Infrastructure Cost-Efficient & Sustainable
Procurement & Management

Overview & Implementation

Mohammed SAFI
Who am I ?!

MOHAMMED SAFI

Infrastructure Life-Cycle Cost Analysis Specialist

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EDUCATION & DEGREES

2013 Ph.D., Structural Engineering and Bridges, KTH Royal Institute of Technology, Sweden.

Thesis: "Life-Cycle Costing: Applications and Implementations in Bridge Investment and Management"

Supervisors: Prof. Håkan Sundquist & Prof. Raid Karoumi
Opponent: Prof. Jan-Eric Nilsson/VTI
Evaluation Committee: Prof. Anne Landin-LTH, Prof. Lennart Elfgren-LTU & Prof. Hans Lind-KTH
## CURRENT & PREVIOUS POSITIONS

<table>
<thead>
<tr>
<th>Year</th>
<th>Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>2014 – Present</td>
<td>Infrastructure Life-Cycle Cost Analysis Specialist, FOLKBRO Konsult</td>
</tr>
<tr>
<td>2012 – 2013</td>
<td>Bridge LCC Analysis Specialist, Trafikverket – The Swedish Transport Administration</td>
</tr>
<tr>
<td>2014 – Present</td>
<td>Researcher, KTH Royal Institute of Technology</td>
</tr>
<tr>
<td>2007 – Present</td>
<td>Board Member &amp; Business Development Manager, AF-SAFI Company</td>
</tr>
<tr>
<td>2006 – 2007</td>
<td>Project Officer, UNRWA – United Nations Relief &amp; Working Agency</td>
</tr>
<tr>
<td>2005 – 2006</td>
<td>Construction Engineer, AC-The Arab Contractors</td>
</tr>
</tbody>
</table>
Agenda

• Introduction
• Infrastructure life-cycle & the possible LCCA applications
• The Swedish bridge stock
• BaTMan and WebHybris
• LCCA for the procurement of new bridges
  • The optimal road/rail corridor
  • The optimal bridge design proposal
  • Holistic approach
• LCCA for management of existing bridges
  • Repair or replace a bridge?
• BaTMan-LCC tool & BaTMan-LCC course
• Questions & discussion
Background

- Selection from multiple alternatives
- Conventional financial costing
- Maximize efficiency, sustainability and ensure the optimum use of taxpayers’ money
- Enhance infrastructure 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.
LCC & LCCA

Bridge Life-Cycle Cost: LCC

- The time value of money, discount rate
- Life-Cycle Costing/Life-Cycle Cost Analysis (LCCA)
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.
- It is the function of the design standards and the qualification requirements to minimize the LCM costs of the bridges.
- Proper implementation of LCC could at least save 488 Mkr/year from Trafikverket’s annual budget assigned for bridge investment and management.
LCC Applications for Bridges

1. Get a preliminary bridge LCC & specify the most cost-efficient road corridor
2. Propose an optimal conceptual design and establish LCC benchmarks
3. Specify the optimal structural member
   - Specify the optimal repair strategy
   - Specify the optimal structural member replacement alternative
   - Should a heavily deteriorated bridge be repaired or replaced?

The Potential Net Saving of the various LCCA Applications

Decision on whether or not to undertake the project

Whole-life costing & LCCA

Life-cycle costing (LCCA)

Tender documents
Contract
Inauguration

Early Planning & Initial Study
Feasibility Study
Building Doc.
Design Plan
Bidding & Tendering
Detail Design & Construction
Operation & Maintenance
End of Life

Demolition
The Swedish Bridge and Tunnel Management System "BaTMan"

https://batman.vv.se/batman/
BaTMan’s Navigation Tool (WebHybris)
The Swedish Bridge Stock

<table>
<thead>
<tr>
<th>Bridge Function Type</th>
<th>Total No. Of Bridges</th>
<th>Bridge Total Area (m²)</th>
<th>Bridge Total Length (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Roadway</td>
<td>Railway</td>
<td>Pedestrian &amp; Bicycle</td>
</tr>
<tr>
<td>BaTMan's Bridges</td>
<td>23,848</td>
<td>4,411</td>
<td>1,619</td>
</tr>
<tr>
<td>Trafikverket's Bridges in</td>
<td>20,050</td>
<td>3,179</td>
<td>207</td>
</tr>
<tr>
<td>BaTMan</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Bridge Construction Material

- Concrete
- Steel
- Timber
- Stone
- Special Material

Bridge Types

- Slab Bridge
- Beam Bridge
- Slab-Frame Bridge
- Beam-Frame Bridge
- Culvert Bridge
- Earth Filled Arch Bridge
- Open Spandrel Arch Bridge
- Cable Stayed Bridge
- Suspension Bridge
- Other Bridge types

