LCCA of the Huvudnäskanalen Railway Bridge

Should this Bridge be Repaired or Replaced?!

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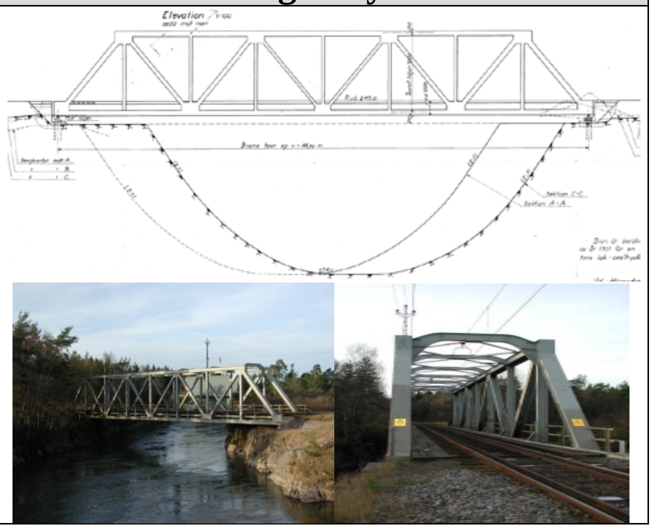
EXISTING BRIDGE

General

On some occasions, the choice has to be made between two or more strategies to upkeep a specific bridge. Huvudnäskanalen Bridge in Sweden was constructed in 1937. The bridge is a simply supported steel truss railway bridge, shown in Table 1. The bridge total length is 47 m and total width is 5.7 m. In to BaTMan, this bridge has a number of [3500-2593-1]. The superstructure, bearings and the electrical cable tray of this bridge are assigned a condition class TK 3. According to BaTMan inspection manual, condition class TK 3 means that an immediate action has to be taken. Few strategies are available to upkeep this bridge. A life-cycle cost analysis comparison will be presented to see if this bridge should be repaired or replaced.

Table 1 Bridge layout and general information

Bridge General Information	Bridge Layout
Konstruktionsnamn: Bro över Huvudnäskanalen km 29+709 Konstruktionsnummer: 3500-2593-1 Konstruktionstyp: Stål Balkbro fackverk fritt upplagd Nybyggnadsår: 1937 Konstruktionslängd= 47 m Konstruktionsbredd= 5.7 m Konstruktionsyta= 268 m^2 Water depth in the in the mid: 12m Superstructure depth restrictions <1.8 m	

Repair Strategy

The choice stands between immediately repairing the bridge or utilizing its residual service life without action then replace the entire bridge, respectively shown in Figure 1and Figure 2.

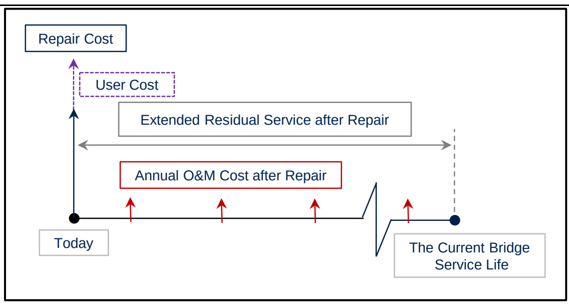


Figure 1 Strategy (A): Immediately repair the bridge

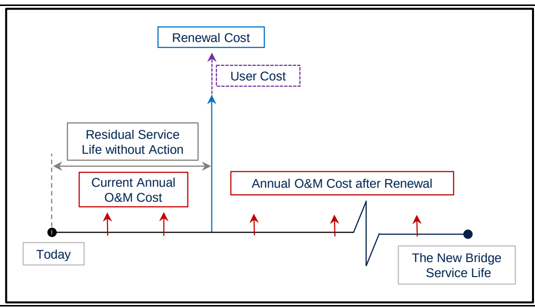


Figure 2 Strategy (B): Utilizing the bridge residual service life without action and then renew it

Using 2012 updated bridge repair actions price list in BaTMan, it was estimated that the repair strategy will cost 2.23 Million SEK, shown in Table 2 . Considering a statistical treatment of an intensive historical data extracted from BaTMan related to similar actions performed on similar bridges, the bridge after implementing this repair strategy is expected to at least stand for 25 years with normal maintenance. Today, the bridge is 76 years old. There are several typical existing bridges having an age of more than 120 years and they are still on service. Therefore, the repair strategy can at least extend the bridge residual service life by 25 years.

