Public defense:

Life-Cycle Costing

Applications and Implementations in Bridge Investment and Management

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Background

- Selection from multiple alternatives
- Conventional financial costing
- Maximize efficiency, sustainability and ensure the optimum use of taxpayers' money
- LCCA has great saving potential

Aim

- Enhance bridge investment and management decisions by integrating LCCA into its procurement processes,

- Thereby helping to optimize use of taxpayers' money and improve the sustainability of bridge infrastructure.

- Develop convenient parameters and techniques for evaluating other life-cycle aspects of bridges, such as, user costs, environmental impacts and aesthetic values

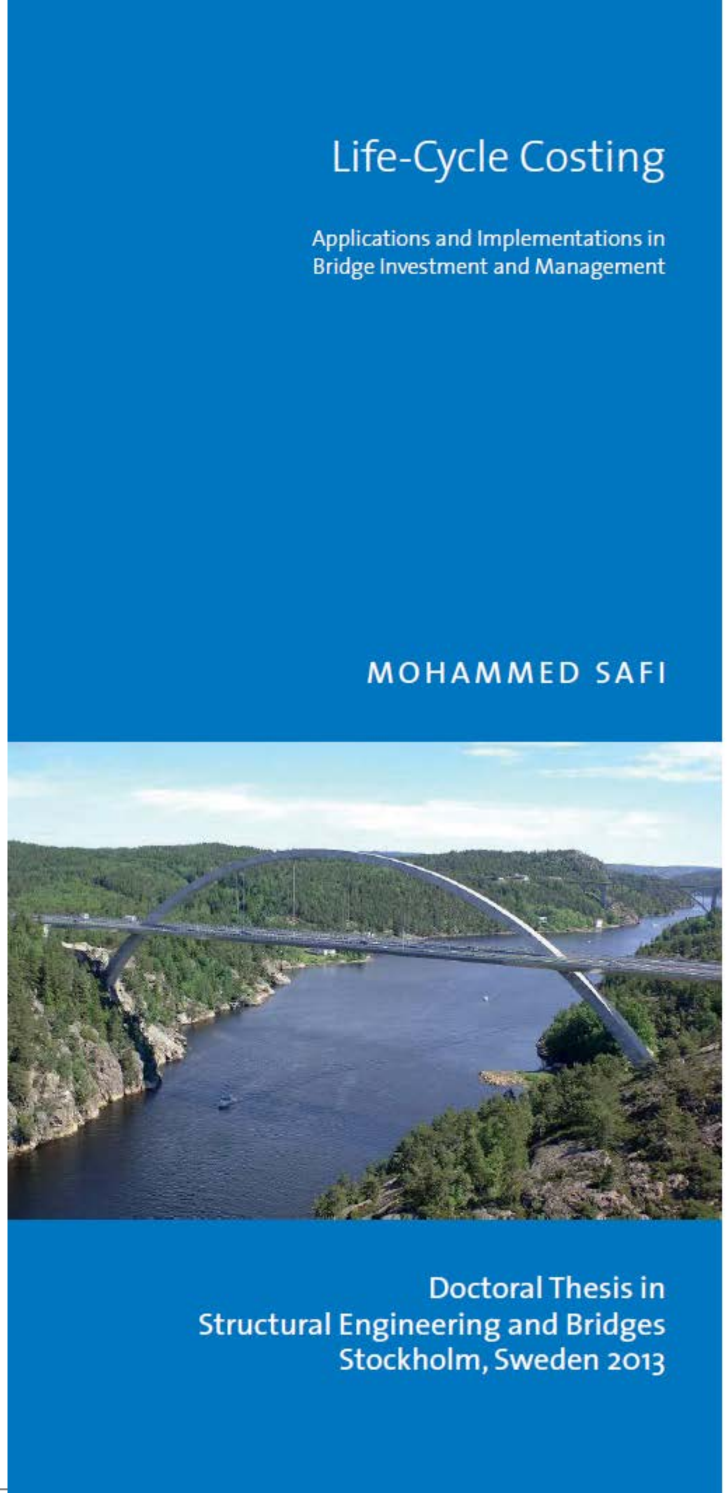
Thesis Contents

- Part I: Extended Summary

  1) Introduction
  2) LCCA and BMSs
  3) LCCA Applications and Obstacles
  4) LCCA for Railway Bridges: a Case Study
  5) BaTMan-LCC Tool
  6) Conclusions

- Part II: Appendices

  1) Appended 5 Papers
  2) Appendix A: LCCA Tools
  3) Appendix B: BSMs' LCPs



KTH Architecture and the Built Environment

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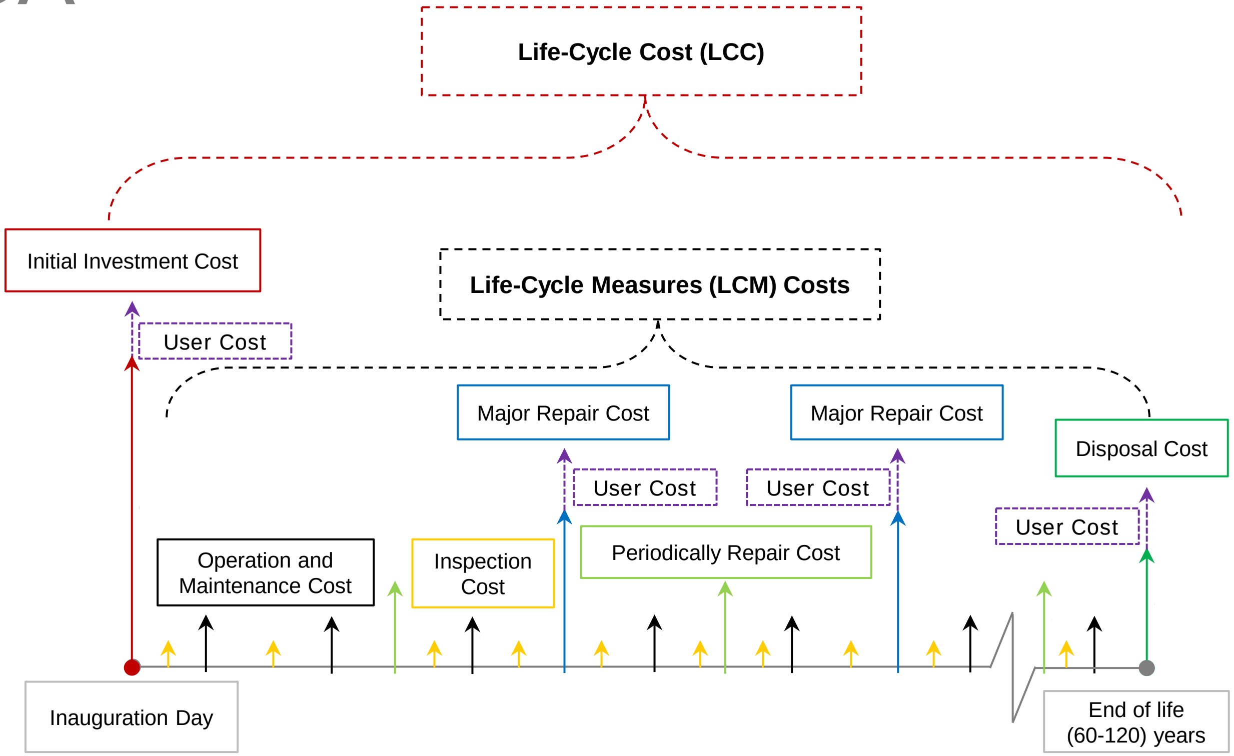
Scope

- The scope of life-cycle costing
- Mainly focuses on project-level decisions
- Some results and conclusions are object-specific
- Trafikverket's established procurement
- Records from BaTMan
- Values of general parameters, such as the discount rate and willingness-to-pay-extra for aesthetic merit and environmental impact

LCC & LCCA



Bridge **L**ife-**C**ycle **C**ost: LCC

- The time value of money, discount rate
- Life-Cycle Costing/**L**ife-**C**ycle **C**ost **A**nalysis (LCCA)