- L < 5m
- 5m ≤ L < 10m
- 10m ≤ L < 20m
- 20m ≤ L < 30m
- 30m ≤ L < 50m
- 50m ≤ L < 100m
- 100m ≤ L < 200m
- 200m ≤ L < 500m
- 500m ≤ L < 1000m
- 1000m ≤ L
Swedish Bridges Real INV Cost

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

Y = 458.37X - 904726
R² = 0.9189
Structural-Members Life-Cycle Measures

Actual Service Life of the Swedish Bridge's Expansion Joints

\[ y = -4.779\ln(x) + 84.151 \]

Based on 288 Replacement Actions performed between 1979 and 2010
LCCA for Procurement of New Bridges
App. No. (1): Specify the most life-cycle cost-effective road corridor
App. No. (2): Specify the most life-cycle cost-effective road corridor
App. No. (2): Specify the most life-cycle cost-effective road corridor
App. No. (2): Propose an optimal conceptual design during
Procurement Principals 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
• Trafikverrekt’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.
Analysis Steps

Comprehensive Approach:

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

**The Karlsnäsv Bridge 2013**

<table>
<thead>
<tr>
<th>Proposal No.</th>
<th>Description</th>
<th>Cross-Section Details</th>
<th>Outlines &amp; Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>One bridge, two steel boxes (Trafikverket’s conceptual design)</td>
<td><img src="image1.png" alt="Cross-section 1" /></td>
<td>5 Spans 4x60m + 2x40m  Superstructure depth: 2.3m</td>
</tr>
<tr>
<td>2</td>
<td>Two bridges, two steel I beams per bridge</td>
<td><img src="image2.png" alt="Cross-section 2" /></td>
<td>5 Spans 4x60m + 2x40m  Superstructure depth: Haunch beam Max. 3.2m Min. 1.8m</td>
</tr>
<tr>
<td>3</td>
<td>Two bridges, one pre-stressed concrete box per bridge</td>
<td><img src="image3.png" alt="Cross-section 3" /></td>
<td>7 Spans 5x50m + 2x35m  Superstructure depth: Haunch beam Max. 2.8m Min. 1.6m</td>
</tr>
<tr>
<td>4</td>
<td>One bridge, two pre-stressed concrete boxes.</td>
<td><img src="image4.png" alt="Cross-section 4" /></td>
<td>7 Spans 5x50m + 2x35m  Superstructure depth: Haunch beam Max. 2.8m Min. 1.6m</td>
</tr>
<tr>
<td>5</td>
<td>One bridge, one integral-cantilever concrete box</td>
<td><img src="image5.png" alt="Cross-section 5" /></td>
<td>4 Spans 2x100m + 2x60m  Superstructure depth: Haunch beam Max. 6.5m Min. 2.3m</td>
</tr>
</tbody>
</table>
LCCA Results

![Diagram showing LCCA Results with Proposal Numbers (1) to (5) and cost comparisons for LCM Cost NPV, r=2%, LCM Cost NPV, r=4%, and INV Cost.](image-url)
Impact of varying the discount rate on the proposals’ LCC
LCC added-values computed at indicated discount rates (SEK)

<table>
<thead>
<tr>
<th>LCC added-values, Million SEK</th>
<th>0%</th>
<th>2%</th>
<th>4%</th>
<th>6%</th>
<th>8%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proposal (1)</td>
<td>14.65</td>
<td>5.48</td>
<td>2.27</td>
<td>-1.54</td>
<td>-0.74</td>
</tr>
<tr>
<td>Proposal (2)</td>
<td>38.44</td>
<td>14.16</td>
<td>5.75</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Proposal (3)</td>
<td>8.77</td>
<td>3.06</td>
<td>1.21</td>
<td>-2.02</td>
<td>-0.97</td>
</tr>
<tr>
<td>Proposal (4)</td>
<td>0.00</td>
<td>-0.01</td>
<td>0.02</td>
<td>-2.54</td>
<td>-1.23</td>
</tr>
<tr>
<td>Proposal (5)</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>-2.57</td>
<td>-1.26</td>
</tr>
</tbody>
</table>
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.

