LCC Applications for bridges and Integration with BMS

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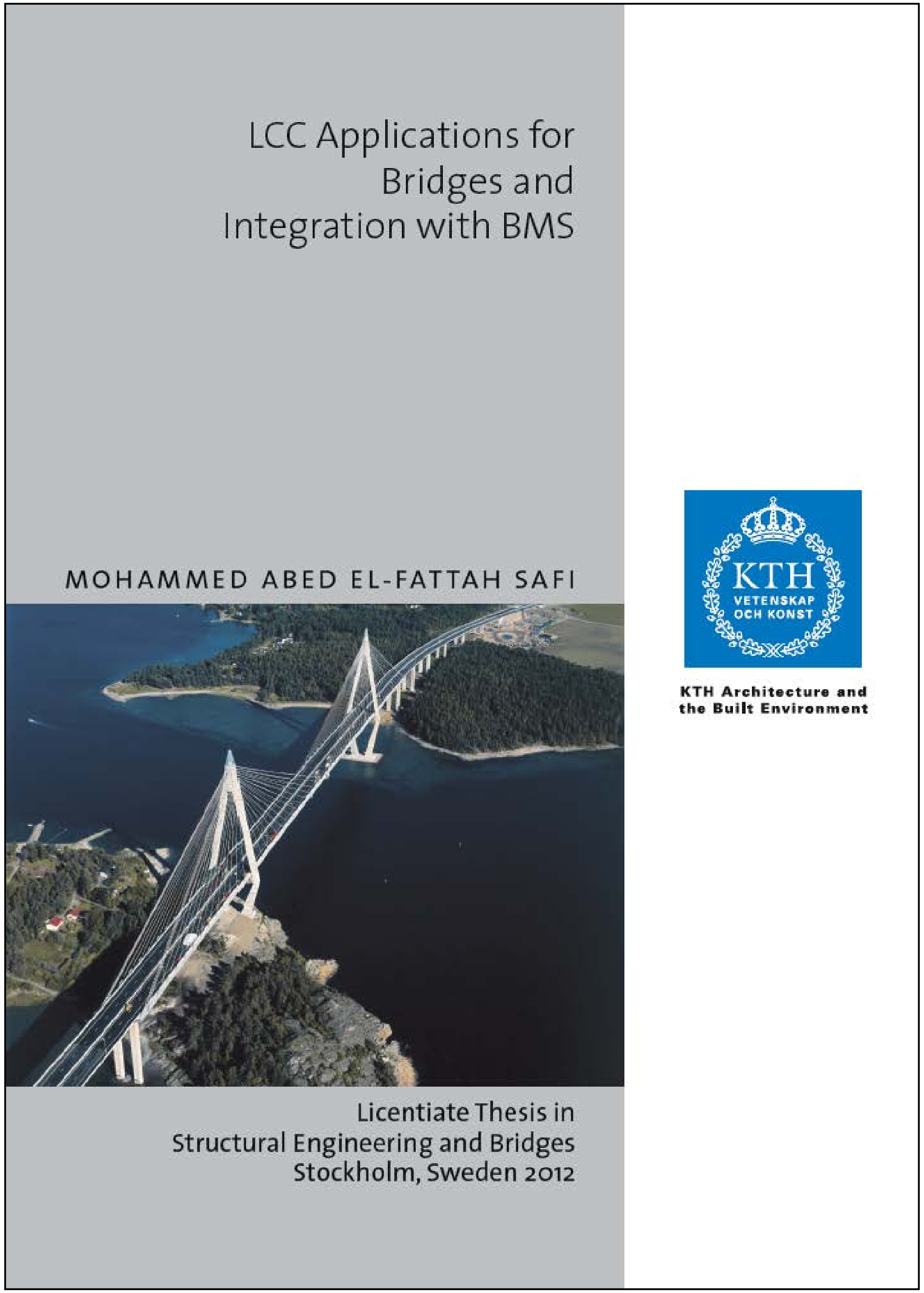
Thesis Structure

- Part I: Extended Summary

    1) Introduction
    2) The Swedish BMS
    3) Bridge Life-Cycle and the Possible LCC Applications
    4) LCC Analysis Tools and Techniques
    5) Case Studies
    6) BaTMan-LCC
    7) Conclusion

- Part II: Appended Papers



Publications

- **Appended Journal Papers**

1) Mohammed Safi, Håkan Sundquist, Raid Karoumi and George Racutanu, Development of the Swedish Bridge Management System by Upgrading and Expanding the Use of LCC, Accepted for publication in the *Structure and Infrastructure Engineering Journal,* UK.

2) Mohammed Safi, Håkan Sundquist, Raid Karoumi and George Racutanu, Life-Cycle Costing Applications for bridges and Integration with Bridge Management Systems, Case-Study of the Swedish Bridge and Tunnel Management System (BaTMan), Accepted for publication on the *Transportation Research Record (TRR): Journal of the Transportation Research Board (TRB),* USA.

3) Mohammed Safi, Håkan Sundquist and George Racutanu, Life-Cycle Costing Integration with Bridge Management Systems, Submitted to the *ICE-Bridge Engineering Journal,* UK.

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Introduction

- Generally, bridge investment and management decisions are multi-alternative-oriented.
- Although many bridge management systems (BMSs) contain some form of life-cycle costing (LCC), the use of LCC in bridge engineering is scarce.
- LCC in many BMSs has mainly been applied within the bridge operation phase to support decisions related to existing bridges.
- Even though BMSs and LCC are interrelated, many bridge management researches have treated them as separate aspects; therefore, neither may lead to the best usable decision-support tools.

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Aim and Scope

- The project aims at enhancing the bridge investment and management decisions by upgrading and expanding the use of LCC in the Swedish Bridge and Tunnel Management System (BaTMan). This licentiate thesis the first development step toward this aim:
  - ➢ Address the possible LCC applications for bridges
  - ➢ Supported with a detailed case study, demonstrate the LCC implementation on whether to ***repair or to replace a bridge, (Paper I and II).***
  - ➢ Supported with a detailed case study, demonstrate the LCC implementation on whether to ***repair or to replace a specific bridge structural member, (Paper III).***

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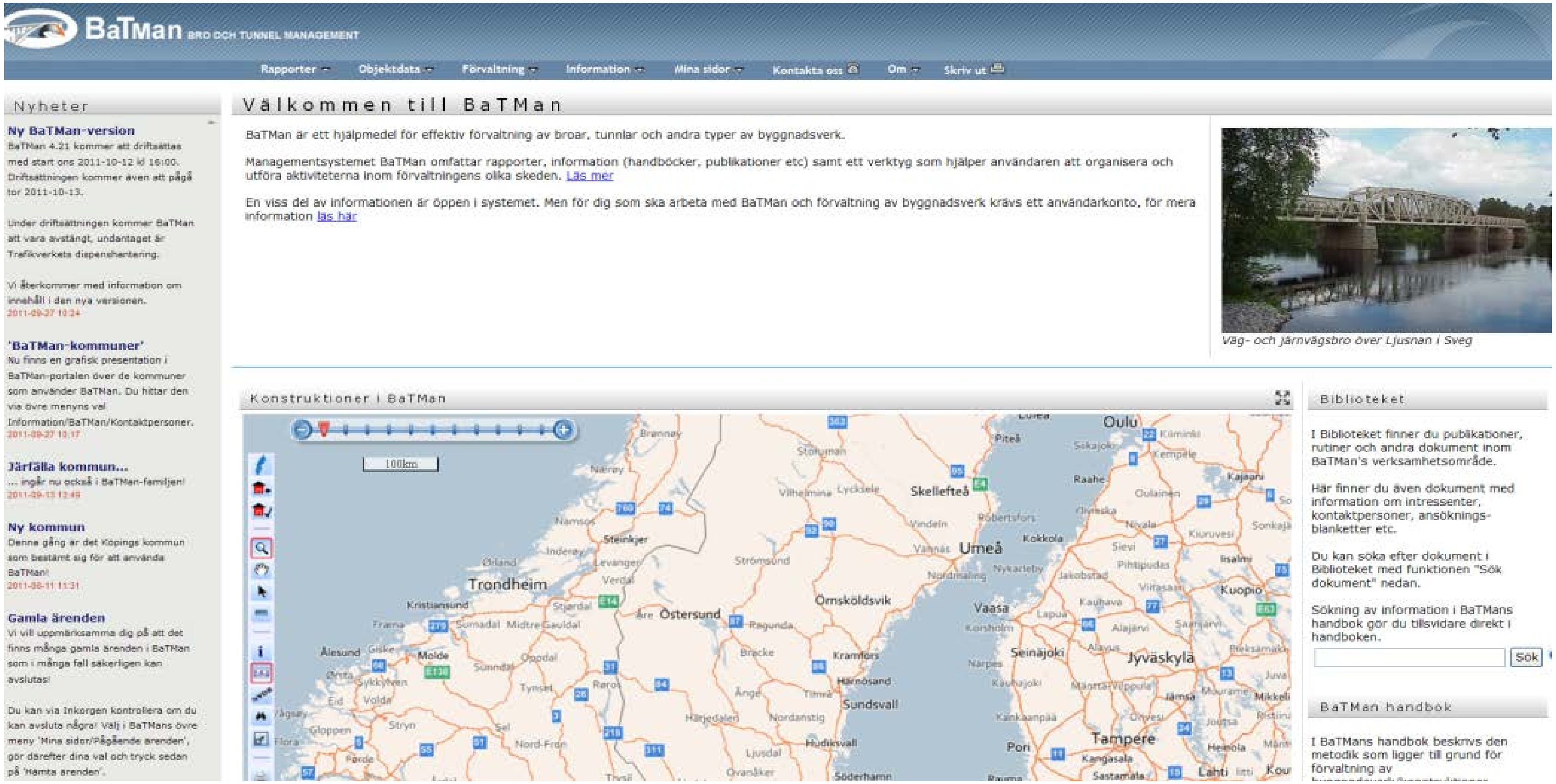
The Swedish Bridge and Tunnel Management System (BaTMan)



https://batman.vv.se/batman/

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BaTMan

- Sweden has a long tradition in bridge management. Since 1944, information about the condition of the national road network has been documented and stored in different archives.