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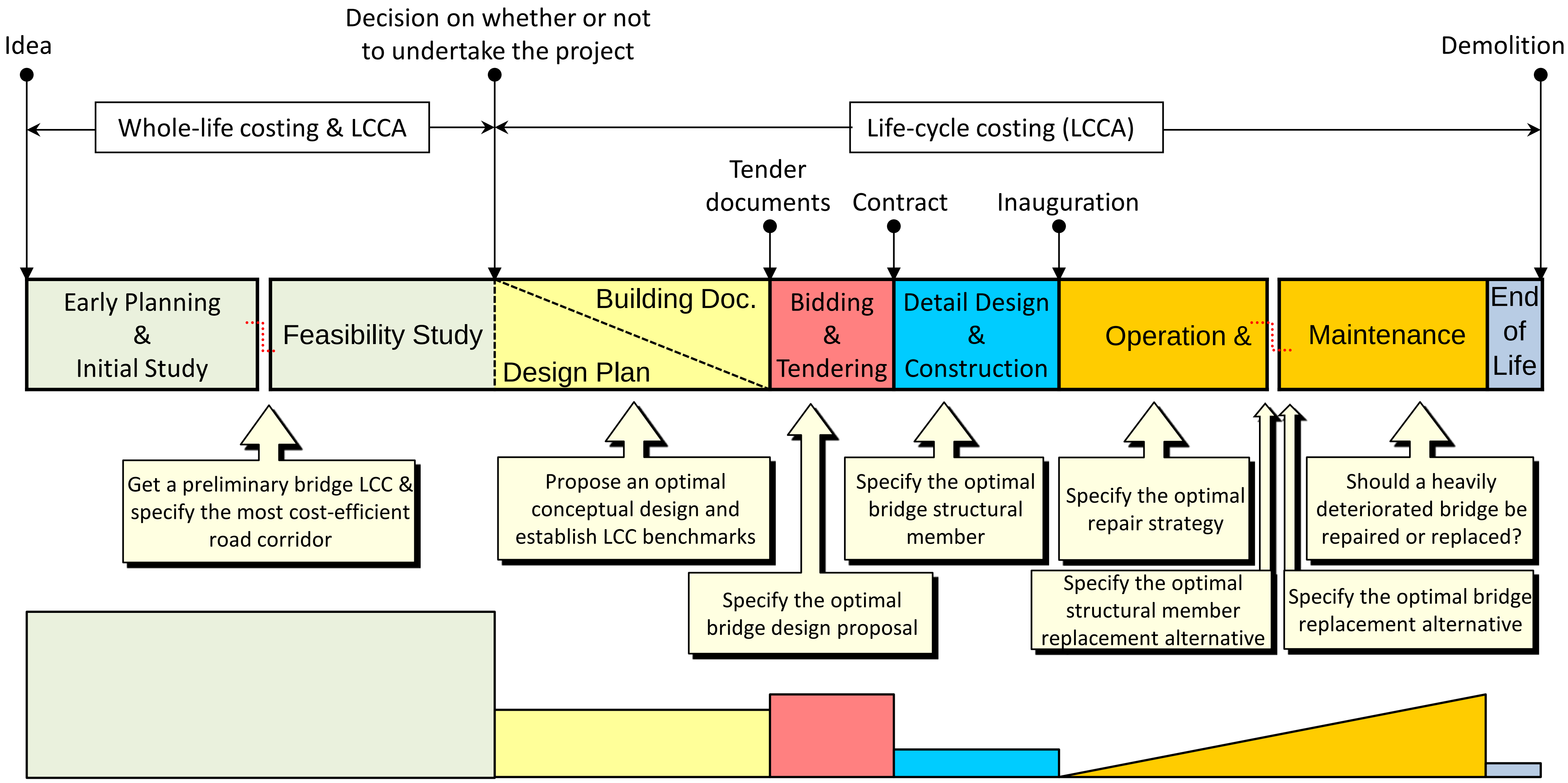
Important to Acknowledge

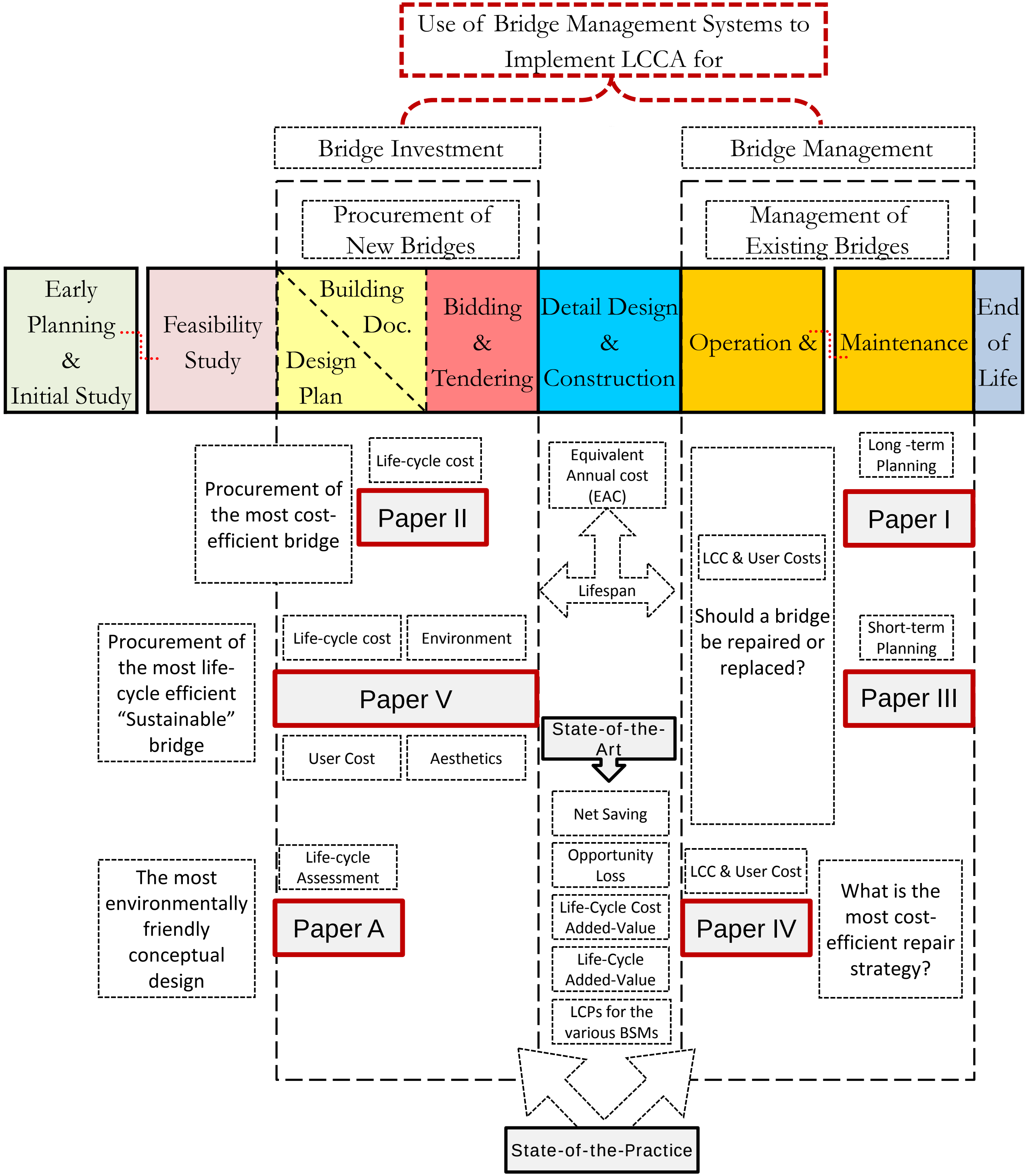
- The objective of LCCA is the minimization of the bridges' LCC not only the LCM costs.
- Not necessarily the most LCC-efficient alternative is the one associated with the least LCM cost or the longest life-span.
- The most LCC-efficient option is the one associated with the lowest equivalent annual cost (EAC), i.e. annual INV and LCM costs over the proposed bridge's life-span.
- It is the function of the design standards and the qualification requirements to minimize the LCM costs of the bridges.