<table>
<thead>
<tr>
<th>Bridge structural-member</th>
<th>Unit</th>
<th>LCC sub added-value</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Unit LCM cost</td>
<td>Fixed Cost</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(K SEK/Unit)</td>
<td>(K SEK)</td>
<td></td>
</tr>
<tr>
<td>Bearings number</td>
<td>set</td>
<td>7.0</td>
<td>54.4</td>
<td></td>
</tr>
<tr>
<td>Expansion joint length</td>
<td>m</td>
<td>5.8</td>
<td>156.4</td>
<td></td>
</tr>
<tr>
<td>Edge beam length</td>
<td>m</td>
<td>1.6</td>
<td>108.3</td>
<td></td>
</tr>
<tr>
<td>Painted area</td>
<td>m²</td>
<td>0.4</td>
<td>85.3</td>
<td></td>
</tr>
<tr>
<td>Parapets’ length</td>
<td>m</td>
<td>1.0</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>Paved area</td>
<td>m²</td>
<td>0.5</td>
<td>462.0</td>
<td></td>
</tr>
<tr>
<td>Drainage system points</td>
<td>set</td>
<td>32.7</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>Slopes and cones area</td>
<td>m²</td>
<td>0.4</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>Superstructure area</td>
<td>m²</td>
<td>0.2</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>Total bridge area</td>
<td>m²</td>
<td>0.6</td>
<td>0.0</td>
<td></td>
</tr>
</tbody>
</table>
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.
<table>
<thead>
<tr>
<th>No.</th>
<th>Description</th>
<th>Elevation and Cross-Section</th>
<th>Similar Existing Bridges</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Concrete beam bridge with integrated breast wall (Trafikverket’s conceptual design)</td>
<td><img src="image1.png" alt="Elevation and Cross-Section" /></td>
<td><img src="image2.png" alt="Similar Existing Bridges" /></td>
</tr>
<tr>
<td>2</td>
<td>Steel I-beam bridge composite with concrete slab with integrated breast wall</td>
<td><img src="image3.png" alt="Elevation and Cross-Section" /></td>
<td><img src="image4.png" alt="Similar Existing Bridges" /></td>
</tr>
<tr>
<td>3</td>
<td>Two steel pipe-arch culverts</td>
<td><img src="image5.png" alt="Elevation and Cross-Section" /></td>
<td><img src="image6.png" alt="Similar Existing Bridges" /></td>
</tr>
</tbody>
</table>

**Case Study**

A wildlife crossing bridge over the European route E6 in Gothenburg, 2015.
Life-cycle aspects’ contributions and net equivalent LCC costs of Proposals

<table>
<thead>
<tr>
<th>Cost and life-cycle aspects equivalent cost, Million SEK</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anticipated INV &amp; TCP cost</td>
<td>33.07</td>
<td>36.08</td>
<td>19.79</td>
</tr>
<tr>
<td>LCC added-value</td>
<td>-1.13</td>
<td>1.11</td>
<td>0.00</td>
</tr>
<tr>
<td>User cost added-value</td>
<td>2.10</td>
<td>-0.54</td>
<td>0.00</td>
</tr>
<tr>
<td>CEEM</td>
<td>-1.06</td>
<td>0.26</td>
<td>-1.83</td>
</tr>
<tr>
<td>CEEI</td>
<td>2.74</td>
<td>2.45</td>
<td>2.01</td>
</tr>
<tr>
<td>The net equivalent LCC</td>
<td>35.72</td>
<td>39.35</td>
<td>19.97</td>
</tr>
</tbody>
</table>
LCCA for Management of Existing Bridges
## Bridge Management

### Repair or replace a heavily deteriorated bridge?

<table>
<thead>
<tr>
<th>Road Bridges</th>
<th>Railway Bridges</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Paper III:</strong> TRR Journal [18-352-1] Bro över Täbyån, Höjen Construction Year: 1929</td>
<td></td>
</tr>
</tbody>
</table>

- An action is required within a 3 years period, CC2
- An immediate action is required, CC3
**Strategies Formulation**

**Strategy A:** Immediately repair the bridge

- Repair Cost
- User Cost
- Extended Residual Service after Repair
- Annual O&M Cost after Repair

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

- Renewal Cost
- User Cost
- Residual Service Life without Action
- Annual O&M Cost after Renewal

**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
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
Practical Implementation

Ange i vilken bro investeringsfas är du nu & Vad vill du göra

Tidig Planering & Förstudie
Vägutredning
Bygghandling
Upphandling & Avtal
Detalj Design & Anläggningsfas
Drift & Underhåll
Slut av livet

Få en preliminär bro LCC och ange det mest kostnadseffektiva vägkorridoren
Föreslå en optimal konceptuell design
Ange optimala entreprenörer, anbud/förslag
Ange den optimala bron konstruktionsdelen
Ange den optimala reparationstrategi
Ska bron repareras eller bytas ut

Utvärdera bron estetiska och kulturella värden
Ange den optimala konstruktionsdelen ersättare alternativ
Ange den optimala bron ersättare alternativ

TRAFIKVERKET

BaTMan-LCC
Bro livscykelkostnad Optimering
Version 1.3 [2013-12-01]
Utvecklare & Upphovsrätt:
FOLKBRÖ
info@folkbro.com

Program Karta & Analys steg
BaTMan-LCC relation with BaTMan

1. Detailed Info., price etc. (N/A in BaTMan)
2. BaTMan-LCC (KTH)
3. WebHybris
4. BaTMan
5. NVDB

NATIONELL VÄGDATABASES
KOMMUNER OCH LANDSTING, LANTMÄTTERIET, TRANSPORTSTYRELSEN
SKOGSNÄRINGEN, Trafikverket
BaTMan-LCC Course
Thank You

Questions?