Equation (1) presents the criterion for evaluating the contractors’ D-B bids mathematically.

\[ LCC_{X,R}^{X} = C_{INV}^{X} + LCC_{AV}^{X,R} \]  

(1)

Proposal \( R \) is given an LCC added-value of zero, and the LCC added-value for proposal \( X \) is calculated using equation (2), with adjustments (if necessary) for differences between them in lifespan and associated LCM costs:

\[ LCC_{AV}^{X,R} = \left( (EAC_{LCM}^{X} - EAC_{LCM}^{R}) \cdot \frac{1-(1+r)^{-Lmin}}{r} \right) \mp \left( \frac{EAC_{AV}^{R} \cdot 1-(1+r)^{-|L_{R}-L_{X}|}}{(1+r)^{L_{min}} \cdot r} \right) \]  

(2)

The second part of equation (2) will have a positive sign if \( L_{X} < L_{R} \) and vice versa.
Cost categories to be Included in LCCA of New Bridges

- Early Planning & Initial Study
- Feasibility Study
- Building Doc.
- Design Plan
- Bidding & Tendering
- Detail Design & Construction
- Operation & Maintenance
- End of Life
- Pre-contract costs
- Capital investment cost

Life-cycle costing (LCCA)

Agency cost

- Capital investment cost
- Life-cycle measures (LCM) Cost
- Pre-contract costs

Direct LCC to be Included in LCCA of New Bridges

R D & L

28 July 2015

Mohammed Safi
Paper V: Origin of the Idea
LCCA

Discount Rate

INV cost and LCM cost NPV, Million SEK

Proposal Number

Proposal (1) LCC EAC
Proposal (2) LCC EAC
Proposal (1) LCC NPV
Proposal (2) LCC NPV
Proposal (3) LCC EAC
Proposal (3) LCC NPV

Proposal (1) LCC NPV
Proposal (2) LCC NPV
Proposal (3) LCC NPV

Proposal (1) LCM Cost NPV, r=2%
Proposal (1) LCM Cost NPV, r=4%
Proposal (2) LCM Cost NPV, r=4%
Proposal (2) LCM Cost NPV, r=2%
Proposal (3) LCM Cost NPV, r=4%
Proposal (3) LCM Cost NPV, r=2%

INV Cost

0% 1% 2% 3% 4% 5% 6% 7% 8%

0 5 10 15 20 25 30 35 40 45 50

0 1 3 8 24 73

73 24 8 3 1 0

(1) (2) (3) (1) (2) (3)
Cost Equivalent of the Lifespan and LCM cost difference

Discount Rate

<table>
<thead>
<tr>
<th>Discount Rate</th>
<th>Life-span sub added-value</th>
<th>LCM cost sub added-value</th>
<th>LCC Added-Value 1,3</th>
<th>LCC Added-Value 2,3</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td>6.16</td>
<td>2.46</td>
<td>-0.38</td>
<td>-0.41</td>
</tr>
<tr>
<td>2%</td>
<td>6.31</td>
<td>2.46</td>
<td>-0.31</td>
<td>-0.41</td>
</tr>
<tr>
<td>4%</td>
<td>6.31</td>
<td>1.08</td>
<td>0.76</td>
<td>0.53</td>
</tr>
<tr>
<td>6%</td>
<td>6.31</td>
<td>0.53</td>
<td>0.21</td>
<td>0.29</td>
</tr>
<tr>
<td>8%</td>
<td>6.31</td>
<td>0.21</td>
<td>0.05</td>
<td>-0.14</td>
</tr>
</tbody>
</table>
Work-Zone User Cost