LCCA Applications for Bridges



The Potential Net Saving of the various LCCA Applications

Research Structure & Contributions



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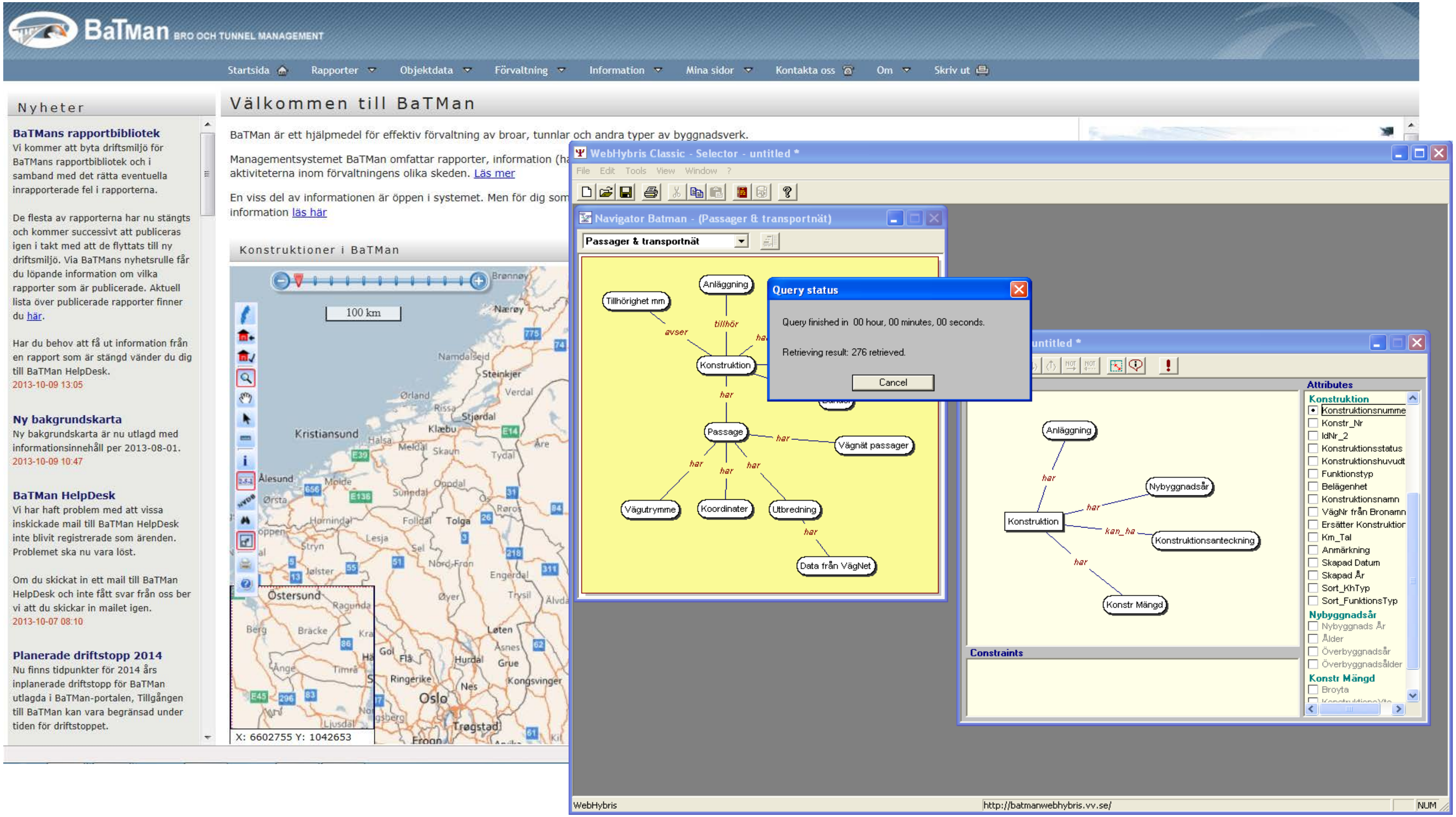
BaTMan & WebHybris



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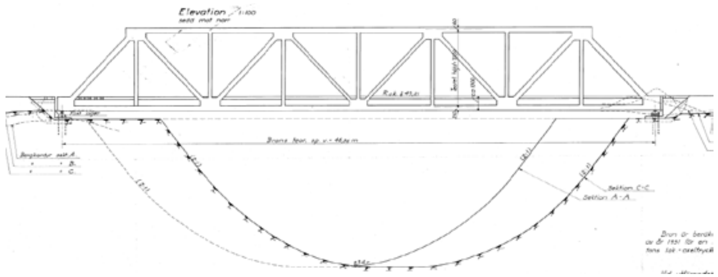
LCCA for Management of Existing Bridges

Bridge Management: Paper I & III

<table>
<tr><th colspan="3">Repair or replace a heavily deteriorated bridge?</th></tr>
<tr><th colspan="2">Road Bridges</th><th>Railway Bridges</th></tr>
<tr><td>Paper I: Str. & Infra. Eng. J.
[6-367-1] Bro över Lillån
Construction Year: 1934</td><td>Paper III: TRR Journal
[18-352-1] Bro över Täbyån, Höjen
Construction Year: 1929</td><td>The Extended Summary
[3500-2593-1]Bro över Huvudnäskanalen
Construction Year: 1937</td></tr>
<tr><td colspan="2">An action is required within a 3 years period, CC2</td><td>An immediate action is required, CC3</td></tr>
<tr><td></td><td></td><td>
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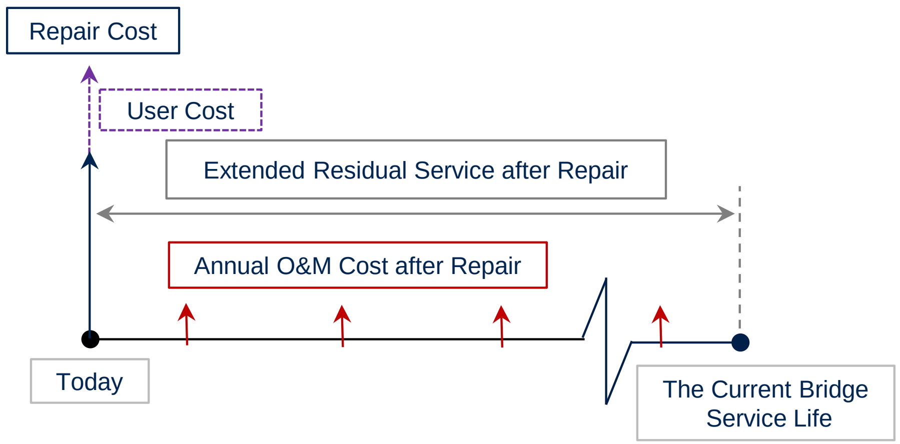
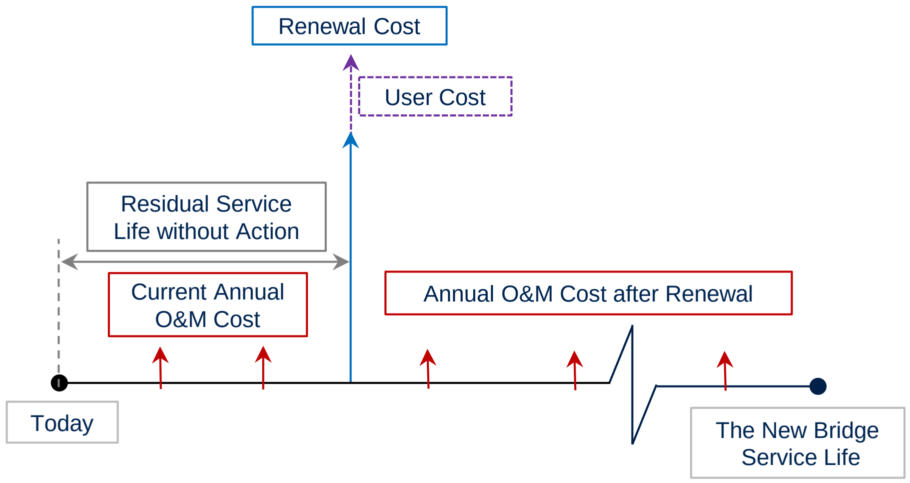
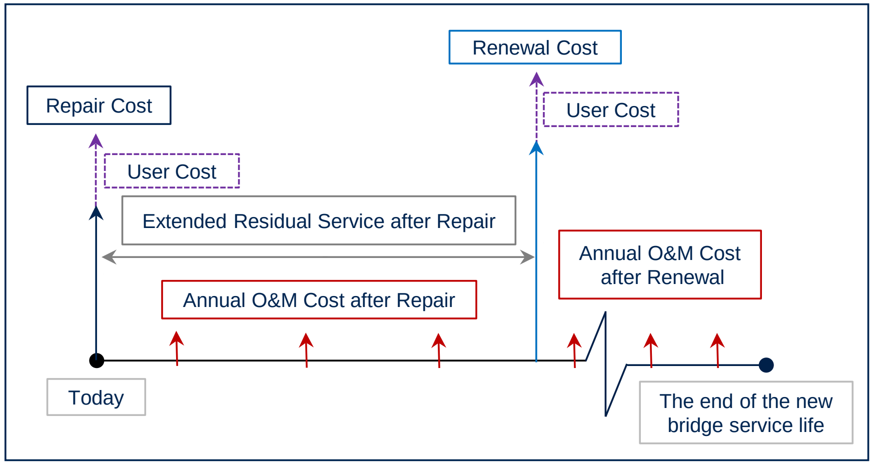
Strategies Formulation