Table 2 Repair strategy cost

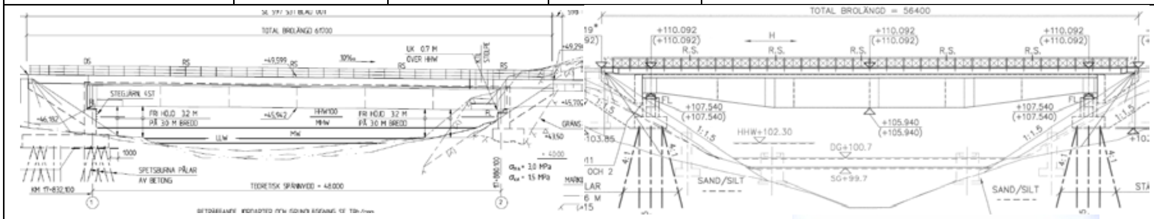
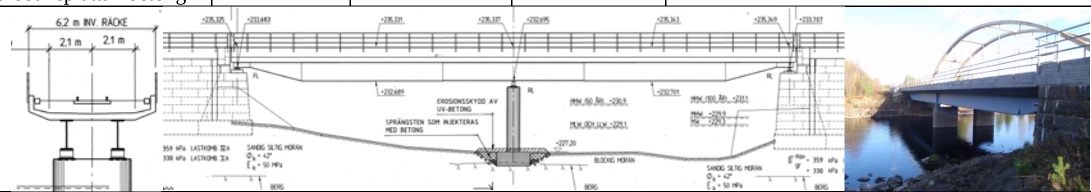
Activity	Quantity	Unit	Cost SEK/unit	Sub-Total (SEK)
Repaint the entire bridge superstructure	940	M^2	1,700	159,8000
Replace the bridge bearings	4	St.	33,000	132,000
Repair and fix all secondary damages				250,000
Overhead and Mobilization				250,000
Total				2,230,000

Replacement Strategy

Currently, although the BaTMan inventory data is accessible by Webhybris, the decision makers at Trafikverekt do not effectively benefit from it. Using Webhybris toll, historical data related to similar existing bridges have been extracted from BaTMan. Considering a deep classification and analysis of the extracted data, 4 replacement proposals are considered technically feasible, presented in Table 3.

Table 3 Technically feasible Replacement options

No.	Bridge type and construction material	Anticipated INV cost SEK/m^2	Anticipated INV cost Million SEK	Similar bridge No.	Remarks
1	Två span Balkbro/Plattbro kontinuerlig, Betong spännarmerad	36,000	10.7	**3500-1522-1** **3500-2048-1** **3500-4810-1** **3500-4391-1** **3500-5909-1*** **3500-5757-1*** **17-1271-1*** **3500-5776-1**	Is it possible to have an intermidiat support? Water depth is about 12 m. 3500-4834-1 is one span concret bridge with a span of 36.5m the depth for a span of 47m can be 3.6m 3500-5776-1 is plattbro with 2m depth
					

No.	Bridge type and construction material	Anticipated INV cost SEK/m^2	Anticipated INV cost Million SEK	Similar bridge No.	Remarks
2	Balkbro fritt upplagd, Stål i samverkan med brobaneplatta i betong	72,000	20.3	**3500-1517-1** **3500-5288-1** **3500-5703-1*** **3500-1925-1** **3500-5338-1** **3500-575-1**	3500-1517-1 is a typical bridge! Need superstructure depth =3.8 m, is it possible to decrease the free hight?
	 				
3	Två span Balkbro kontinuerlig, Stål i samverkan med brobaneplatta i betong	48,000	13.9	**3500-1588-1**	Need superstructure Depth of 2.2 m? Intermidiat support?
					
4	Två span Balkbro kontinuerlig, Stål med brobaneplatta i stål/av trä	34,000	10.1	**3500-3451-1**	Need superstructure Depth of 2 m? Intermidiat support?
					

The bridge number that has a * symbol indicates that the initial investment (INV) cost SEK/m^2 of this bridge has been used to anticipated the INV cost of a new similar bridge. Option (2) in Table 3 might be technically infeasible because this structure type with a 47m span needs a minimum superstructure depth of 3.8m which could not be achieved in the bridge location due to the limited free height.

LIFE-CYCLE COST ANALYSIS (LCCA)

The analysis was conducted in two steps. The first step is to optimize between the available replacement options. The second step is to optimize between the most LCC-effective replacement proposal and the repair strategy.

Replacement Options Optimization

Considering the proposals' data given in Table 3, the LCCA was conducted. Only the bridge initial cost and the annual operation and maintenance (O&M) cost were included in analysis. 100 years as a design life-span have been assigned for all the proposals. The LCCA showed that, proposal (1) is associated with the least net present value as it doesn't need to be painted regularly and it is also associated with a low INV cost. Therefore, proposal (1) has been chosen as the most LCC-effective replacement option. The train passage will not be affected during replacement as the new bridge will be built beside the existing one and after construction completion the rail will be direct to the new bridge within a short time and then the existing bridge will be demolished if necessary.

Replacement or Repair Optimization

In this step, an optimization process will be conducted to compare the repair strategy (A) with proposal (1) as the replacement strategy (B). Table 4 presents the strategies' specifications. Figure 1 and Figure 2 present the cash flow of the repair strategy (A) and the replacement strategy (B) respectively.