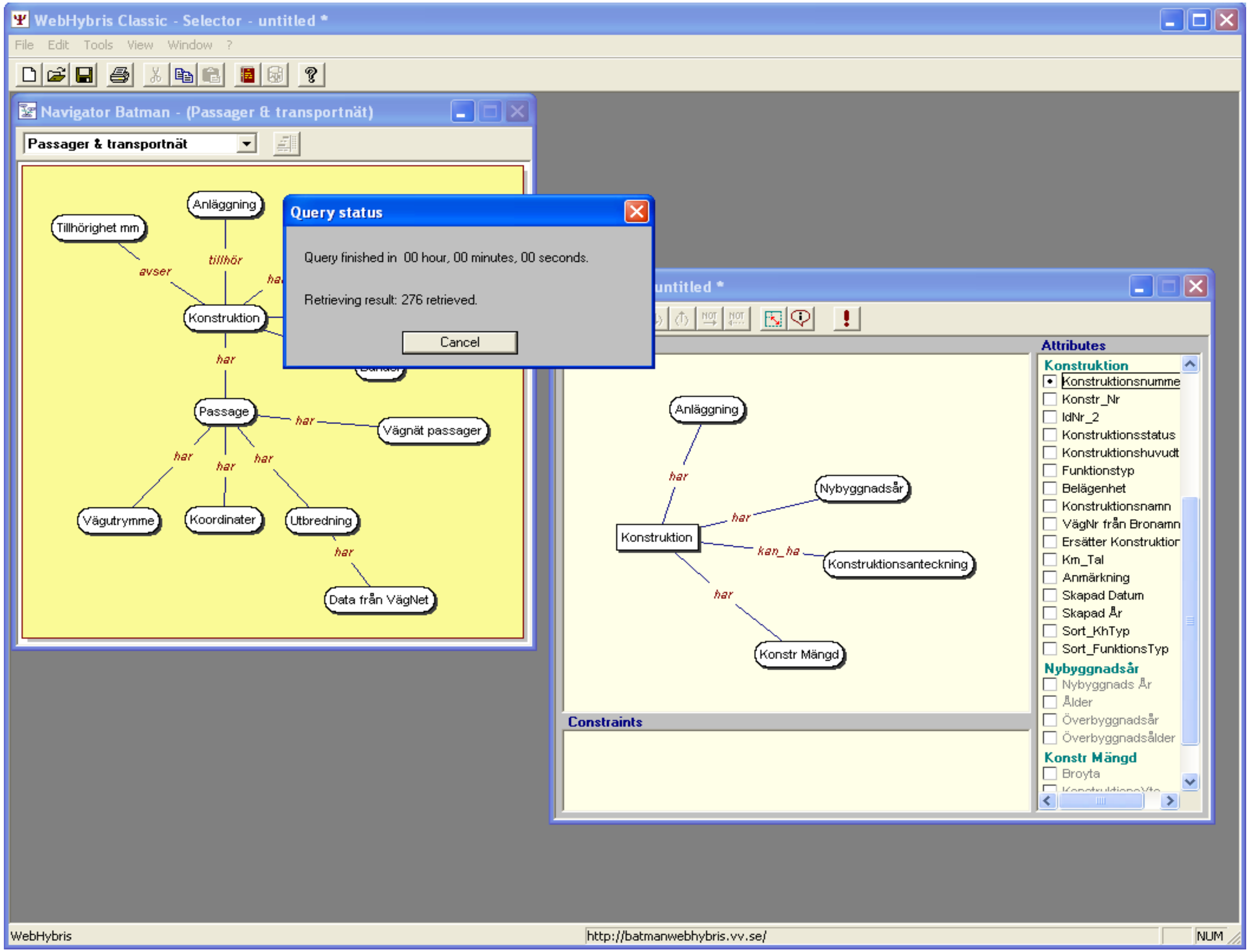
- The Swedish Transport Administration (Trafikverket) is the largest bridge manager in Sweden. The latest update of Trafikverket's BMS is called a Bridge and Tunnel Management system (BaTMan), which was introduced in 2004.

- BaTMan is recognized as the best-known software-based digital BMS in Europe.

- All information is given on repair, strengthening, and maintenance, including their costs.

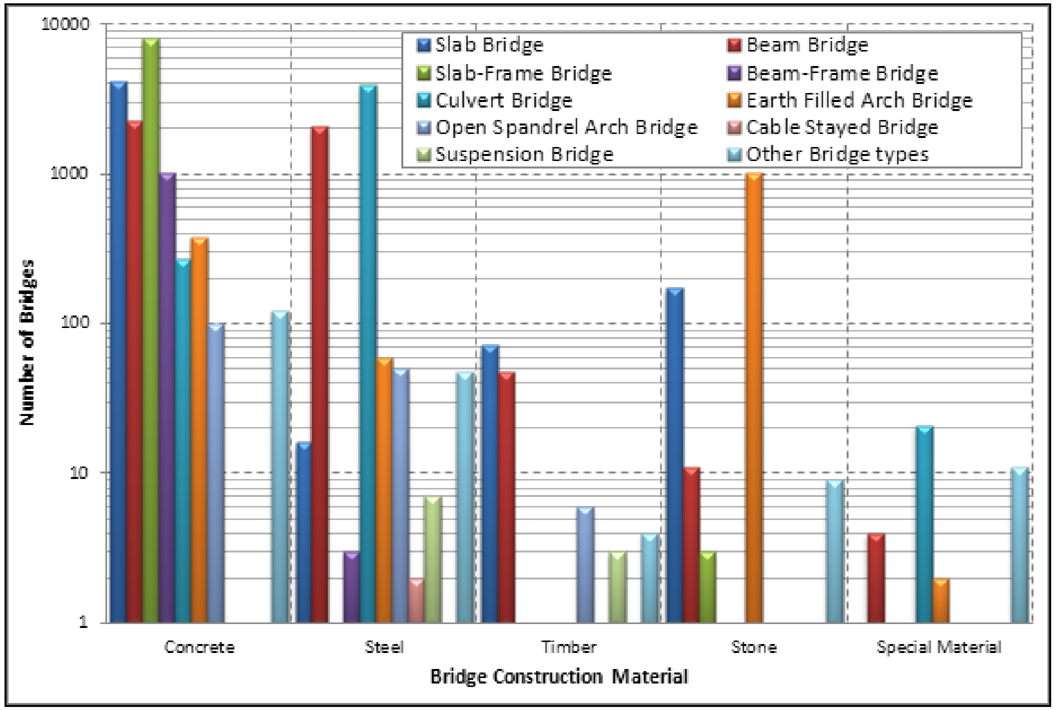
- Furthermore, the system consists of a separate navigation tool (WebHybris) that can access the BaTMan’s database and answer any related question for any research or management purposes.

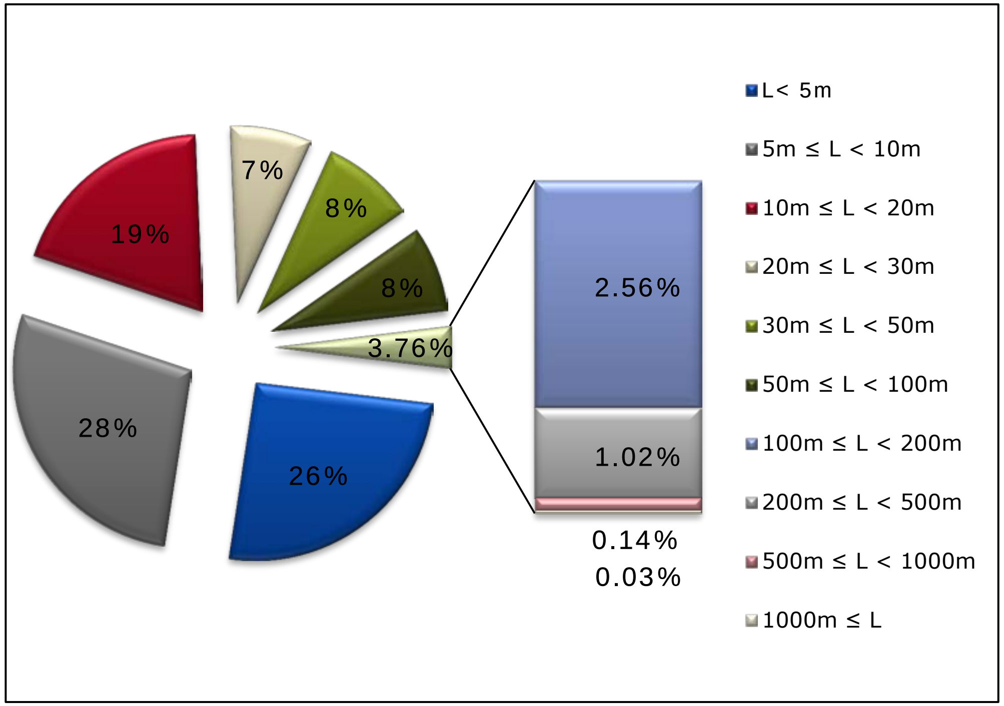
BaTMan Navigation Tool (WebHybris)