Strategy A: Immediately repair the bridge	**Strategy B:** Utilize the bridge for its residual service life without action and then renew it







Sensitivity analysis:

1. Discount rate
2. The INV cost of a new bridge
3. Residual service life extension after repair
4. Residual service life without action
5. Actual service life of a new bridge
6. Long- and short-term planning of the repair
7. User cost inclusion

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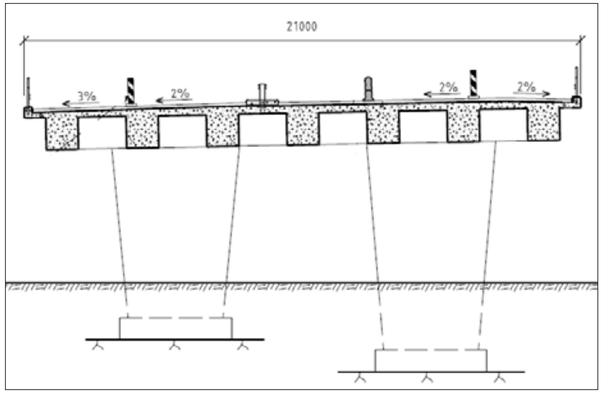
Bridge Management: Paper IV

Repair or replace a bridge structural-member?

An action is required within a 3 years, CC2

Vårbyvägen Bridge [1-813-1]
The surfacing of the bridge deck is CC 2, 3 years
The bridge deck, CC 0



Parameters affecting the analysis, Sensitivity analysis:

1. Discount rate
2. The INV cost of the various strategies
3. User cost inclusion
4. Residual service life without action
5. Dominating structural member residual service life
6. Impact of the various strategies on the residual service life extension

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LCCA for Procurement of New Bridges

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Important Principals in Procurement within Public Agencies

"The Swedish Transport Administration is an authority and by law must endeavor to procure goods, services and contracts in competition"

To ensure credibility and transparency

Bridge Investment & Management from a LCCA Perspective

- The main difference lies in the procurement method/contract type
- Fixed target strategy in management but not usually fixed in investment, particularly under D-B
- The lowest bid and no consistent LCC guidelines
- Trafikverekt’s goal is: 50% D-B by 2018
- A new award criterion under D-B: lowest LCC bid

Unified LCC-Efficient Benchmarks

- There are several improper ways to employ the concept of the lowest LCC bid as the contract award criterion under D-B
- The optimal way is for procurers to establish consistent LCC-efficient benchmarks and guidelines then clearly present them as core specification in the tender documents.

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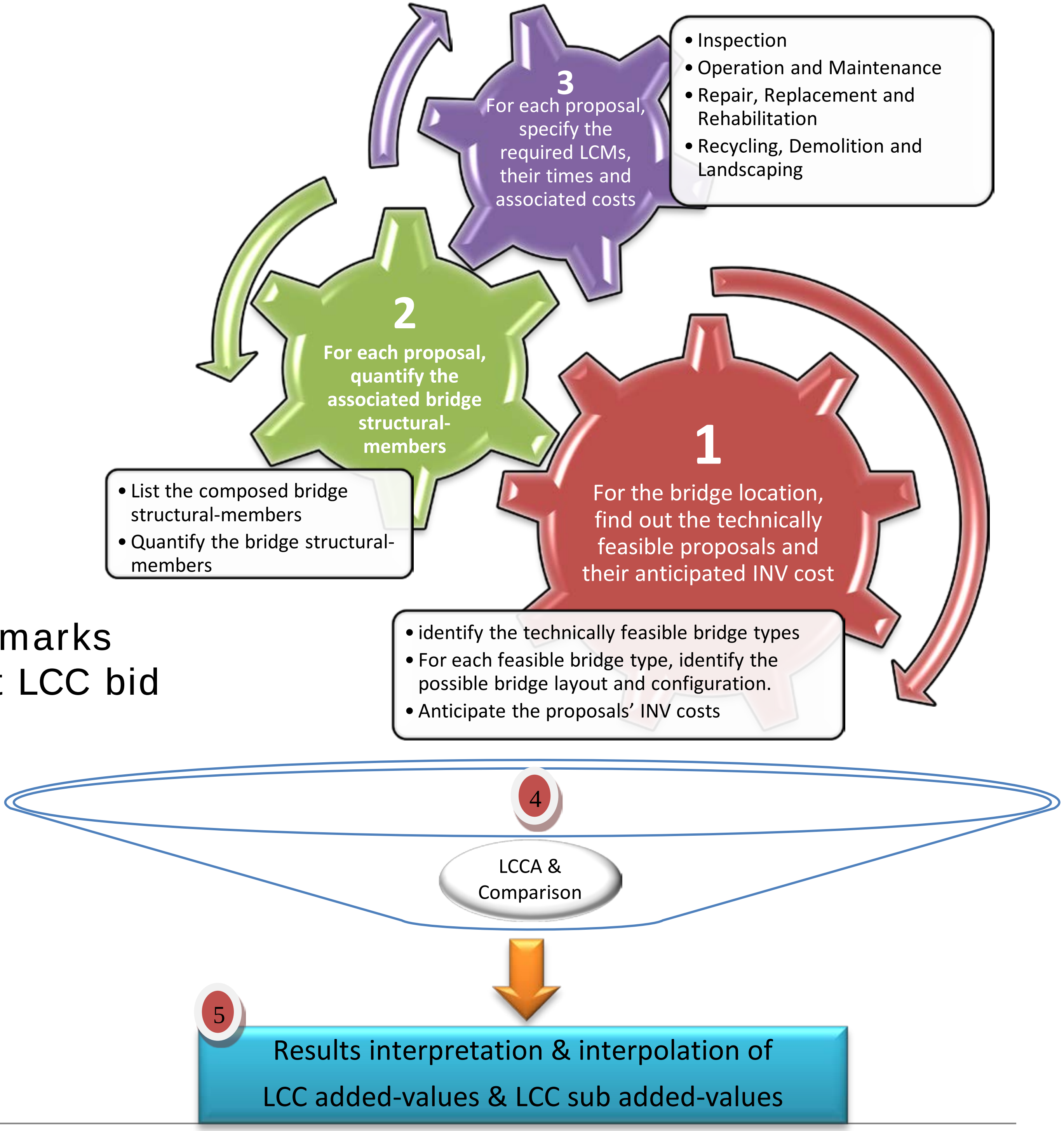
Paper II

Comprehensive Approach:

1. A preliminary LCCA
2. Monetary LCC-efficient benchmarks
3. Bid evaluation criteria: lowest LCC bid



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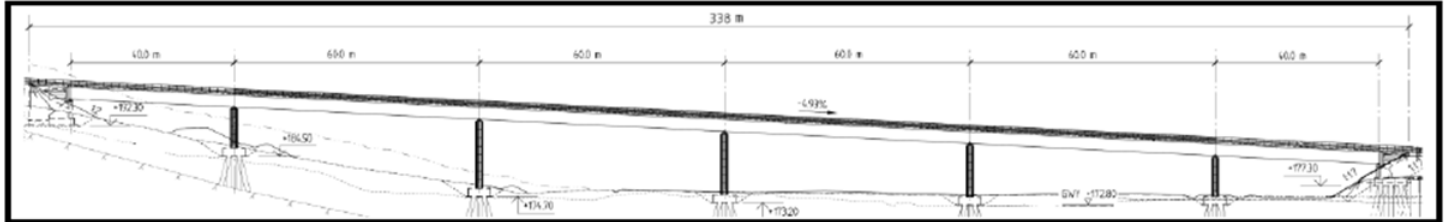
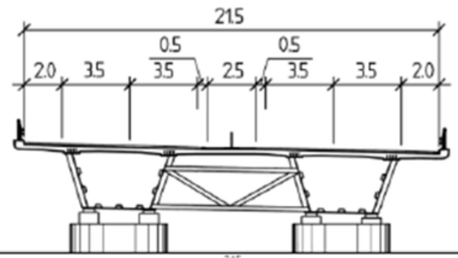
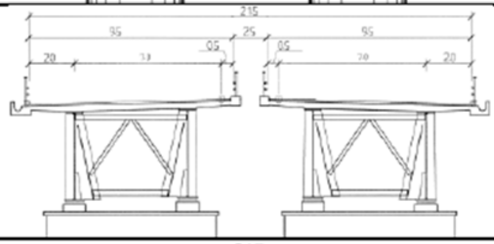
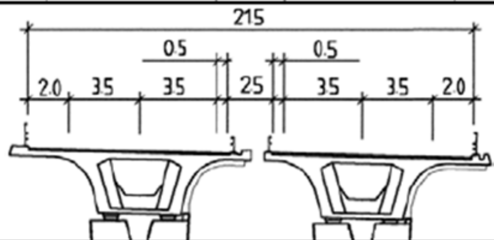
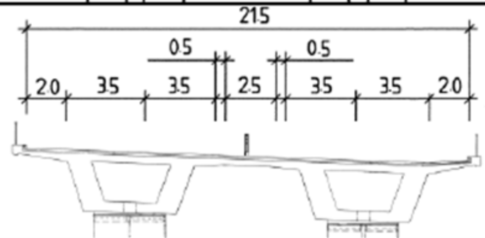
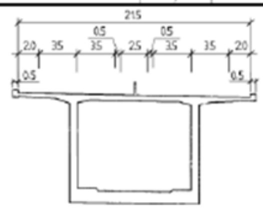
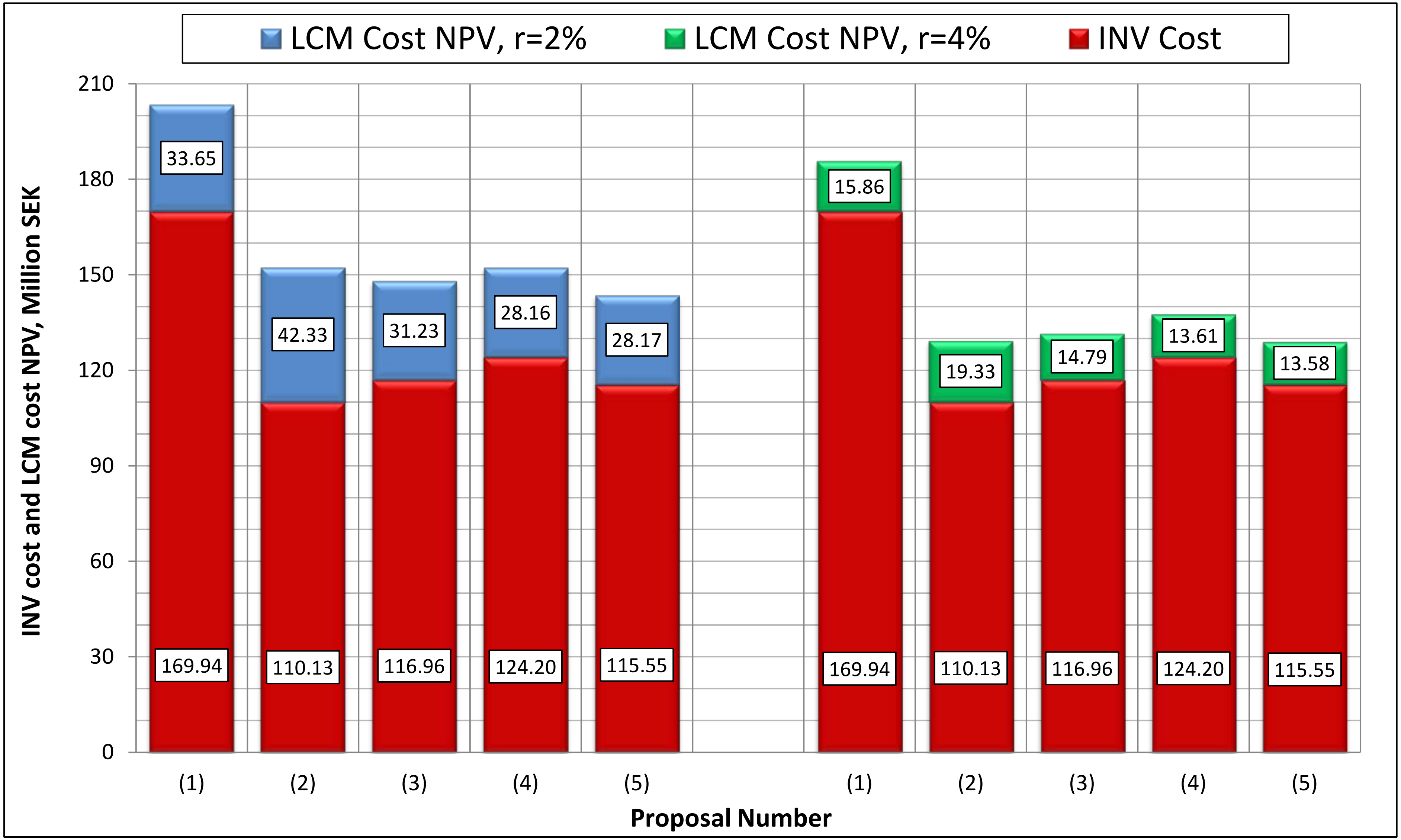
Case Study