Table 4 Bridge repair and replacement strategy's data

<table>
<tr><th>Strategies Input Data</th><th>Strategy (A)</th><th colspan="2">Strategy (B)</th></tr>
<tr><td>Strategies description</td><td>Immediate repair</td><td colspan="2">Utilizing the bridge residual service life without action and then replace it by proposal (1)</td></tr>
<tr><td>Residual service life without action, (Years)</td><td colspan="3">Zero</td></tr>
<tr><td>Discount rate</td><td colspan="3">4.0%</td></tr>
<tr><td>Anticipated service life after an action (Year)</td><td>25</td><td colspan="2">100</td></tr>
<tr><td>Strategy initial cost (SEK)</td><td>2,230,000</td><td colspan="2">10,700,000</td></tr>
<tr><td rowspan="2">Annual O&M cost (SEK)</td><td rowspan="2">7,000</td><td>During the current bridge residual service life</td><td>After the bridge replacement</td></tr>
<tr><td>8,500</td><td>5,000</td></tr>
</table>

Special technique will be used during the bridge repair in strategy (A) that will not affect the train pass. The LCC analysis was conducted based on the given strategies' specifications on Table 4.

As shown in Table 5, the NPV of strategy (A) is less than (B). However, this does not mean that strategy (A) is the most cost-effective, simply because the strategies have unequal life-span. Therefore, the equivalent annual cost (EAC) was calculated for each strategy, shown in Table 5. The EAC of strategy (A) is also less than (B). Consequently, strategy (A) is the most LCC-effective strategy. The Net Saving (NS) in case of implementing strategy (A) is equal to 4.56 Million SEK/25 years or 291,899 SEK/year for a life span equals to 25 years. If the bridge is replaced instead of repairing it by strategy (A), the Opportunity Loss (OL) will be equal to 7.153 Million SEK/100 years or 291,899 SEK/year for a life span equals to 100 years.

Table 5 Life-Cycle cost analysis (LCCA) results

	Strategy (A)	Strategy (B)
Total Net Present Value (SEK)	2,339,355	10,822,525
Total Equivalent Annual Cost (SEK)	149,747	441,646

Sensitivity Analysis

By performing sensitivity analysis to study the impact of varying the discount rate (*r*) from zero to 2*r*, shown in Figure 3, strategy (A) remains the most LCC-effective strategy regardless of the discount rate variation. Therefore, in this case, the discount rate does not have any considerable impact on the final decision.