The Swedish Bridge Stock

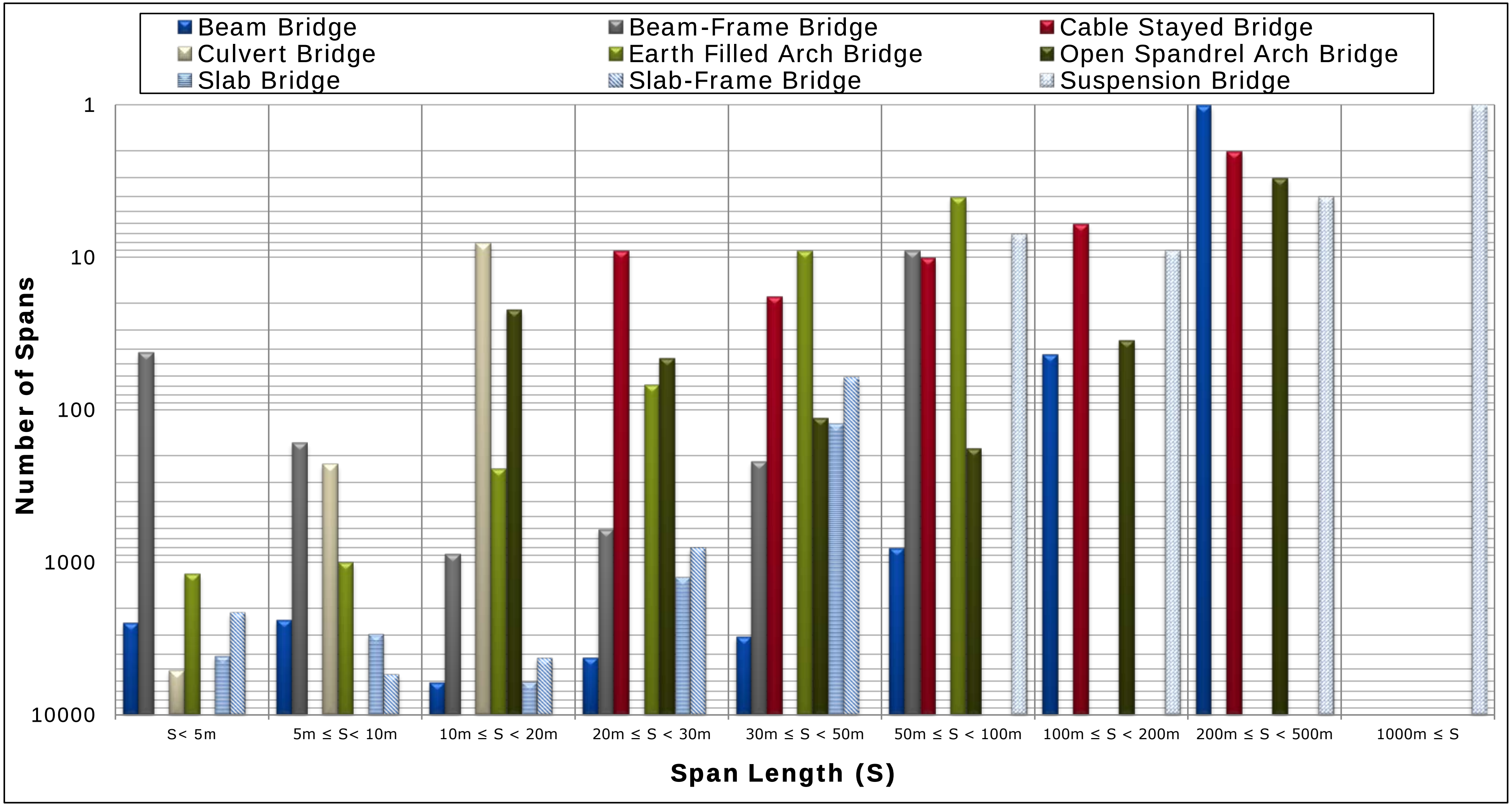
	Bridge Function Type				Total No. Of Bridges	Bridge Total Area (m^2)	Bridge Total Length (m)
	Roadway	Railway	Pedestrian & Bicycle	Other			
BaTMan's Bridges	23,848	4,411	1,619	251	**30,129**	7,644,208	668,381
Trafikverket's Bridges in BaTMan	20,050	3,179	207	14	**23,450**	5,858,570	528,905





The Swedish Bridge Stock

Based on 56,291 spans for 34,591 bridges



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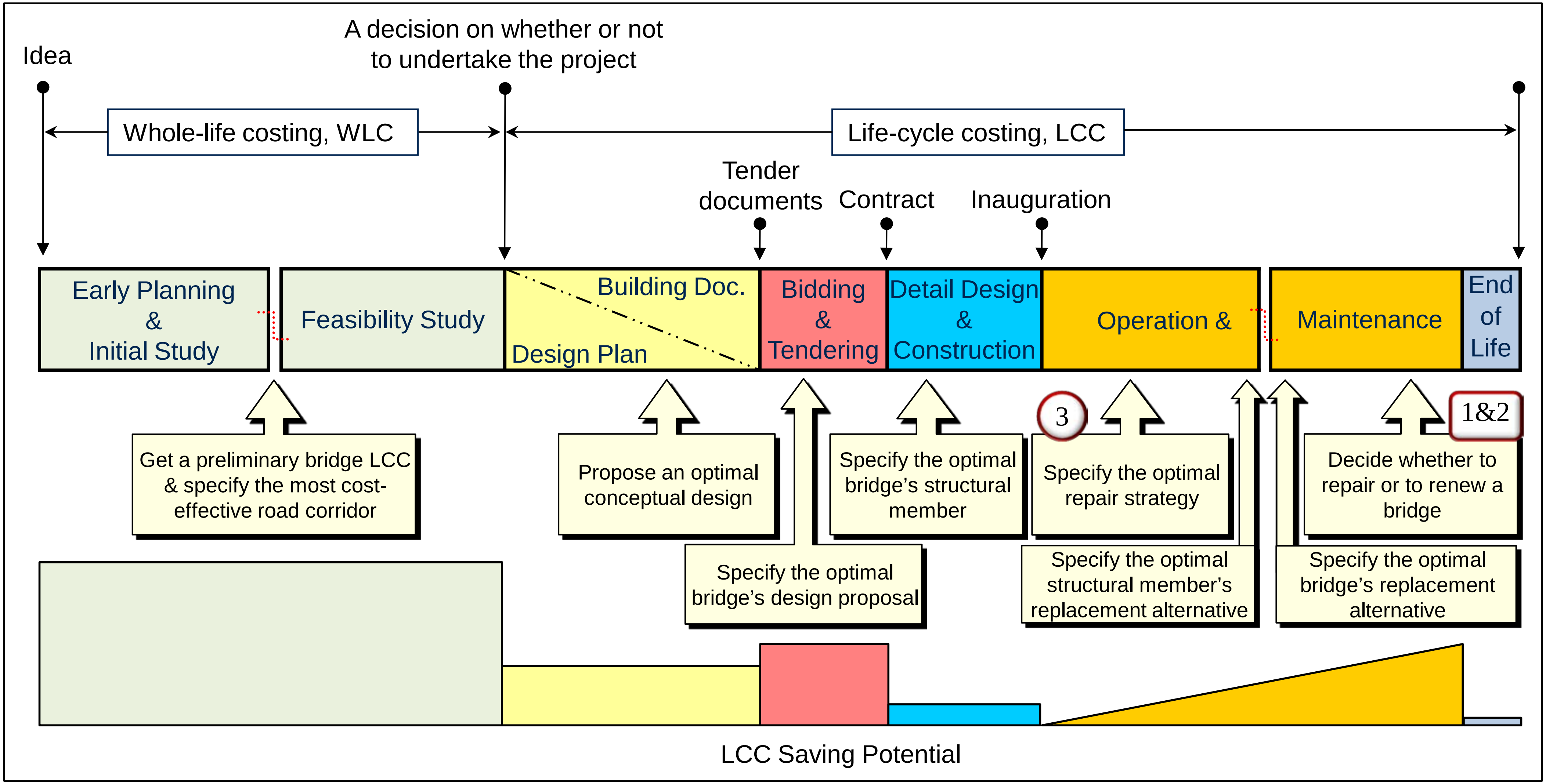
BaTMan’s Condition Class (CC) System

CC	Assessment	Description
3	Defective function	Immediate action is needed
2	Defective function within 3 years	Action has to be taken within 3 years period
1	Defective function within 10 years	Action has to be taken within 10 years period
0	Defective function beyond 10 years (No damage at time of inspection)	No action is needed within the coming 10 years

- ✓ The structural members functional conditions will automatically be converted to numerical values that can easily be used in the LCC analysis.

Comprehensive Integrated LCC Implementation Scheme



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LCC Analysis Tools

- Net Present Value Method (NPV):

$$NPV = \sum_{n=0}^{L} \frac{C_n}{(1+r)^n}$$

- Equivalent Annual Cost Technique (EAC):

$$EAC = NPV \times A_{t,r} = NPV \times \frac{r}{1-(1+r)^{-L}}$$

- Net Saving (NS) and the Opportunity Loss (OL):