The Karlsnäs Bridge 2013

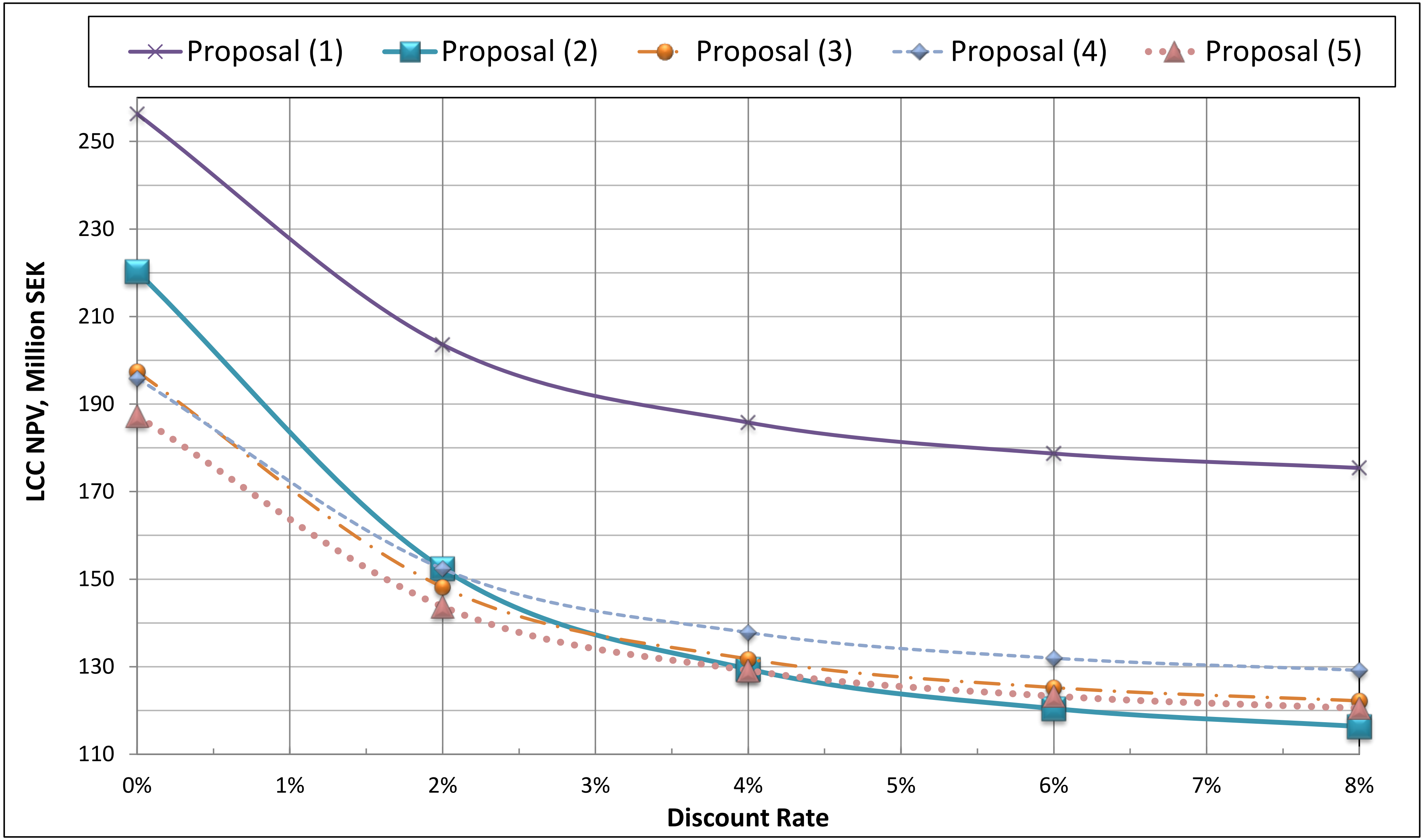


Proposal No.	Description	Cross-Section Details	Outlines & Remarks
1	One bridge, two steel boxes (Trafikverket's conceptual design)		5 Spans 4x60m + 2x40m Superstructure depth: 2.3m
2	Two bridges, two steel I beams per bridge		5 Spans 4x60m + 2x40m Superstructure depth: Haunch beam Max. 3.2m Min. 1.8m
3	Two bridges, one pre-stressed concrete box per bridge		7 Spans 5x50m + 2x35m Superstructure depth: Haunch beam Max. 2.8m Min. 1.6m
4	One bridge, two pre-stressed concrete boxes.		7 Spans 5x50m + 2x35m Superstructure depth: Haunch beam Max. 2.8m Min. 1.6m
5	One bridge, one integral-cantilever concrete box	 	4 Spans 2x100m + 2x60m Superstructure depth: Haunch beam Max. 6.5m Min. 2.3m

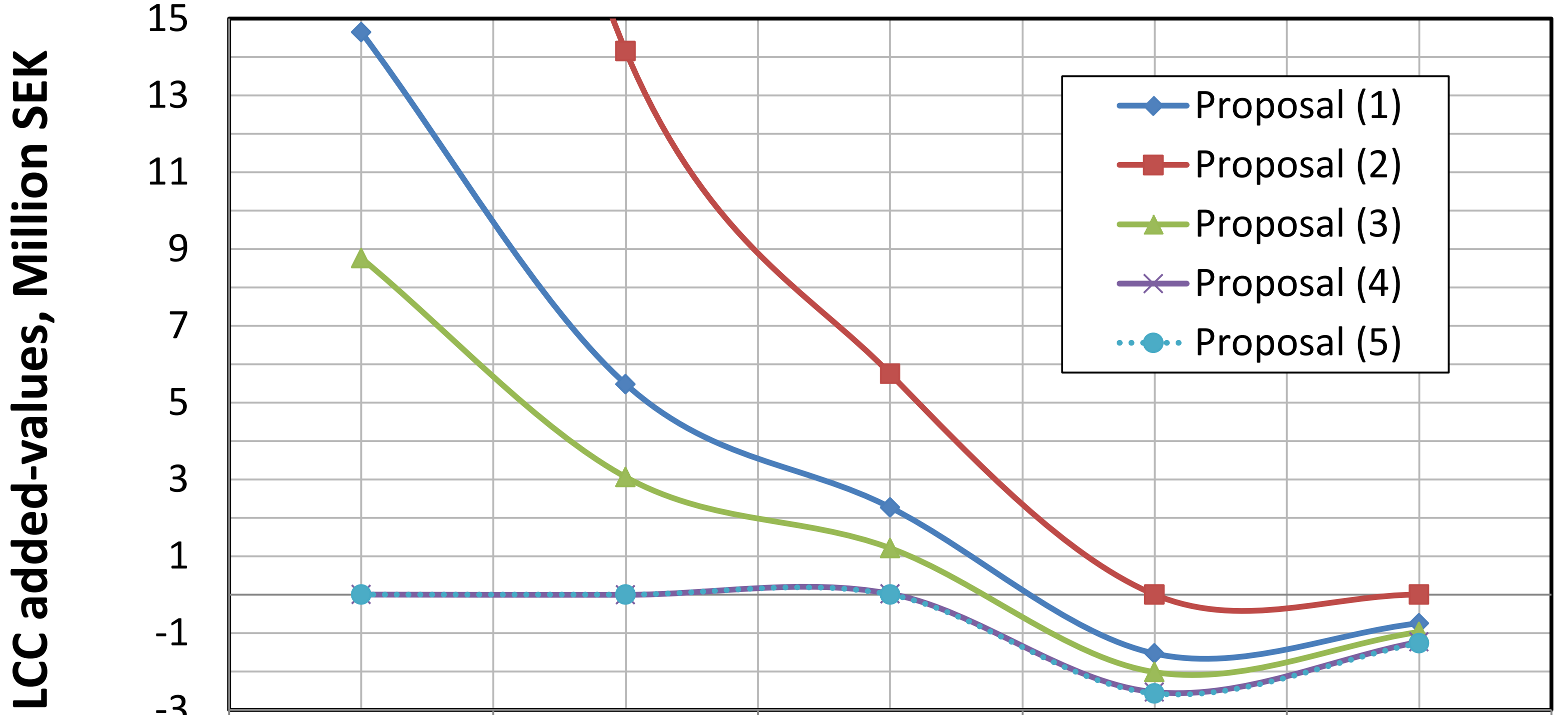
LCCA Results



Impact of varying the discount rate on the proposals' LCC



LCC added-values computed at indicated discount rates (SEK)



	0%	2%	4%	6%	8%
Proposal (1)	14.65	5.48	2.27	-1.54	-0.74
Proposal (2)	38.44	14.16	5.75	0.00	0.00
Proposal (3)	8.77	3.06	1.21	-2.02	-0.97
Proposal (4)	0.00	-0.01	0.02	-2.54	-1.23
Proposal (5)	0.00	0.00	0.00	-2.57	-1.26

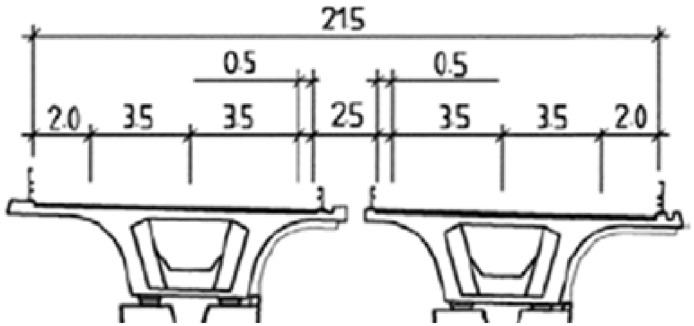
Structural-members' LCC added-values at a discount rate of 4%

To maintain contractors' freedom in D-B tendering processes and allow consideration of innovative/different designs.