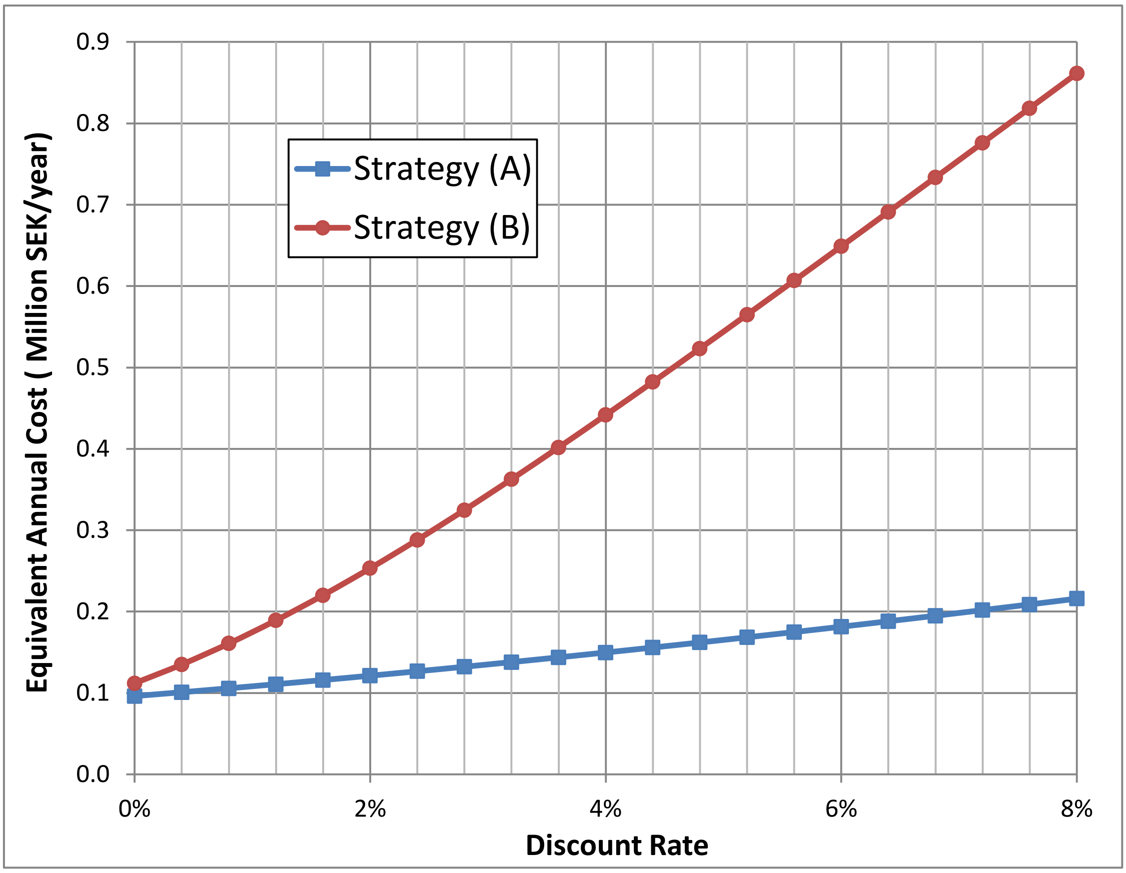


Figure 3 the discount rate's variation impact on final decision

At 4% discount rate, repairing the bridge using strategy (A) remains the most LCC-effective solution as long as the replacement strategy INV cost is higher than 3.6 Million SEK instead of 10.7 Million SEK, shown in Figure 4.

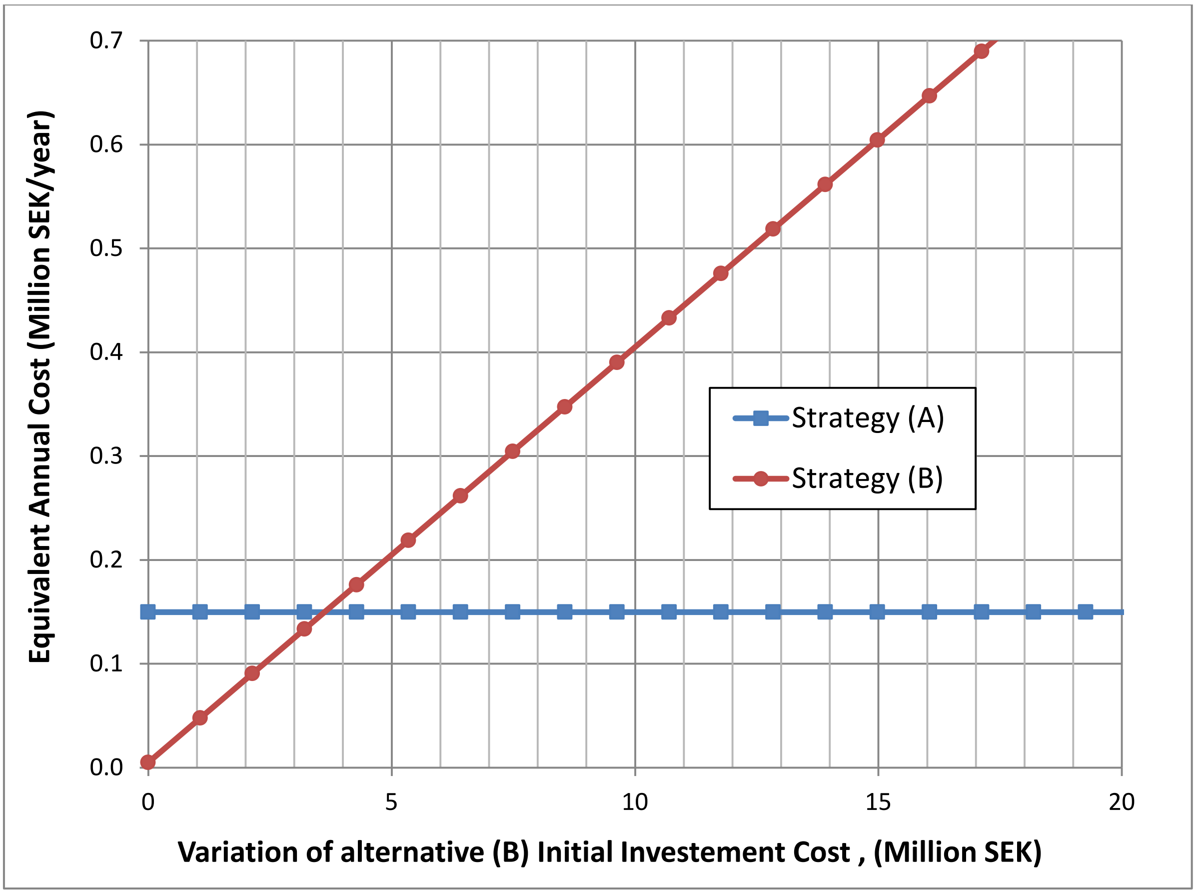


Figure 4 the impact of varying the replacement strategy anticipated INV cost on the final decision

At 4% discount rate, If the repair strategy can guarantee a service life extension of 25 years, it would be more LCC-effective to repair the bridge instead of replacing it as long as the repair strategy will cost less than 6.79 Million SEK.