$$NS = (EAC_A - EAC_B) \times \frac{1-(1+r)^{-L_B}}{r}$$

$$OL = (EAC_A - EAC_B) \times \frac{1-(1+r)^{-L_A}}{r}$$

- Bridge work zone user cost (WZUC): Will be calculated using BaTMan-LCC

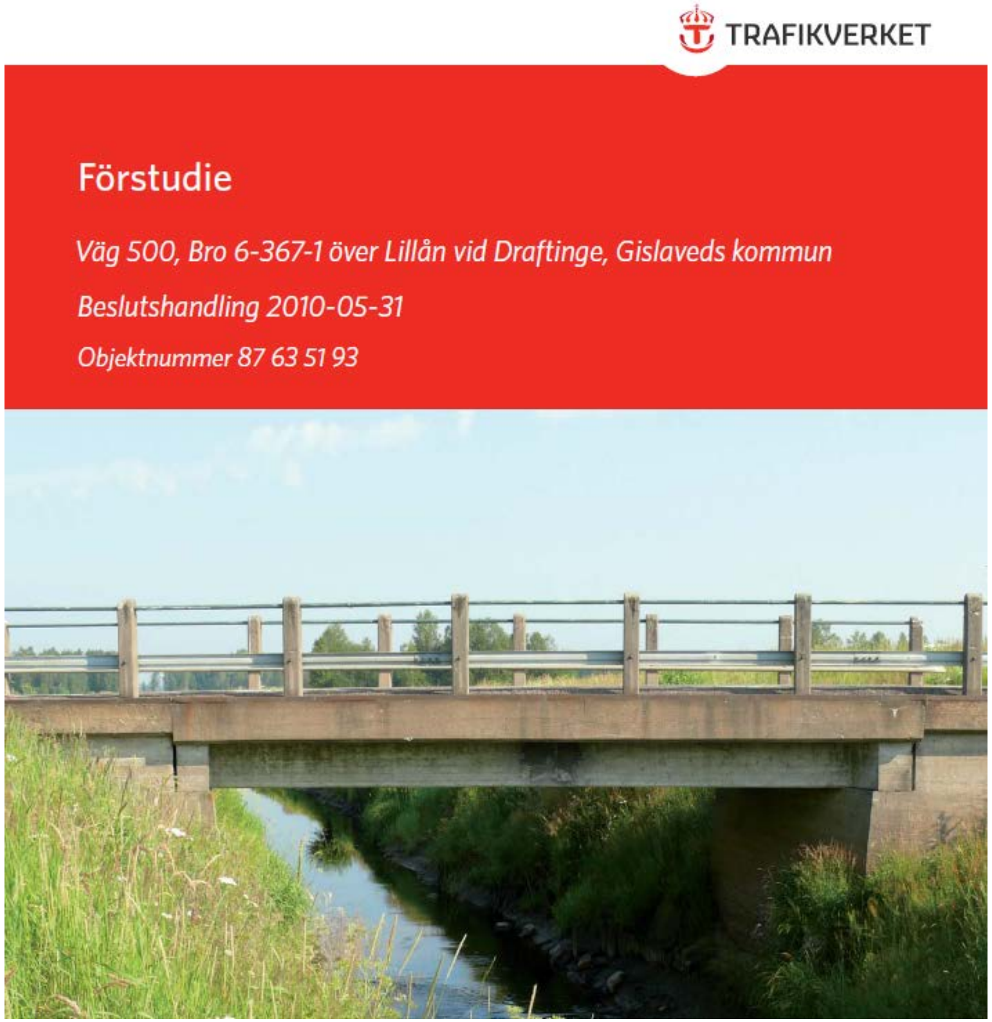
Case-Studies

Paper I: Struc. & Infrastructure Eng. J.
[6-367-1] Bro över Lillån
Construction Year: 1934

Paper II: TRR Journal
[18-352-1] Bro över Täbyån, Höjen
Construction Year: 1929

(Residual service life is not more than three years, if no action is taken CC2)

Case-Study: Täbyån Bridge



Bridge No.:[18-352-1]

Construction Year: 1929

Simply Supported

Total length= 9.5 m

Total width= 5.3 m

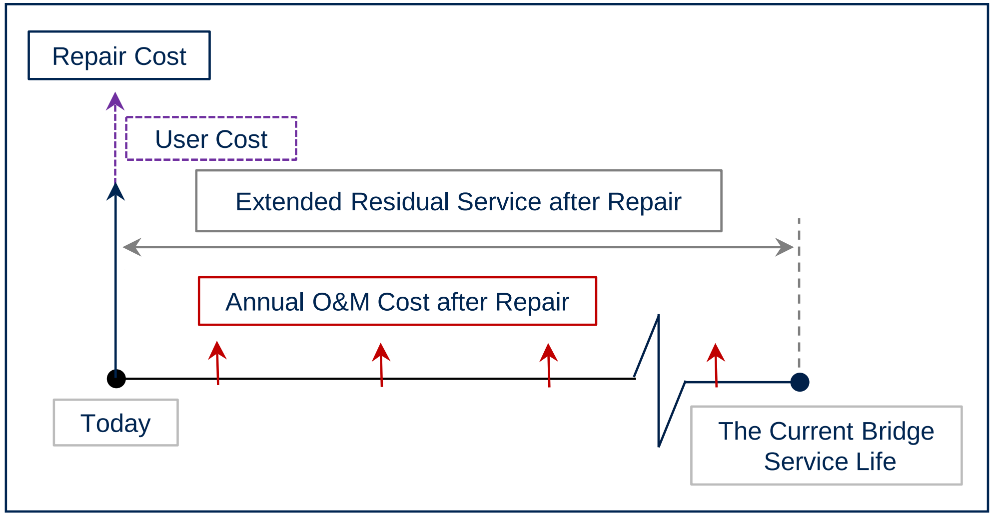
ADT= 84

Superstructure:CC2

Substructure: CC2

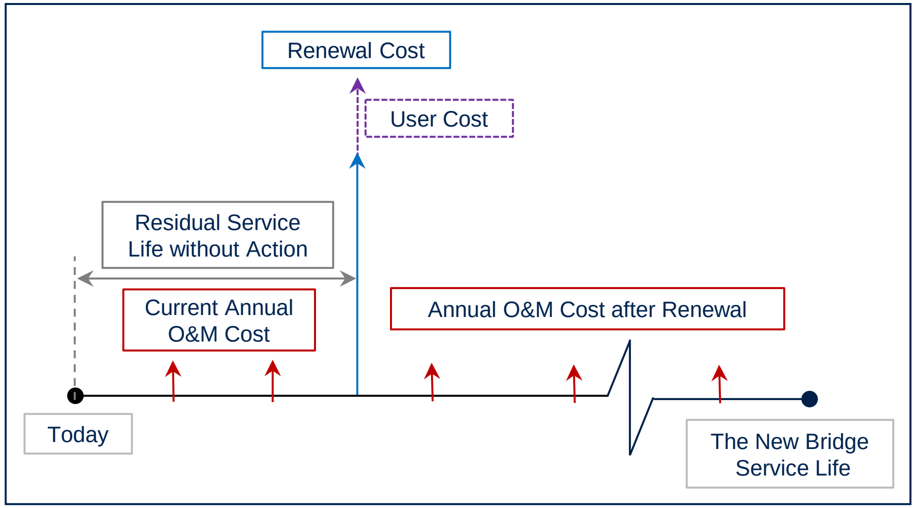
Strategies: Repair or Renewal

Strategy (A)



Immediately repair the bridge

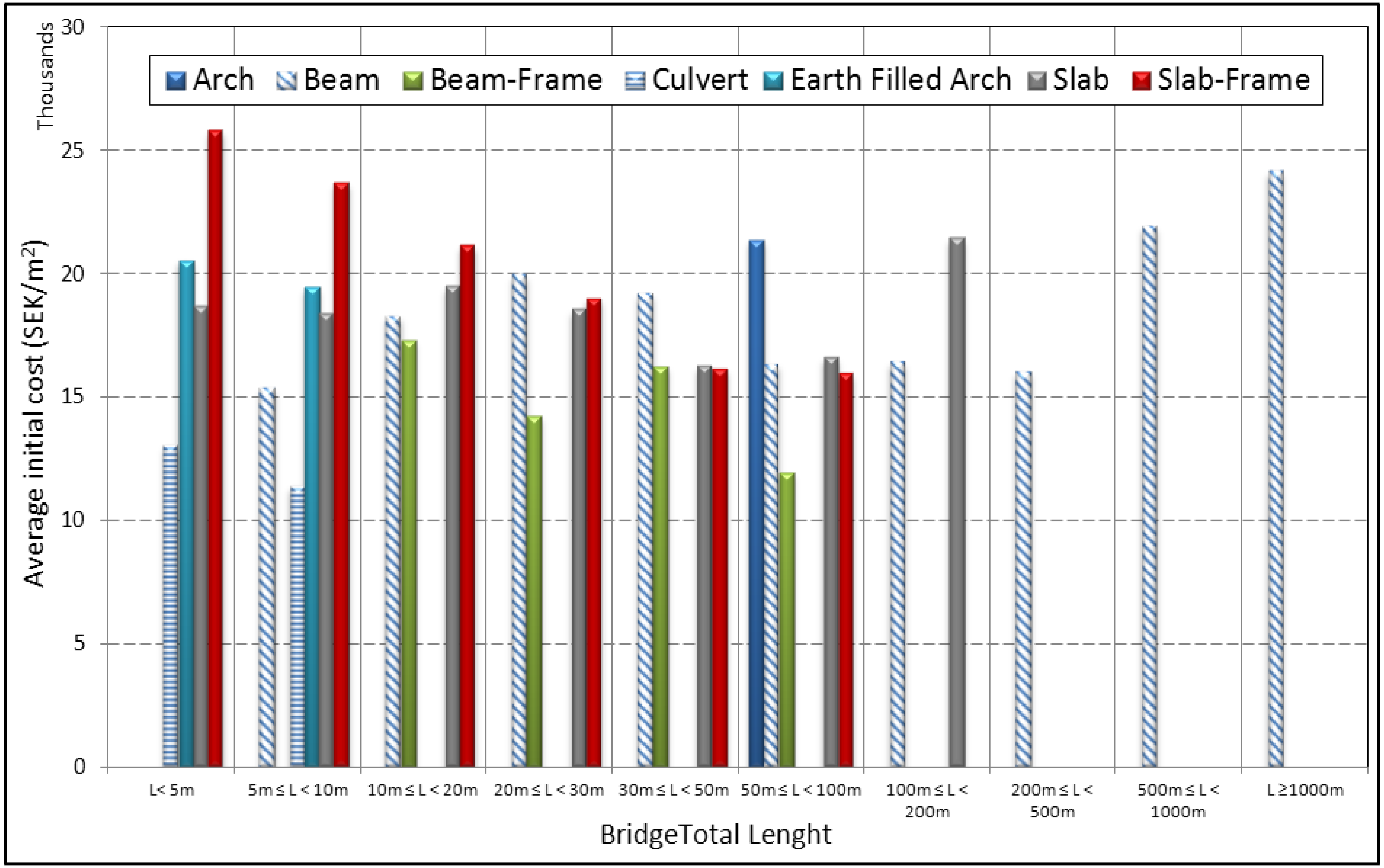
Strategy (B)