The proposals' WZUC NPV and LCC EAC, Million SEK

Accident Cost, Vehicle Operation Cost, Traffic Delay Cost

Proposal (1) LCC EAC, Proposal (2) LCC EAC, Proposal (3) LCC EAC

Proposal (1) WZUC NPV, Proposal (2) WZUC NPV, Proposal (3) WZUC NPV

WZUC incurred by establishing a work-zone for a day during construction

The proposals' WZUC NPV, Thousands SEK

Discount Rate

0% 1% 2% 3% 4% 5% 6% 7% 8%

0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0

28 July 2015

Mohammed Safi
Integration and Evaluation of Aesthetic Aspects

<table>
<thead>
<tr>
<th>Items considered for evaluation</th>
<th>Weight factors $w_j$ (out of 100)</th>
<th>Average evaluation points $p_j$ for Proposal no.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structure simplicity and integration with the site</td>
<td>10</td>
<td>1 2 3</td>
</tr>
<tr>
<td>Structure honesty and visibility from the underpass traffic perspective</td>
<td>10</td>
<td>1 1 -2</td>
</tr>
<tr>
<td>Bridge view from above</td>
<td>10</td>
<td>1 -1 2</td>
</tr>
<tr>
<td>Bridge form as a whole</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Symmetry, order &amp; rhythm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unity of design and harmony of spans</td>
<td>5</td>
<td>1 1 2</td>
</tr>
<tr>
<td>Proportion</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Depth to span ratio</td>
<td>5</td>
<td>1 1 2</td>
</tr>
<tr>
<td>Deck to parapet depth ratio</td>
<td>2</td>
<td>0 0 1</td>
</tr>
<tr>
<td>Span to parapet depth ratio</td>
<td>2</td>
<td>0 0 1</td>
</tr>
<tr>
<td>Superstructure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parapet design &amp; shape</td>
<td>5</td>
<td>1 0 2</td>
</tr>
<tr>
<td>Elevation</td>
<td>5</td>
<td>0 0 2</td>
</tr>
<tr>
<td>Cross-section</td>
<td>4</td>
<td>-1 -2 2</td>
</tr>
<tr>
<td>Headstock and pier combination</td>
<td>5</td>
<td>0 -2 2</td>
</tr>
<tr>
<td>Piers</td>
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<td></td>
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<tr>
<td>Longitudinal pier spacing</td>
<td>4</td>
<td>-1 -1 -2</td>
</tr>
<tr>
<td>Pier cross-section</td>
<td>4</td>
<td>1 -1 -2</td>
</tr>
<tr>
<td>Pier short elevation</td>
<td>2</td>
<td>0 0 -2</td>
</tr>
<tr>
<td>Pier long elevation</td>
<td>2</td>
<td>0 0 -2</td>
</tr>
<tr>
<td>Substructure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visible size</td>
<td>4</td>
<td>1 1 2</td>
</tr>
<tr>
<td>Placement</td>
<td>2</td>
<td>1 1 1</td>
</tr>
<tr>
<td>Shape</td>
<td>4</td>
<td>1 1 2</td>
</tr>
<tr>
<td>Details</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Joints and connections</td>
<td>3</td>
<td>0 0 1</td>
</tr>
<tr>
<td>Barriers &amp; railings</td>
<td>3</td>
<td>1 1 1</td>
</tr>
<tr>
<td>Lighting, color &amp; embellishments</td>
<td>4</td>
<td>1 1 2</td>
</tr>
<tr>
<td>Aesthetic coefficient: $k_{AES}$</td>
<td>-0.29</td>
<td>0.07 -0.50</td>
</tr>
<tr>
<td>Willingness-to-pay-extra for the bridge’s aesthetic appeal: $WTPE_{SEK}$ (Million SEK)</td>
<td>3.66</td>
<td></td>
</tr>
<tr>
<td>Cost equivalent of the aesthetic merit: $CEAM^3$ (Million SEK)</td>
<td>-1.06</td>
<td>0.26 -1.83</td>
</tr>
<tr>
<td>Aesthetic rank</td>
<td>2nd</td>
<td>3rd 1st</td>
</tr>
</tbody>
</table>
LCA Results

Impact categories with their measured unit

- GWP, 1.0E+06 kg CO2 eq
- HTP, 3.3E+05 kg 1,4-DB eq
- POFP, 3.3E+03 kg NMVOC
- PMFP, 3.3E+03 kg PM10 eq
- ODP, 1.0E-01 kg CFC-11 eq

Characterized environmental impact

- Asphalt Pavement
- Filling material
- Traffic Delay
- Painting
- Bearing
- Steel Railing
- Structural Steel
- Reinforcement Steel
- Concrete
## Monetary weighting of the LCA