It is not easy task to anticipate the long-term performance of the bridge or its individual structural members. The assessment of the service life extension after repair was assessed based on statistical treatment of an intensive historical data extracted from BaTMan related to similar actions performed on similar bridges. Therefore, the bridge service life extension after implementing the repair strategy is subjected to uncertainties in the assessment. The impact of this uncertainty on the final decision was studied and presented in Figure 5. Strategy (A) more LCC-effective than strategy (B) as long as the repair strategy can guarantee a service life extension more than 6 years. This is absolutely possible according to the feedback from the statistical treatment of the related historical data. Therefore, this parameter, in this case, does not have that considerable impact on the final decision.

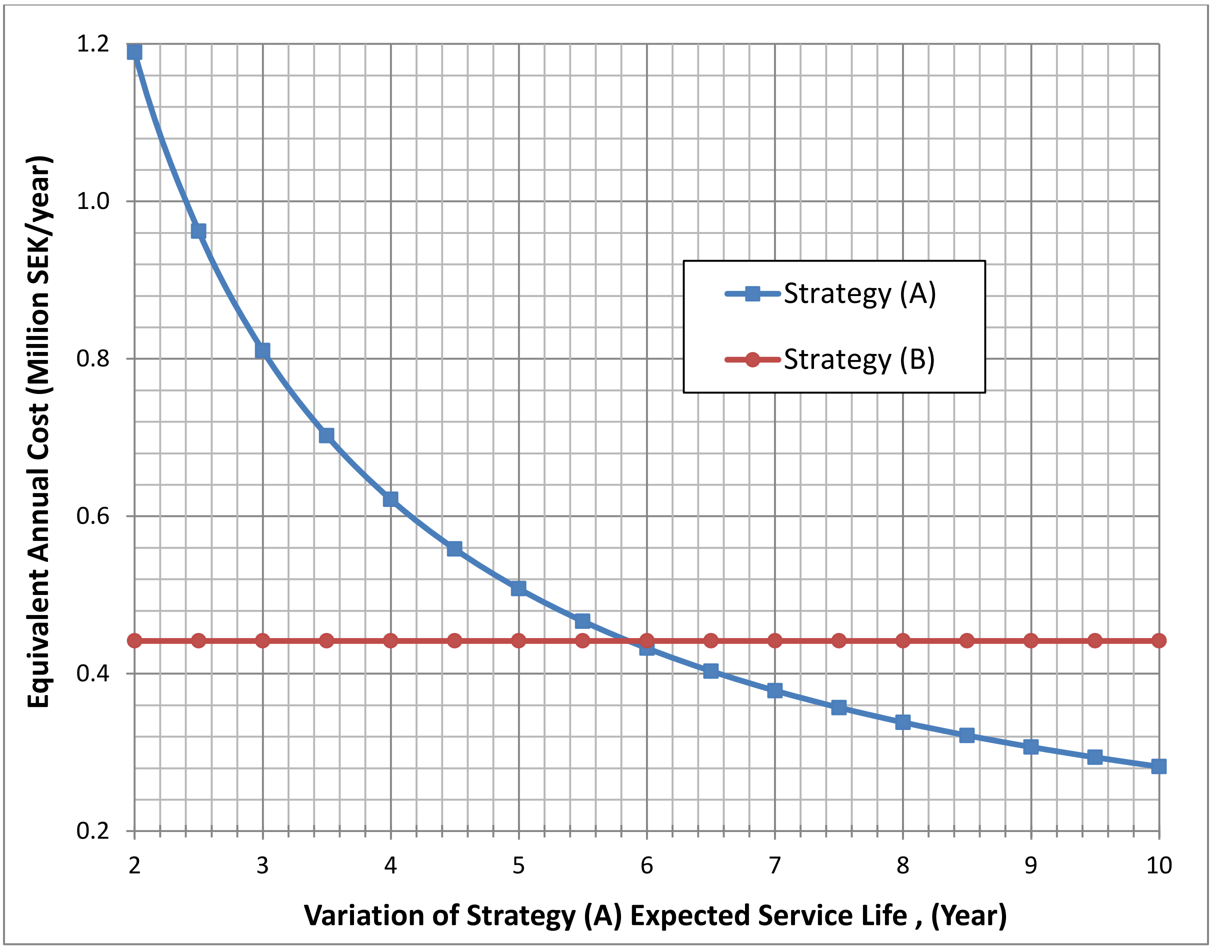


Figure 5 the impact of varying the bridge expected service life extension on the final decision

For the repair strategy (A) to be more LCC-effective than the replacement strategy (B), Figure 6 depicts the relationship between the maximum initial investment cost of the repair strategy (A) and the minimum required residual service life extension that has to be guaranteed after implementing this repair strategy. As it can be seen in Figure 6, if the repair strategy (A) costs 3.5 Million SEK, a residual service life extension of at least10 years has to be guaranteed in order for strategy (A) be more LCC-effective than the replacement strategy (B). It also can be said that, if the repair strategy (A) can guarantee a maximum residual service life extension of 10 years, the initial investment cost of repair strategy (A) should not exceed 3.5 Million SEK in order for the repair strategy (A) be more LCC-effective than the replacement strategy (B).