Utilizing the bridge's residual service life without action and then renew it

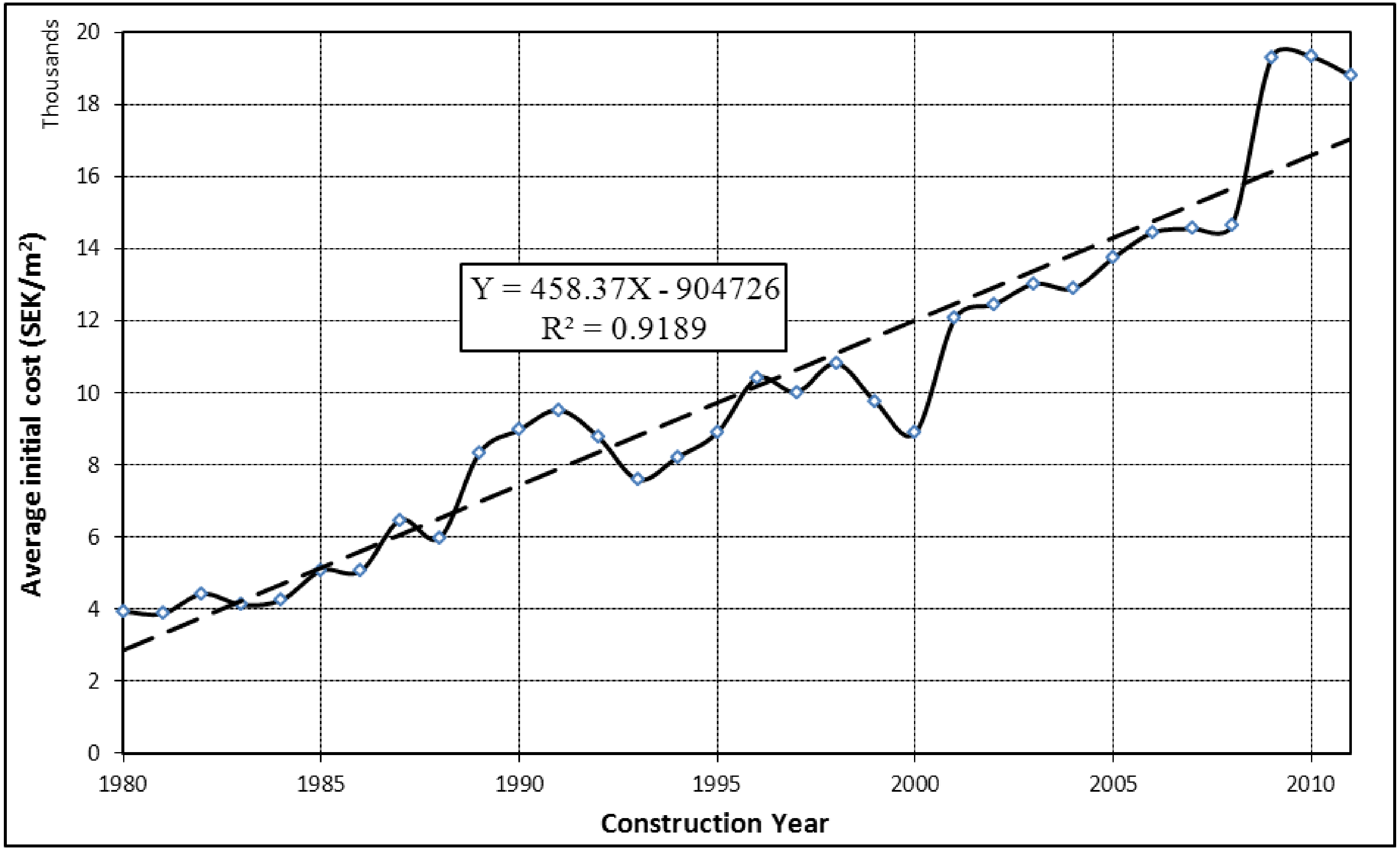
- ✓ Step 1: optimize between the available replacement options.
- ✓ Step 2: optimize between the promoted replacement proposal and the repair strategy.

Replacement Alternatives



The average real initial costs of the Swedish bridges different types, based on cost data for 2,508 bridges constructed between 1980 and 2011.

Replacement Alternatives

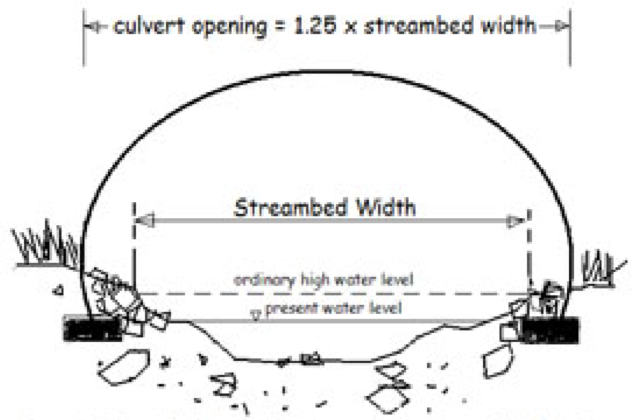


The inflation rate for the Swedish bridges initial costs

Replacement Options Optimization

Proposal NO.	Proposal description	Bridge Width(m)	Bridge Length (m)	Anticipated initial cost (SEK/m2) at year 2015	Anticipated service life (Year)	Required annual O&M (SEK)	Required construction duration (Day)
1	Steel-Timber Beam	7	16,5	12,578	80	8,500	100
2	Concrete Beam	7	16,5	23,510	100	5,000	100
3	Steel Open-Bottom Arch Culvert	8	9,5	19,400	60	2,500	80

✓ The LCC analysis excluding and including the user cost has promoted the third alternative, Steel arch culvert, EAC equals to 67,671 SEK/year.



Correctly installed open-bottom arch culvert with footings

Replacement and Repair Optimization

Strategies Input Data	Strategy (A)	Strategy (B)	
Strategies description	Immediate repair	Utilizing the bridge residual service life without action and then replace it by a steel open-bottom arch culvert	
Bridge's Residual service life without action, (Years)	3		
Discount rate (%)	4		
Anticipated service life after an action (Year)	20	60	
Strategy initial cost (SEK)	895,000	1,474,400	
Annual O&M cost (SEK)	7,000	During the current bridge residual service life	After the bridge replacement
		8,500	2,500
The required construction duration (Days)	60	80	

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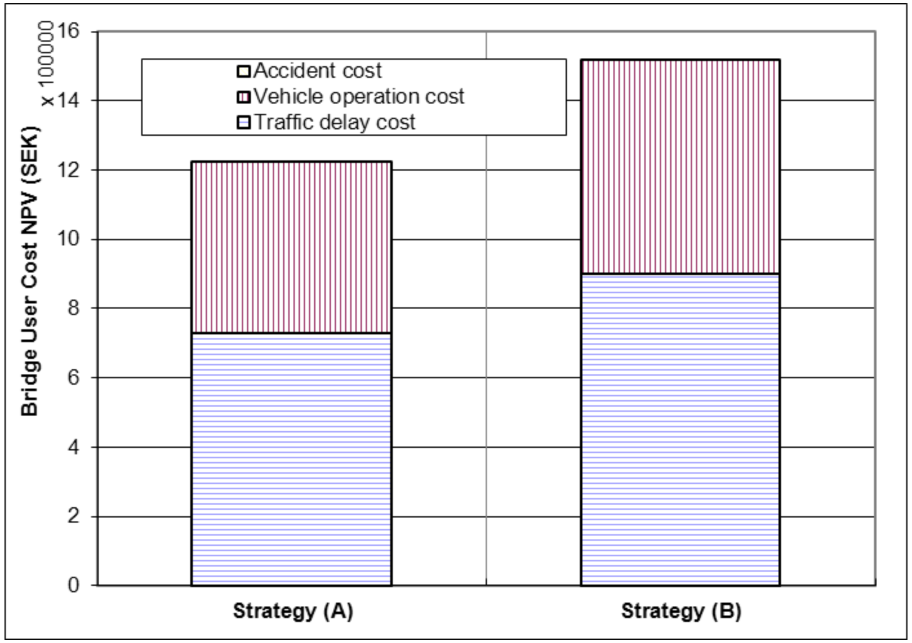
Analysis Results Excluding the Bridge User Cost

Cost Category &Term	Strategy (A)	Strategy (B)
Net Present Value (SEK)	990,132	1,384,605
Equivalent Annual Cost (SEK/year)	72,856	60,497

- ✓ Consequently, strategy (B) is the most cost-effective strategy.
- ✓ The NS is equal to 282,864 SEK/63 years or 12,359 SEK/year for a life span equals to 63 years.
- ✓ The OL is equal to 167,963 SEK/20 years or 12,359 SEK/year for a life span equals to 20 years.

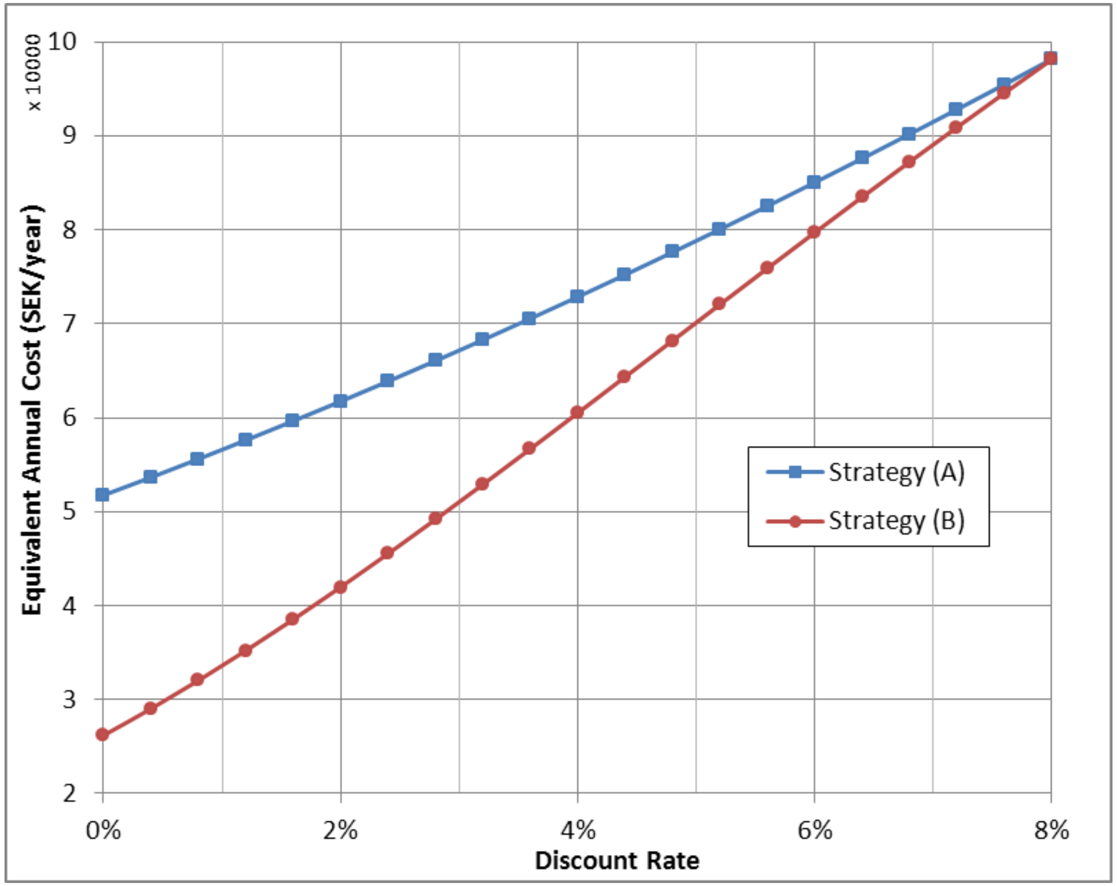
Analysis Results Including the Bridge User Cost