Bridge structural-member	Unit	LCC sub added-value	
		Unit LCM cost (K SEK/Unit)	Fixed Cost (K SEK)
Bearings number	set	7.0	54.4
Expansion joint length	m	5.8	156.4
Edge beam length	m	1.6	108.3
Painted area	m^2	0.4	85.3
Parapets' length	m	1.0	0.0
Paved area	m^2	0.5	462.0
Drainage system points	set	32.7	0.0
Slopes and cones area	m^2	0.4	0.0
Superstructure area	m^2	0.2	0.0
Total bridge area	m^2	0.6	0.0

Procurement of the Karlsnäs Bridge

- The LCC added-values and BSM's LCC added-values had been stated in the tender documents.
- 5 Contractors had participated, all of them are Proposal 3



- The contract was awarded to the lowest LCC bid, with an INV cost of 115 million SEK.
- **Trafikverket has saved 57 million SEK**

Paper V: Holistic Approach

- Bridge LCC
  - Agency cost INV & LCM
  - User Cost
  - Society Cost
    - Aesthetical & Cultural Effects
    - Environmental Impact (LCA)

Holistic Approach

- The **lowest Net Equivalent LCC bid** should be the criterion used to identify the most sustainable bridge proposal and select the D-B contractor offering it.

- The approach combines LCC Added-Value analysis with other novel techniques that make proposals' aesthetic merit and environmental impact commensurable,

- Thereby enabling agencies to establish **Monetary Benchmarks** concerning those aspects in an early planning phase and embed them in the tender documents as core specifications.

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WTP & WTPE

- In economics, the willingness-to-pay (WTP) is the maximum amount a person would be willing to pay in order to receive a good or avoid something undesired.
- Extending this concept, we propose here a novel parameter, willingness-to-pay-extra (WTPE), the maximum extra amount a person would be willing to pay to receive a good that is better than another in terms of a specific attribute.
- This is not meant to imply that designs of great aesthetic merit or more environmental friendly are necessarily more expensive than ugly substitutes, or vice versa.

KTH VETENSKAP OCH KONST

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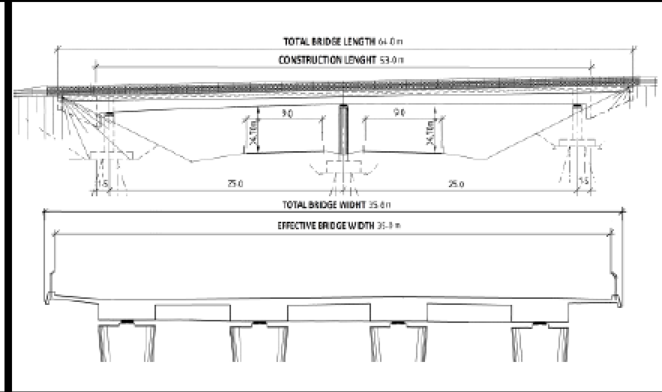
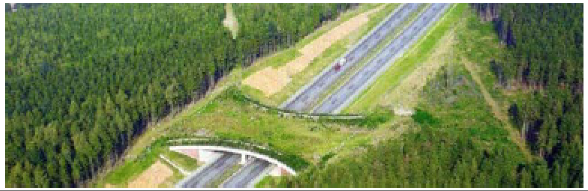
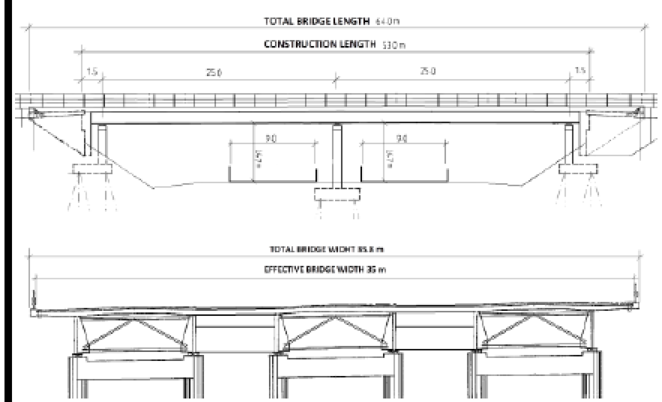
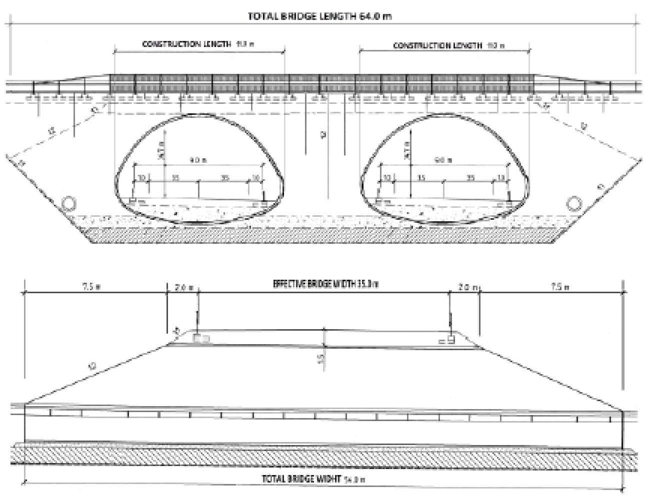
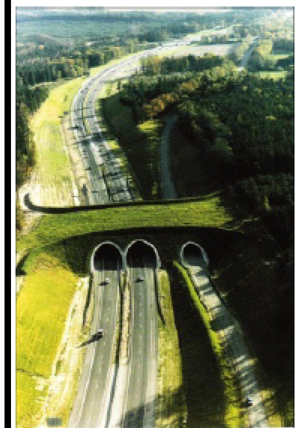
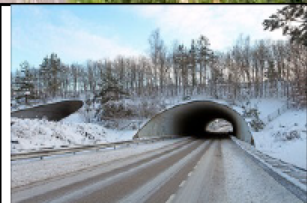
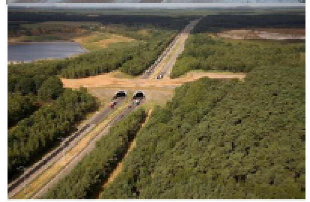
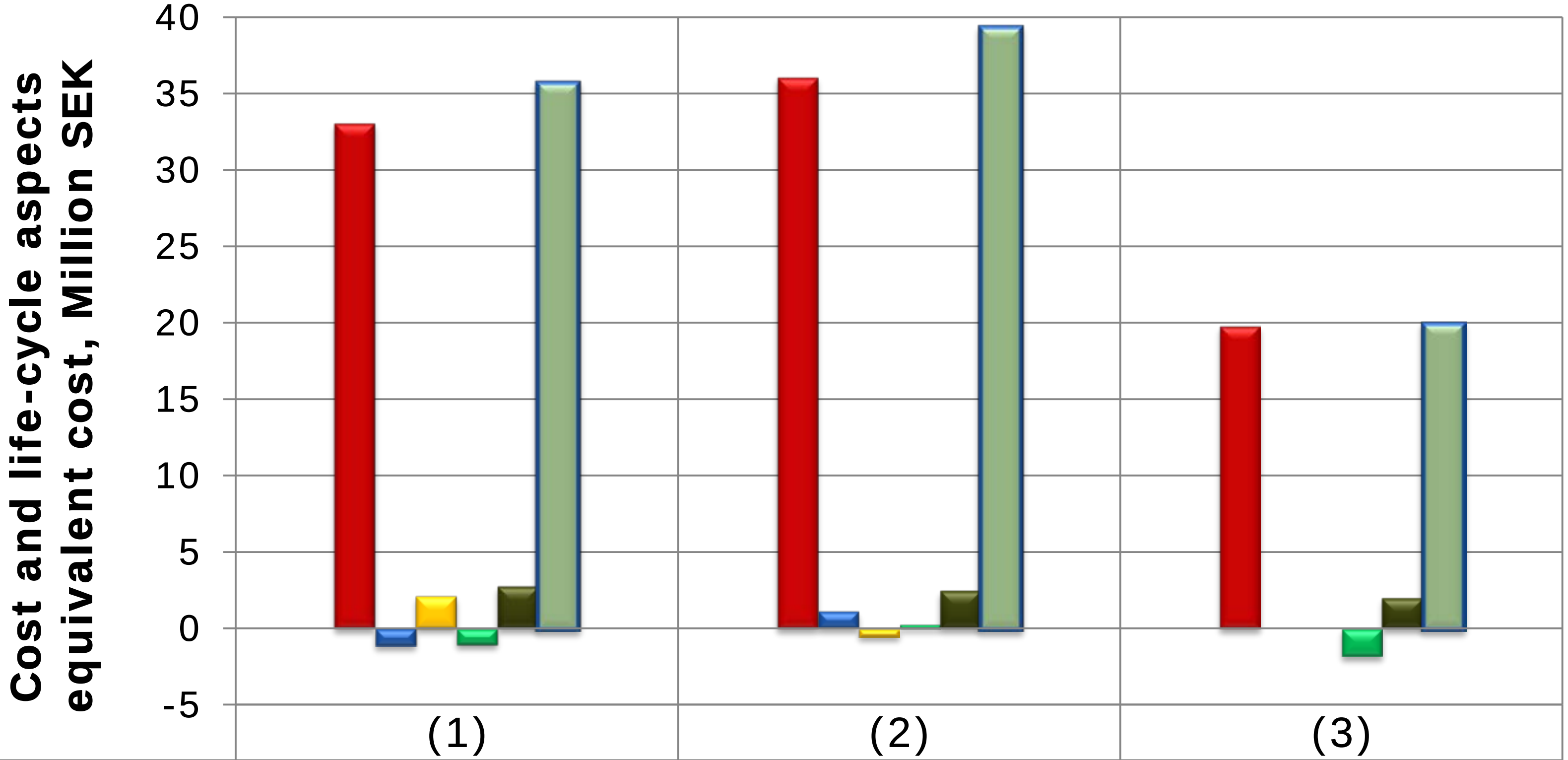
Case Study