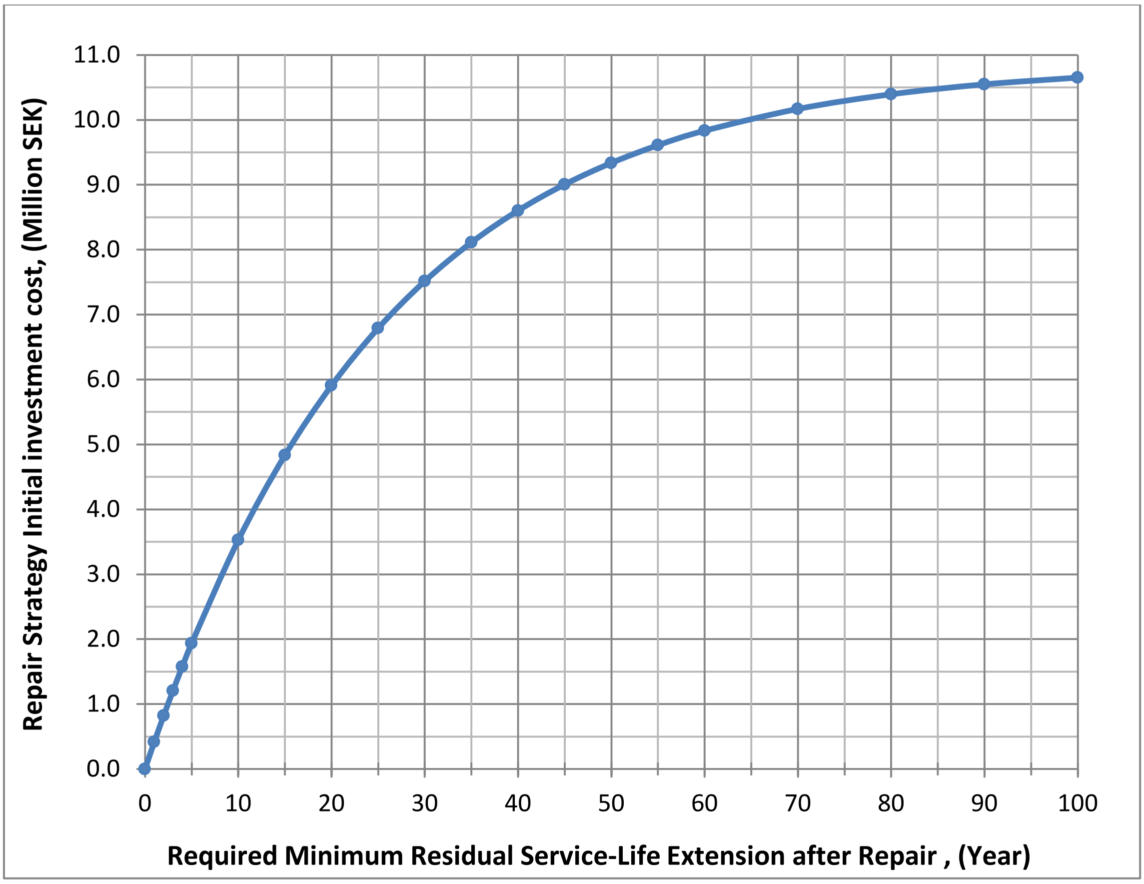


Figure 6 the relation between the repair strategy cost and the required minimum residual service life extension in order for the repair strategy to be more LCC-effective than the replacement strategy

The residual service life without action, presented in Table 4, is also subjected to uncertainty in the assessment. According to BaTMan's inspection manual, bridges with such deterioration have to be more frequently inspected. Even though important bridge structural members are assigned TK3, due to possible budget limitations, the bridge replacement might be postponed to the next year instead of this year and so on. A sensitivity analysis is conducted to study the impact of this uncertainty on the final decision. This sensitivity analysis presented in Figure 7 shows that, even if the replacement strategy could be postponed to 6 years instead of today, repairing the bridge today using strategy (A) remains more LCC-effective than replacing the bridge after 6 years using strategy (B).

