5 687 805 (82,3 %)	566 062 (8,2 %)	115 171 (1,7 %)	153 291 (2,2 %)	385 937 (5,6 %)
8	25-1432-1	5 528 032	12 643	3 661 878 (66,2 %)	784 242 (14,2 %)	735 164 (13,3 %)	168 926 (3,1 %)	177 822 (3,2 %)
9	25-1674-1	8 135 651	30 361	5 149 139 (63,3 %)	861 204 (10,6 %)	1 758 818 (21,6 %)	144 621 (1,8 %)	221 869 (2,7 %)
10	25-1888-1	16 869 118	38 999	11 005137 (65,2 %)	639 842 (3,8 %)	4 873 428 (28,9 %)	114 560 (0,7 %)	236 151 (1,4 %)
11	25-780-1	4 005 242	9 260	2 490 693 (62,2 %)	450 142 (11,2 %)	597 090 (14,9 %)	150 348 (3,8 %)	316 968 (7,9 %)

The first thing we can notice is that the most cost-efficient bridge, at a first sight, is the number 2, a slab bridge followed by the number 11, a slab frame bridge. For what concern the bridge number 2, the reason this bridge is so cost-efficient is why it is subjected to the smallest traffic volume among all the bridges analyzed. On the other hand, the bridge number 11, with an annuity cost of 9 260 SEK has the smallest initial investment among the totality of the bridges included in the analysis. Initial investment is, in more of the cases, the factor that most influence the final total life cycle cost of a bridge. As it can be seen from the table, bridges with high initial investment results to have high life cycle costs. The second factor that influence the final total cost, in order of importance, is the cost for users. In many cases it is higher than the cost for the maintenance itself, that is one of the causes of this cost. The main factor that influence this cost item is the location of the bridge; but it is important to notice that also in areas like the northern regions, poorly populated, user costs are in many cases pretty influent. Another important factor that influence the annuity cost is the service life of the bridge. In the histogram below we can notice the influence of service life on the annuity cost for the different bridges analyzed. In general, for service life longer than 100 years, the annuity cost decrease consistently [Ditrani, 2009].

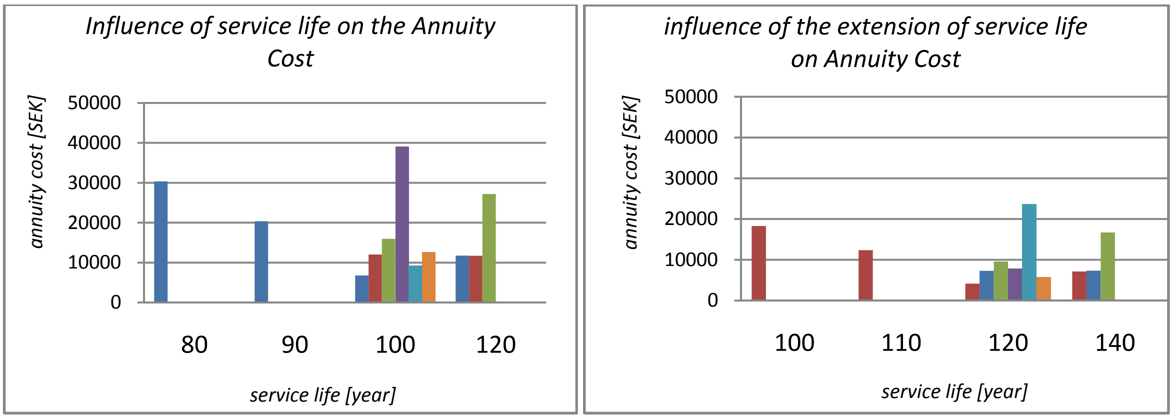

Figure 2. Influence of service life on annuity cost

When an operation that can extend the service life of the bridge is planned in the Life Cycle Cost Analysis, the annuity cost decrease in each of the studied cases between the 38,3 % and the 39,3 %.

The Life Cycle Cost is not decreased, but it is grown instead, to take into consideration the operation of strengthening (the most common to extend the service life of a bridge) but this decrease in the annuity cost mean that it is possible to save around the 38 % of the whole cost, because the total life cycle cost is spread on a longer service life.

The histogram above (on the right) shows the influence of this extension of the service life on the annuity cost [Ditrani, 2009].

4.2 Perspectives of Soil-Steel and Timber Bridges

Among the Soil-Steel Bridges, the ones that allow longer spans are the SuperCor bridges. SuperCor have a bigger corrugation than the others soil-steel bridges that allow spans up to 25 meters; this is the reason why only this kind of Soil-Steel Bridge is considered into the analysis.

Because this time the analysis is more general, where all the data are taken from Swedish based companies, it has been chosen to consider three different scenarios of traffic: the initial data (traffic in 2009) has been arbitrary chosen, according to the reality of the area, then the first scenario reflect the forecast for the Stockholm region, the second one for the Norrbotten region and the third one for the Västerbotten region.