Cost Category &Term	Strategy (A)	Strategy (B)
Total Net Present Value (SEK)	2,215,523	2,902,067
Equivalent Annual Cost (SEK/year)	163,022	126,798



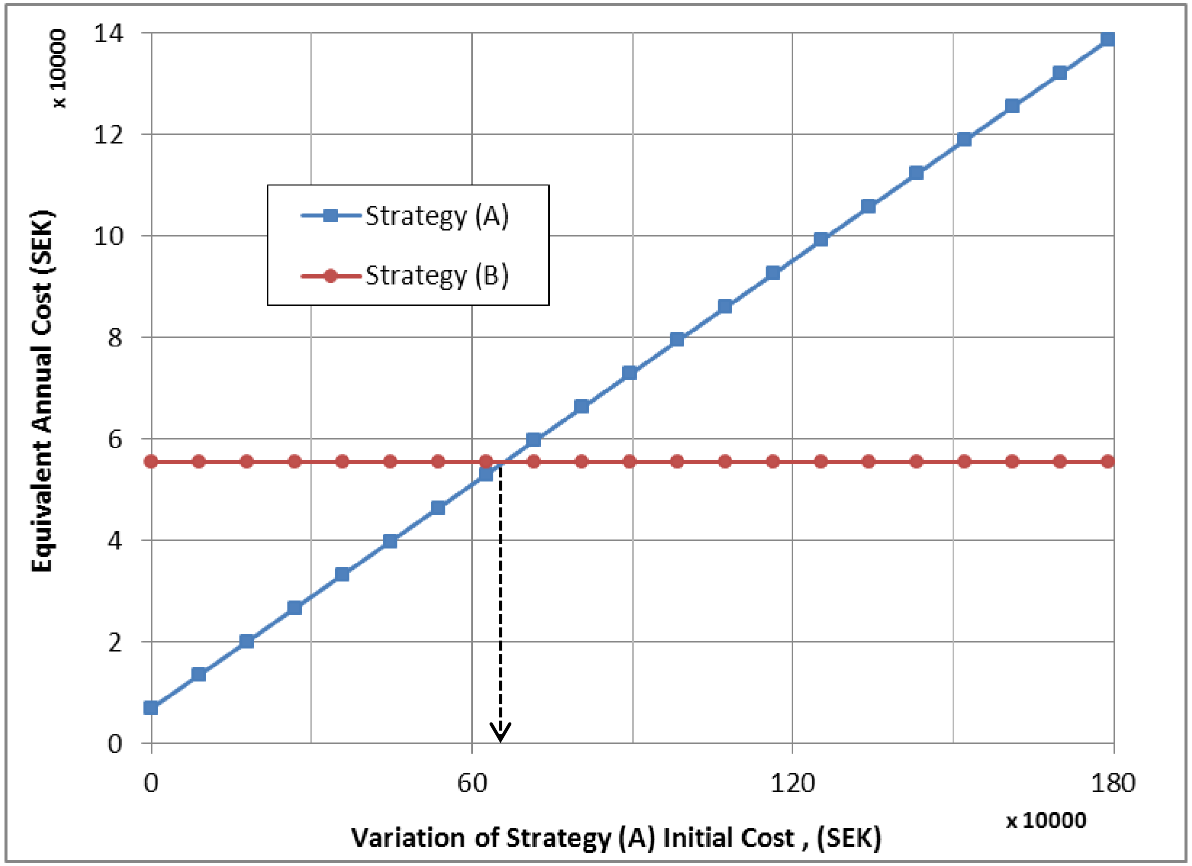
✓ Consequently, strategy (B) remains the most cost-effective strategy.

Sensitivity analysis (1): The impact of varying the discount rate



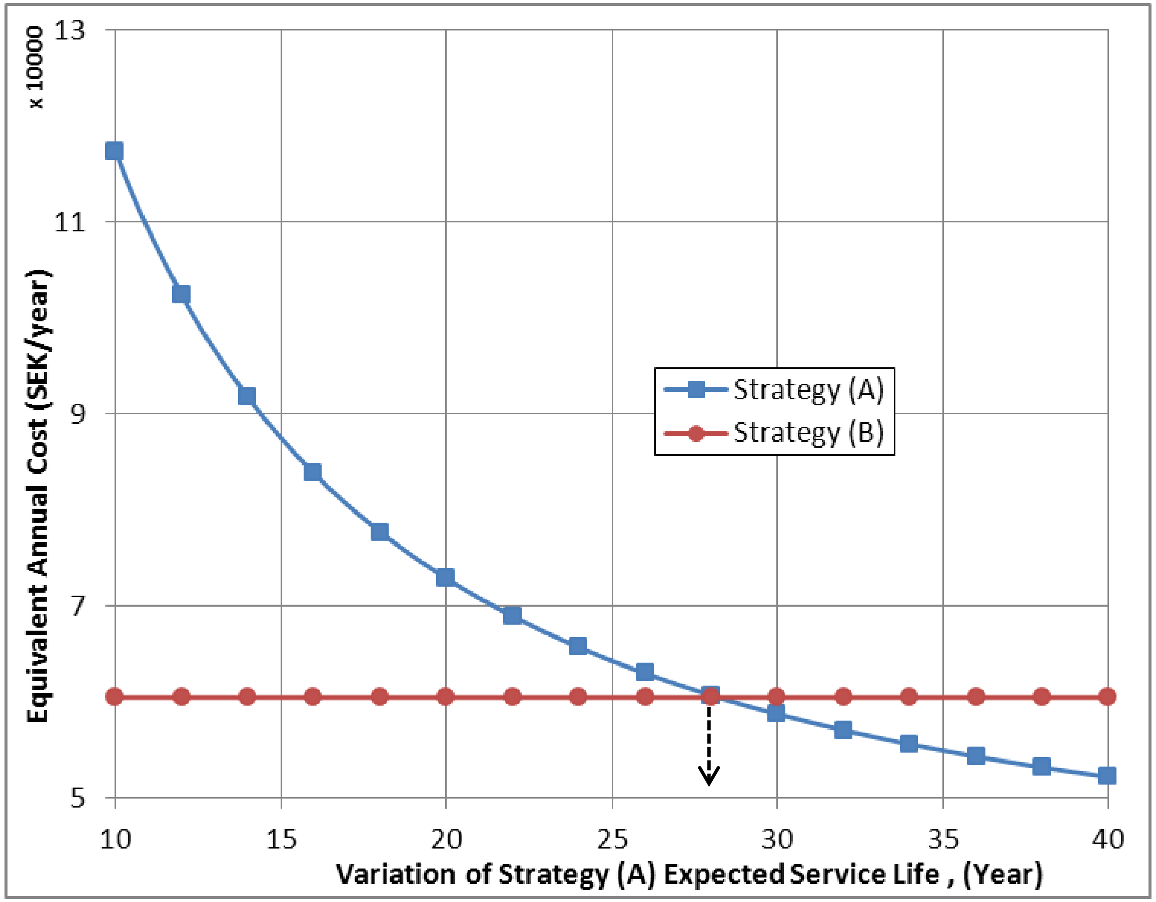
- ✓ Strategy (B) remains the most cost effective strategy.
- ✓ The discount rate, in this case, does not have considerable impact on the final decision.

Sensitivity analysis (2): The impact of varying the initial cost of strategy (A)



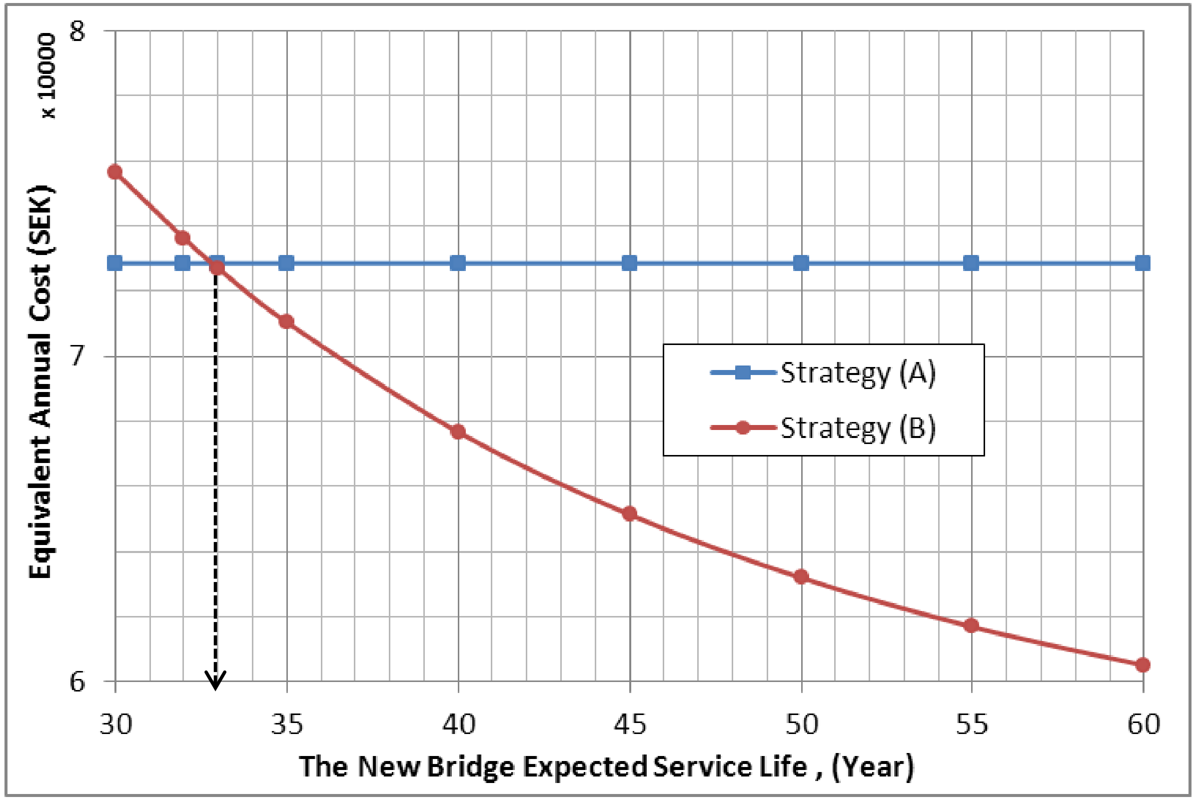
✓ If there is a possibility to negotiate the initial cost of strategy (A), it might be more profitable to choose it as the most cost-effective solution when its initial cost is less than 727,037 SEK instead of 895,000 SEK.