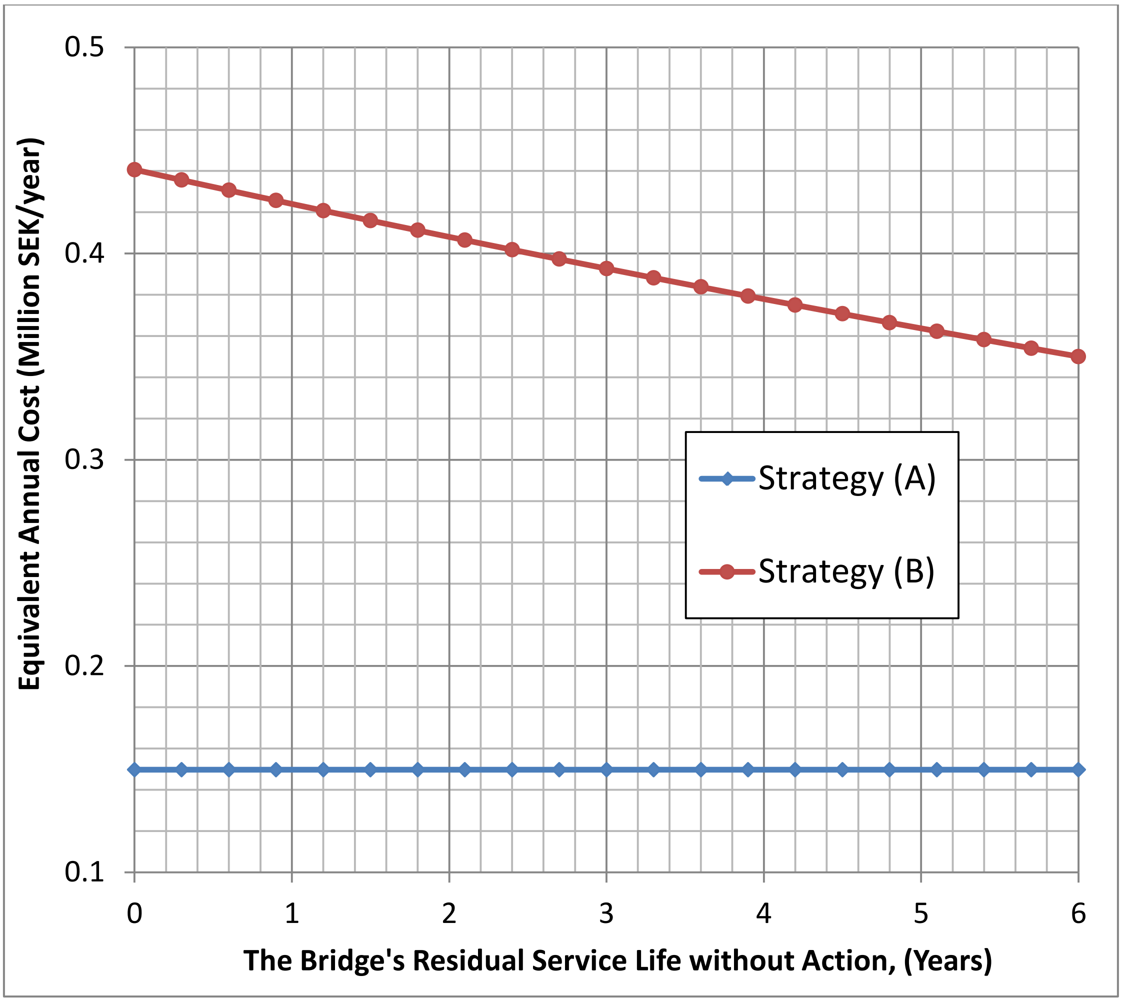


Figure 7 the impact of varying the bridge residual service life without action on the final decision

A new bridge like proposal (1) in Table 3 might stand for a service longer than 100 years that was assumed in Table 4 and used in the LCCA. In this respect, the replacement strategy might become more LCC-effective if a longer service life for a completely new bridge is assumed. The impact of this uncertainty on the final decision was also studied and presented in Figure 8. Tis figure shows that even if the service life of a new bridge is considered to be 200 years instead of 100 years, repairing the bridge using strategy (A) remains the more LCC-effective than replacing it using strategy (B) . Therefore, the new bridge anticipated service life does not have that considerable effect on the final decision.