The results concerning the analysis of the perspectives of Timber and SuperCor bridges are summarized below:

Table 4. Comparison of the results from the LCCA of SuperCor and Timber Bridges

PV 2009						
[SEK]	**Scenario 1**		**Scenario 2**		**Scenario 3**	
	SuperCor	Timber	SuperCor	Timber	SuperCor	Timber
Total LCC	4 324 438	4 705 779	2 274 364	2 657 317	2 175 468	2 485 054
Annuity Cost	16 696	18 946	9 097	10 698	8 750	10 005
Impact of the cost items on the total LCC						
Initial investment	1 379 000 (31,9 %)	1 925 000 (40,9 %)	1 379 000 (60,6 %)	1 925 000 (72,4 %)	1 379 000 (63,4 %)	1 925 000 (77,5%)
Planning&design	100 000 (2,3 %)	100 000 (2,1 %)	100 000 (4,4 %)	100 000 (3,8 %)	100 000 (4,6 %)	100 000 (4 %)
MR&R	641 052 (14,8 %)	257 253 (5,5 %)	641 052 (28,1 %)	257 253 (9,7 %)	641 052 (29,5)	257 253 (10,4 %)
User costs	2 169 762 (50,2 %)	2 261 949 (48,1 %)	119 688 (5,3%)	213 487 (8 %)	20 792 (1%)	41 225 (1,7 %)
Dismantle	34 624 (0,8 %)	161 577 (3,4 %)	34 624 (1,5 %)	161 577 (6,1 %)	34 624 (1,6 %)	161 577 (6,5 %)

For every scenario studied the annuity cost of SuperCor is smaller than the one of Timber Bridge, because of the constant difference in the initial investment. Furthermore, the difference between the expenditures related to the user costs in SuperCor and Timber Bridges increase by the decreasing of traffic volumes [Ditrani, 2009].

5 CONCLUSIONS

The results of this project show that the cost efficiency of a bridge does not depend on the type of the bridge in general (histogram below). Instead it varies from site to site.

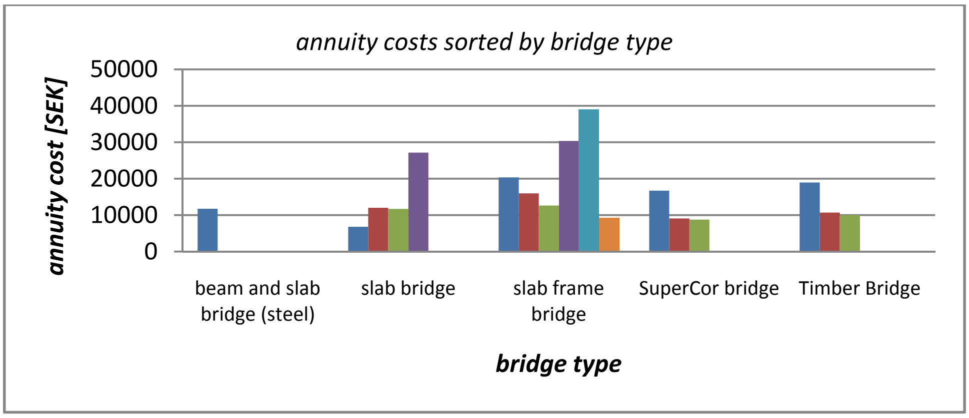

Figure 4. Annuity Cost sorted by bridge type

Considering the impact of the different cost items, the most influent parameters on the Life Cycle Cost are initial investment and user costs. The methodology adopted and the results show that a different approach can be considered in the planning and design stage. When deciding which bridge type is considered and which design strategy has to be followed, that strategy should take into account the scope of the design: for example decrease user disturbance through optimal choices of design variables (such as concrete cover or properties of materials) in areas with big traffic volumes or to allow higher disturbances for users in areas where the smaller traffic volumes causing lower initial investments. It should be noticed the importance to preserve the life standards that people are used to, otherwise seemingly cost-efficient choices could increase inequalities in the society which may lead to social tension.

Furthermore, the importance of the service life in the Life Cycle Cost is highlighted in the Figure 2. If a strengthening is performed, extending the service life of 20 years, this will end up in savings estimated to around 38 % of the Annuity Cost. If we consider just the eleven bridges analyzed in this paper, the cost saving would be around 2 million Euro.

A further conclusion may be drawn about the way the analysis should be performed. An improvement in this work has been done using different ‘V’ parameters, to take into account the different ways different goods grow. Analyzing the user costs, the way the traffic volume change over the years is considered by using historical data, but also using results from a National Traffic Model. The linear extrapolation for the past and the future is used [Ditrani, 2009].

6 FUTURE DEVELOPMENTS

Based on the results and methodology adopted, some developments may be proposed.

- The improvement of mathematical models that describe traffic, interest and inflation forecasts will be fundamental to get more reliable results;
- Extend and update use of databases to collect information on initial investments, operation of MR&R, and time and costs related to.
- Increase the number and sites of traffic surveys: they give valuable information when the tendency of the traffic volume is needed over the years.
- Include in the Life-Cycle Cost Analysis the reliability of companies as parameter when choosing between different alternatives. The reliability of the information the companies give to the project leader is of fundamental importance; information could be too optimistic and the consequent choice of the project alternative will result in an uneconomic decision.
- Finally, complete and user friendly software that includes all of these different aspects and developments of the Life-Cycle Cost Analysis would be a necessary tool to estimate the costs.

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