Sensitivity analysis (3): The bridge service life extension after repair



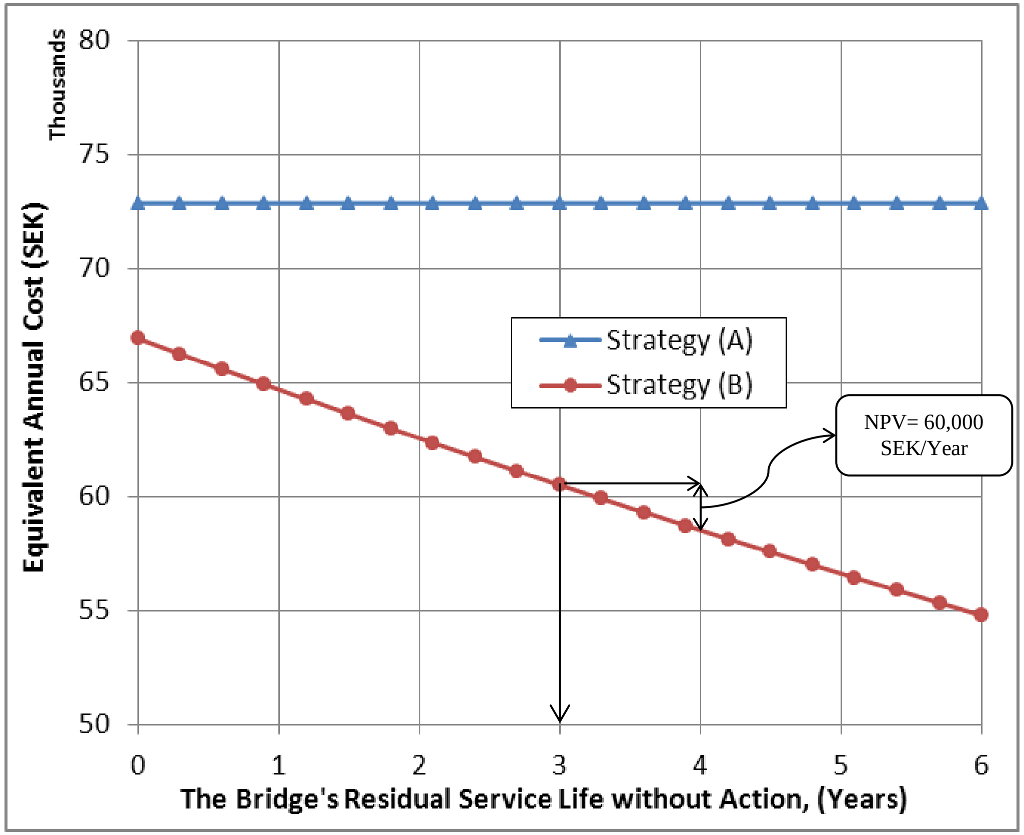
✓ If the repair strategy (A) can guarantee a bridge's service life extension longer than 28 years instead of 20 years, then it can be chosen as the most cost-effective choice instead of strategy (B). This is fairly impossible.

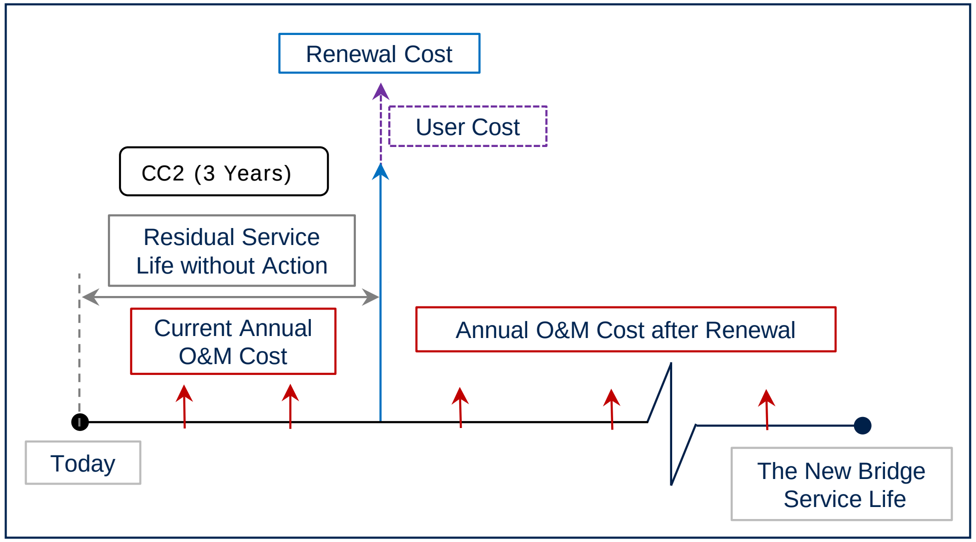
Sensitivity analysis (4): The new bridge's anticipated service life



✓ Strategy (B) remains the most cost-effective choice as much as the service life of the new bridge is longer than 33 years. It is fairly well known.

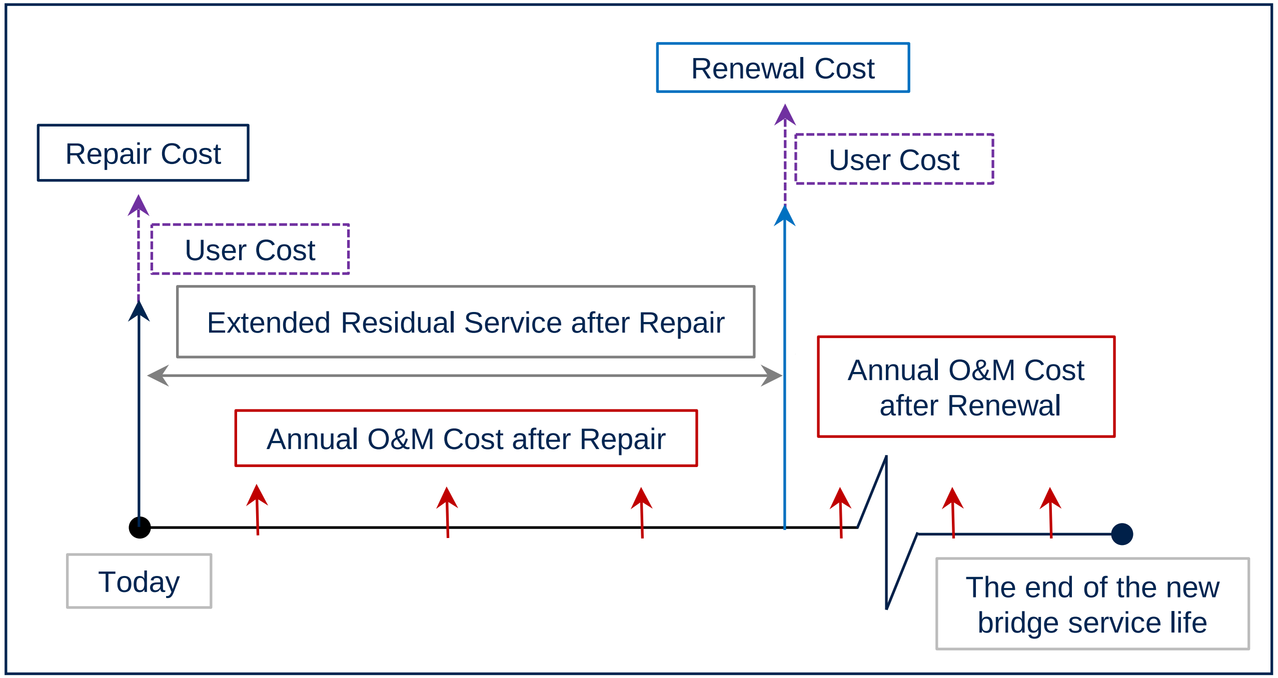
Sensitivity analysis (5): The bridge's residual service life without action





- ✓ Even if the three years in becomes zero "Replace now" (CC3), strategy (B) remains the most-cost effective.