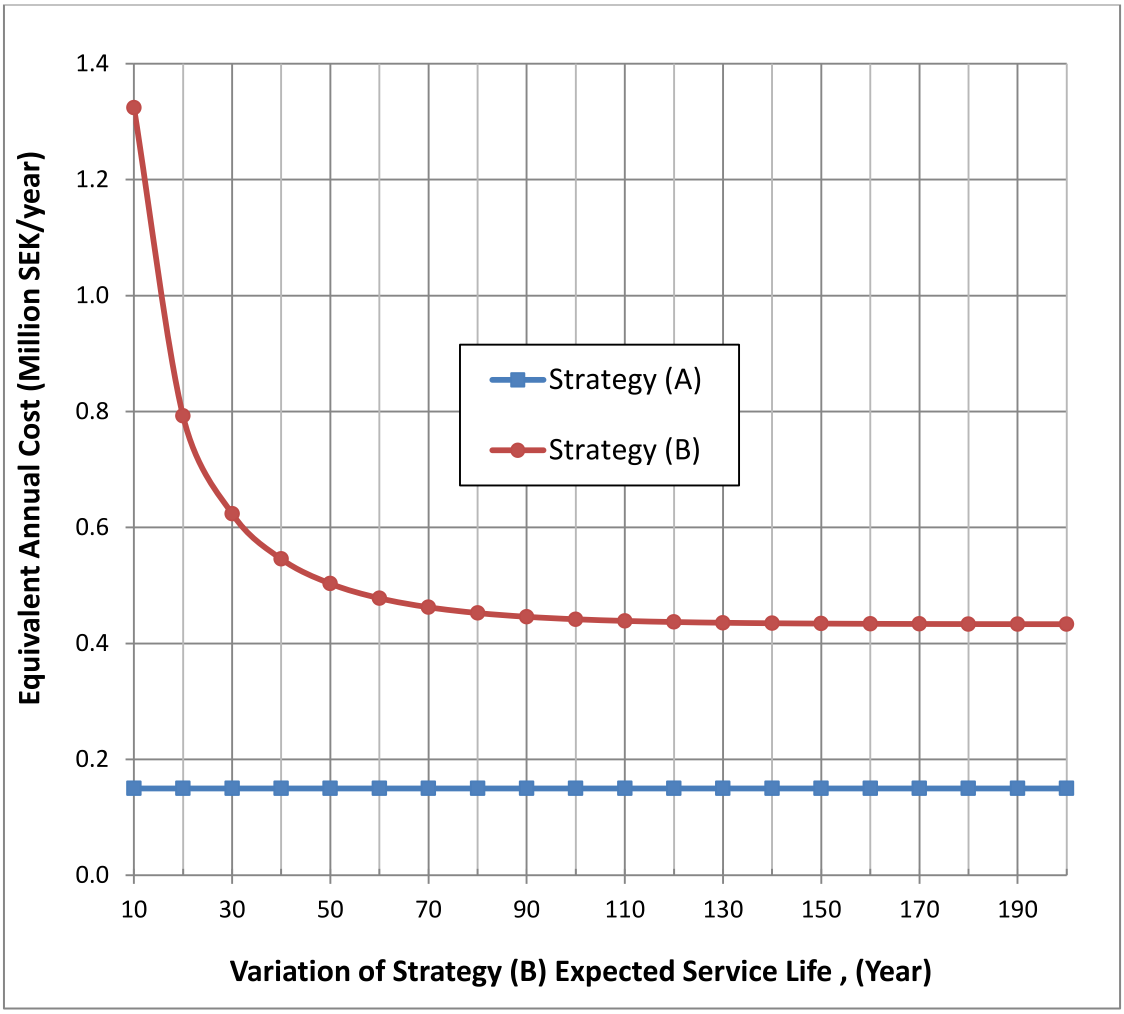


Figure 8 the impact of varying the service life of a new bridge on the final decision

CONCLUSION

According to the LCCA as well as the sensitivity analysis conducted for this case study, the bridge should absolutely not be replaced and instead should be repaired.

The presented LCCA results are based on a comparison between a repair strategy that costs 2.23 Million SEK and a replacement strategy that costs 10.7 Million SEK. A discount rate of 4 % was used in the LCCA. If repair strategy can guarantee a minimum residual service life extension of 6 years, it would be more LCC-effective to repair the bridge instead of replacing. If the repair strategy can guarantee a minimum residual service life extension of 25 years, as it is expected, it would be more LCC-effective to repair the bridge instead of replacing it even if the repair strategy will cost up to 6.79 Million SEK instead of 2.23 Million SEK. The replacement option should not be implemented until the initial investment cost of a new bridge becomes less than 3.6 Million SEK instead of 10.7 Million SEK.

The amount of money Trafikverket could save as Net Saving (NS) in case of repairing the bridge instead of replacing it will be equal to 4.56 Million SEK/25 years or 291,899 SEK/year for a life span equals to 25 years. If Trafikverket decided to replace the bridge instead of repairing it, Trafikverket would lose an amount of money equals to 7.153 Million SEK/100 years or 291,899 SEK/year for a life span equals to 100 years as an Opportunity Loss (OL).

Today, Trafikverekt is responsible for 400 railway bridges similar to the bridge presented in this study; older than 50 years and have conditions class TK3. The total area of these bridges 400 bridges is 60,500 m^2. The LCCA presented for the case study in this report showed that Trafikverket can save an average amount of money equivalents to 1,089 SEK/m^2/year. Assume that 50 % of these 400 bridges got a wrong decision; this means that Trafikverket might lose/can save an amount of money equivalents to 65 Million SEK/year for a life span of 25 years. Moreover, it also means that Trafikverket might lose/can save an amount of money equivalent to 1.64 Billion SEK within the coming 25 years.

Instead of optimize between repair and replace this bridge, a LCCA optimization should be conducted to specify the most LCC-effective repair strategy. In this respect, the initial investment cost as well as anticipated residual service life extension after implementing each of the repair strategies should be taken into account. In considering the renewal alternative, allowance should also be made for the benefits that might be afforded by a completely new bridge in view of routing, road safety, bearing capacity, traffic, etc. The historic value for some special old bridges should also be taken into account. These aspects are important to consider but are beyond the scope of this study.