A wildlife crossing bridge over the European route E6 in Gothenburg, 2015.

No.	Description	Elevation and Cross-Section	Similar Existing Bridges
1	Concrete beam bridge with integrated breast wall (Trafikverket's conceptual design)		 
2	Steel I-beam bridge composite with concrete slab with integrated breast wall		 
3	Two steel pipe-arch culverts		   

Life-cycle aspects' contributions and net equivalent LCC costs of Proposals



	(1)	(2)	(3)
Anticipated INV & TCP cost	33.07	36.08	19.79
LCC added-value	-1.13	1.11	0.00
User cost added-value	2.10	-0.54	0.00
CEEM	-1.06	0.26	-1.83
CEEI	2.74	2.45	2.01
The net equivalent LCC	35.72	39.35	19.97

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Network-level Benefits of LCCA Considering Trafikverket's Bridges

If improper decisions are taken for 50% of Trafikverket's bridges, the agency might lose (or could otherwise save):

- **Paper I, III**
  - Road bridges: 75 million SEK each year
  - Railway bridges: 65 million SEK each year
- **Paper IV:**
  - 8 million SEK per year
- **Paper II and V:**
  - 340 million SEK per year

Total of 488 million SEK each year?!

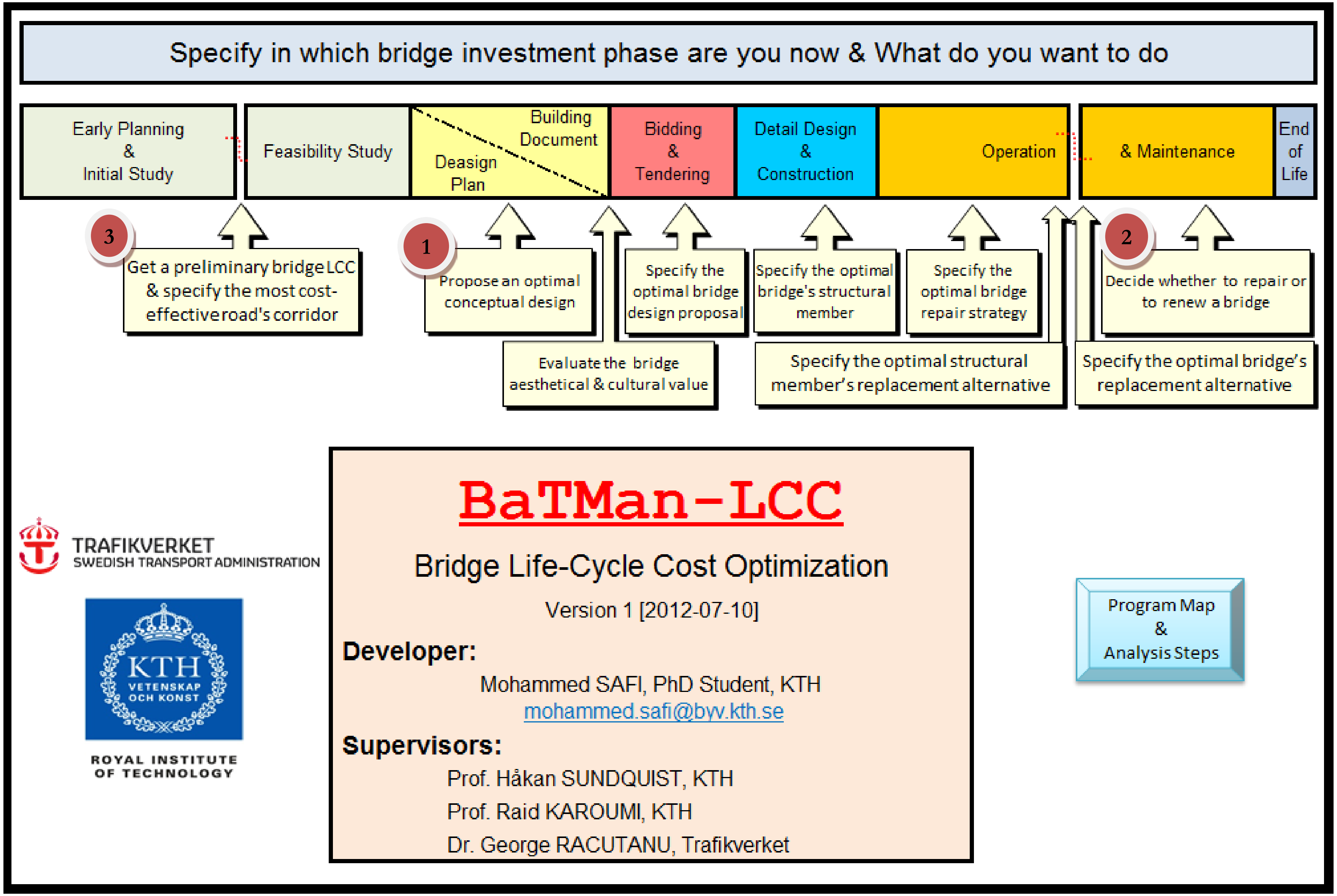
Conclusions

- Undoubtedly, LCCA can be feasibly and fruitfully applied in both bridge management and bridge investment.
- The most expensive bridge proposal is not necessarily the most environmentally friendly, beautiful or LCC-efficient, and vice versa. Costs, aesthetic merit and environmental concerns could be complementary in bridge design.
- The greatest saving potential in bridge procurement could be achieved by allowing more proposals to be considered
- D-Bs together with the lowest LCC bid affords greater opportunities to consider LCC aspects in bridge procurement than traditional contracts and the lowest bid criterion.
- The sensitivity analysis is, NS and OL parameters are important that allows decision-makers to evaluate their confidence in the optimality of their chosen solution and estimate the consequences of their decisions.
- The discount rate is usually has a considerable impact on the LCCA, but this does not hinder the implementation of the proposed applications and.

Proposals for Further Research

- Standard LCC sub added-values
- Technically feasible bridge-designs
- LCCA curves for the various bridge locations
- Effect of repairs on the residual service life
- Network-level LCCA

Practical Implementation



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BaTMan-LCC Course


Thank You!
Questions?