Long-term planning for strategy (A)

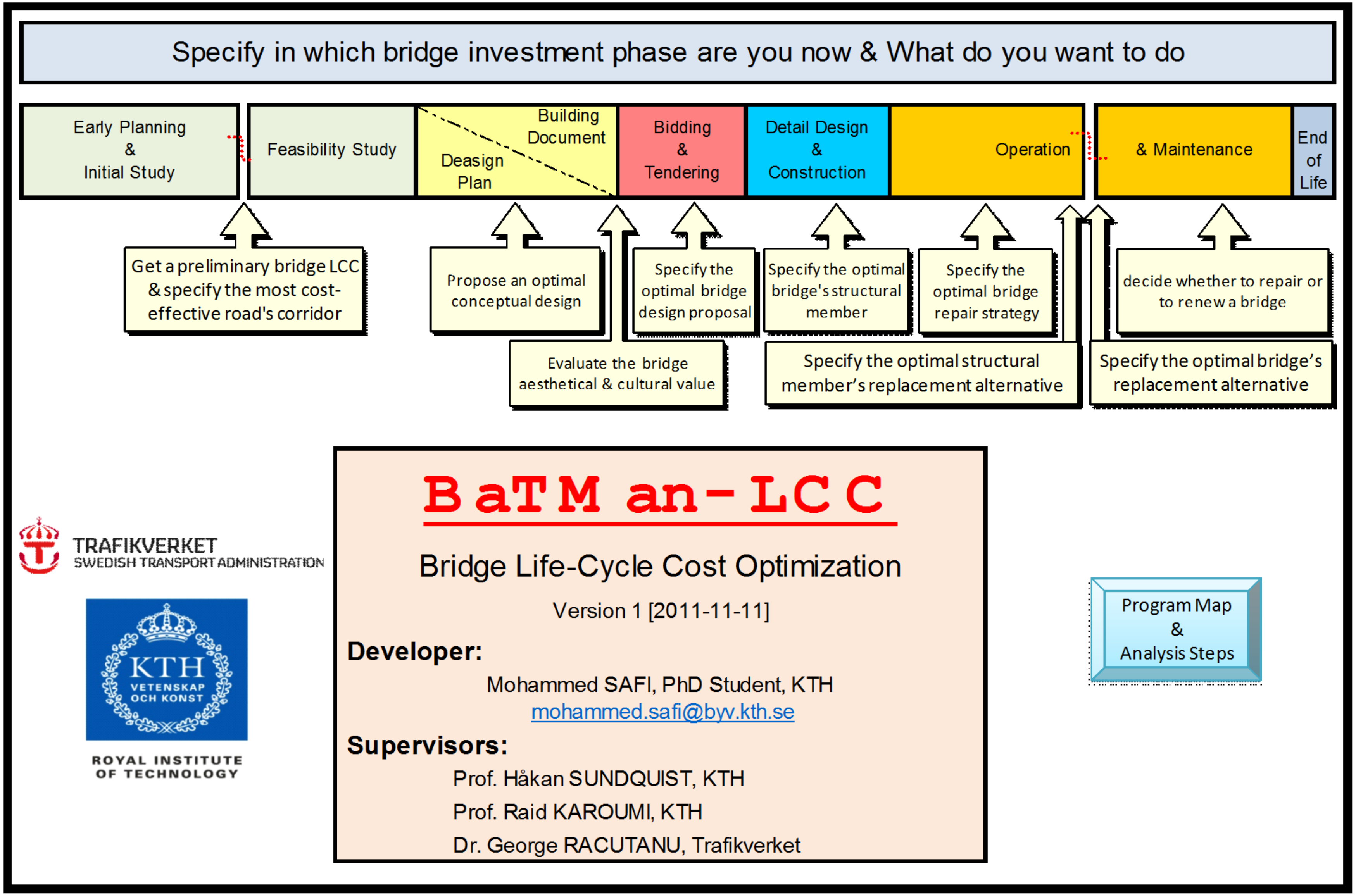


- ✓ The EAC for strategy (A) and (B) are equal to 69,612 SEK/year and 60,497 SEK/year respectively.
- ✓ Consequently, strategy (B) remains the most cost-effective choice.

Large-Scale Feasibility

- Confidently, the bridge should not be repaired and should be replaced after utilizing its residual service life.
- Trafikverket is responsible for:
  - 23,948 bridges with a total bridge area of 5,516,590 m^2
  - 6,268 bridges older than 70 years, total bridge area of 619,944 m^2.
- The analysis shows that, the opportunity loss is equal to 241 SEK/year/m^2
- Consider that 50% of the Trafikverket's old bridges might be subjected to wrong decision, This means:
  - Trafikverket can save/might loos 74.7 million SEK each year
- This loss will stand for 20 year, this also means:
  - Trafikverket can save/might loose 1.49 billion SEK during the coming 20 years.

BaTMan-LCC



Specify in which bridge investment phase are you now & What do you want to do
Early Planning & Initial Study
Feasibility Study
Deasign Plan
Building Document
Bidding & Tendering
Detail Design & Construction
Operation
& Maintenance
End of Life
Get a preliminary bridge LCC & specify the most cost-effective road's corridor
Propose an optimal conceptual design
Evaluate the bridge aesthetical & cultural value
Specify the optimal bridge design proposal
Specify the optimal bridge's structural member
Specify the optimal bridge repair strategy
Specify the optimal structural member's replacement alternative
decide whether to repair or to renew a bridge
Specify the optimal bridge's replacement alternative
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BaTMan-LCC
Bridge Life-Cycle Cost Optimization
Version 1 [2011-11-11]
Developer:
Mohammed SAFI, PhD Student, KTH
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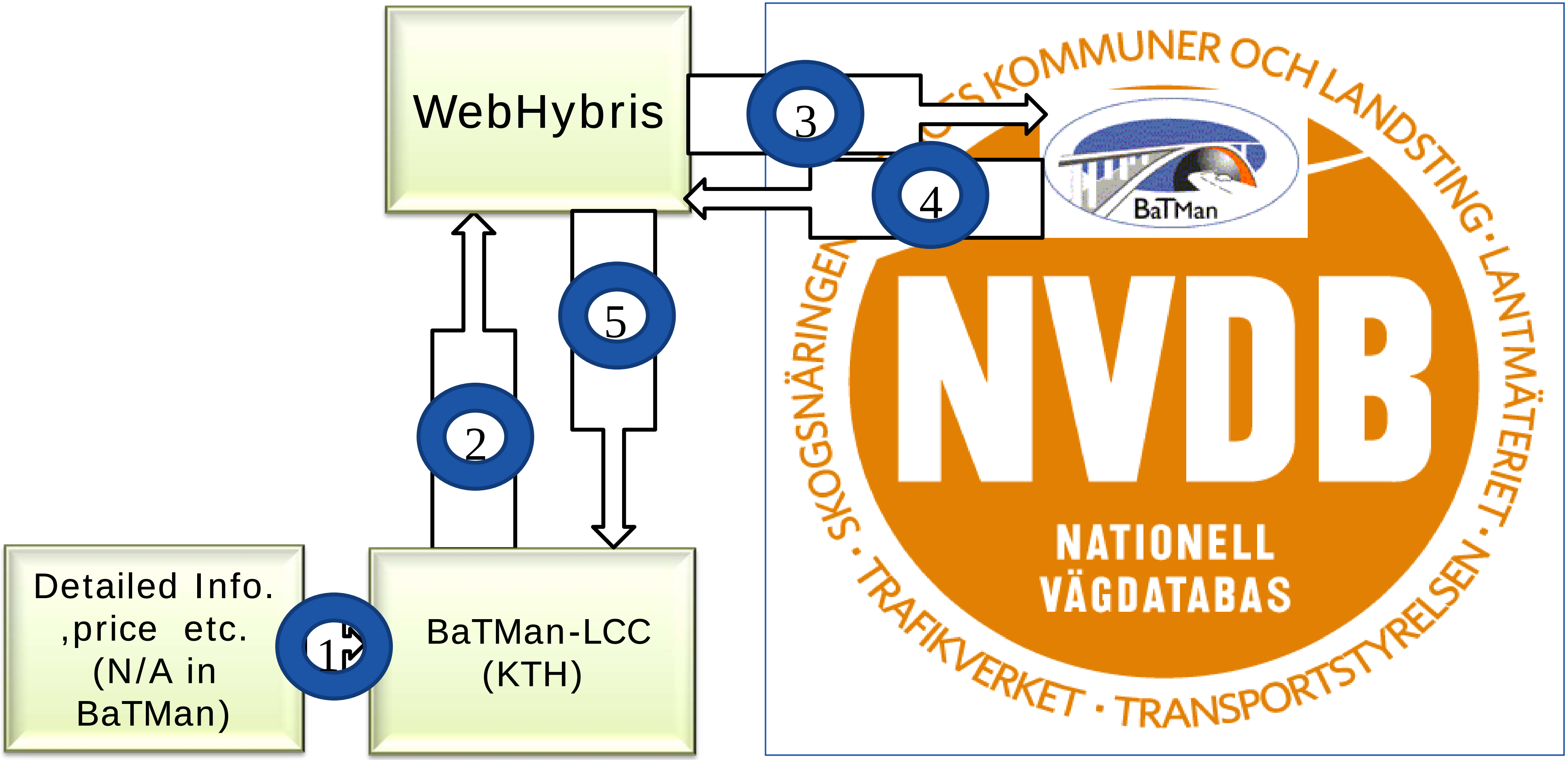
Supervisors:
Prof. Håkan SUNDQUIST, KTH
Prof. Raid KAROUMI, KTH
Dr. George RACUTANU, Trafikverket
Program Map & Analysis Steps

BaTMan-LCC relation with BaTMan



Conclusion & Comments

- LCC applications for bridges should be developed in accordance with the available BMS and should benefit from the BMS's inventory data.
- Not easy to draw a general conclusion from LCC analysis because the results are strongly dependent on the input. However, usually when the NS is a considerable amount, the variation of the included parameters will not have that significant influence on the final decision and vice versa.
- By using OL technique, the decision makers will be able to estimate the consequences of their decisions, and it will promote forward thinking.
- One of the key components of the LCC is the incorporation of uncertainty into the analysis. Therefore, the sensitivity analysis is an important step in such analysis which can address the critical parameters for the final decision.

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Further Research

- The main goal of ETSI is to develop a unified, reliable and usable Nordic methodology and an Internet-based computer tool for bridge life-cycle optimization. Same methodology could be adopted to fit the BMSs in other Nordic counties.
- Clarify how a BMS with an integrated LCC tool can support network-level decisions for prioritizing bridges for repair or replacement purposes, taking into account the OL from the project-level analysis.
- Clarify the possible LCC applications for bridges during the tendering phase where the largest LCC saving potential can be achieved.
- Upgrading BaTMan itself to accommodate the LCC applications of BaTMan-LCC tool is the main future task of this project.
- Possibilities of using ***advance monitoring systems*** which may increase the allowable time needed to implement an action.

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Thank You
Questions?