### Results

<table>
<thead>
<tr>
<th>Impact category</th>
<th>Unit</th>
<th>Monetary weighting factor (SEK/Unit)</th>
<th>Proposal 1</th>
<th>Proposal 2</th>
<th>Proposal 3</th>
<th>Monetar y impact cost (kSEK)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GWP</td>
<td>kg CO2 eq</td>
<td>2.85</td>
<td>1.9E+06</td>
<td>5,422</td>
<td>1.6E+06</td>
<td>4,548</td>
</tr>
<tr>
<td>ODP</td>
<td>kg CFC-11 eq</td>
<td>--</td>
<td>1.2E-01</td>
<td>--</td>
<td>8.2E-02</td>
<td>--</td>
</tr>
<tr>
<td>HTP</td>
<td>kg 1,4-DB eq</td>
<td>2.81</td>
<td>3.3E+05</td>
<td>934</td>
<td>3.6E+05</td>
<td>1,026</td>
</tr>
<tr>
<td>POFP</td>
<td>kg NMVOC</td>
<td>15.97</td>
<td>6.6E+03</td>
<td>106</td>
<td>5.2E+03</td>
<td>83</td>
</tr>
<tr>
<td>PMFP</td>
<td>kg PM10 eq</td>
<td>273</td>
<td>3.5E+03</td>
<td>960</td>
<td>3.5E+03</td>
<td>960</td>
</tr>
<tr>
<td>IRP</td>
<td>kg U235 eq</td>
<td>--</td>
<td>7.1E+04</td>
<td>--</td>
<td>7.0E+04</td>
<td>--</td>
</tr>
<tr>
<td>TAP</td>
<td>kg SO2 eq</td>
<td>30</td>
<td>5.3E+03</td>
<td>158</td>
<td>4.5E+03</td>
<td>135</td>
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<tr>
<td>FEP</td>
<td>kg P eq</td>
<td>670</td>
<td>4.5E+01</td>
<td>30</td>
<td>5.7E+01</td>
<td>38</td>
</tr>
<tr>
<td>MEP</td>
<td>kg N eq</td>
<td>90</td>
<td>2.1E+02</td>
<td>19</td>
<td>1.6E+02</td>
<td>14</td>
</tr>
<tr>
<td>TETP</td>
<td>kg 1,4-DB eq</td>
<td>--</td>
<td>1.4E+02</td>
<td>--</td>
<td>1.3E+02</td>
<td>--</td>
</tr>
<tr>
<td>FETP</td>
<td>kg 1,4-DB eq</td>
<td>--</td>
<td>5.3E+02</td>
<td>--</td>
<td>4.5E+02</td>
<td>--</td>
</tr>
<tr>
<td>METP</td>
<td>kg 1,4-DB eq</td>
<td>12</td>
<td>1.3E+03</td>
<td>16</td>
<td>1.5E+03</td>
<td>18</td>
</tr>
</tbody>
</table>

**Total monetary impact cost (kSEK):**

- Proposal 1: 7,645
- Proposal 2: 6,821
- Proposal 3: 4,478

**Total monetary impact cost/year, (kSEK):**

- Proposal 1: 76
- Proposal 2: 68
- Proposal 3: 56

**Total monetary impact cost for 80 years (kSEK):**

- Proposal 1: 6,116
- Proposal 2: 5,457
- Proposal 3: 4,478

**Environmental rank:**

- Proposal 1: 3rd
- Proposal 2: 2nd
- Proposal 3: 1st

**\( k_{EI}^{X} \):**

- 100%
- 89%
- 73%

**\( WTEP_{Hi}(kSEK) \):**

- 2,744

**\( CEEI^{X,R}(kSEK) \):**

- 2,744
- 2,448
- 2,009
Relation between the INV cost of the repair strategy and the minimum required residual service life extension

![Graph showing the relationship between the INV cost of the repair strategy and the minimum residual service-life extension after repair, measured in years and million SEK.](image)
# The Swedish Bridge Stock

<table>
<thead>
<tr>
<th>Bridge Function Type</th>
<th>Roadway</th>
<th>Railway</th>
<th>Pedestrian &amp; Bicycle</th>
<th>Other</th>
<th>Total No. Of Bridges</th>
<th>Bridge Total Area (m²)</th>
<th>Bridge Total Length (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BaTMan's Bridges</td>
<td>23,848</td>
<td>4,411</td>
<td>1,619</td>
<td>251</td>
<td>30,129</td>
<td>7,644,208</td>
<td>668,381</td>
</tr>
<tr>
<td>Trafikverket's Bridges in BaTMan</td>
<td>20,050</td>
<td>3,179</td>
<td>207</td>
<td>14</td>
<td>23,450</td>
<td>5,858,570</td>
<td>528,905</td>
</tr>
</tbody>
</table>

**Graphs:**

- **Bar Graph:**
  - Number of Bridges by Bridge Construction Material
  - Materials: Concrete, Steel, Timber, Stone, Special Material

- **Pie Chart:**
  - Bridge Length Distribution
  - Length Categories: 2.0 - 5.0 m, 5.0 - 10.0 m, 10.0 - 20.0 m, 20.0 - 30.0 m, 30.0 - 50.0 m, 50.0 - 100.0 m, >100.0 m
  - Percentages: 30.24%, 26.39%, 19.09%, 6.86%, 6.92%, 7.18%, 0.99%

- **Other:**
  - Slab Bridge
  - Slab-Frame Bridge
  - Beam Bridge
  - Beam-Frame Bridge
  - Culvert Bridge
  - Earth Filled Arch Bridge
  - Open Spandrel Arch Bridge
  - Cable Stayed Bridge
  - Suspension Bridge
  - Other Bridge Types

28 July, 2015

Mohammed Safi
The Average Real INV cost/m²

Based on cost data for 2,508 bridges constructed between 1980 and 2011.
The real inflation rate of the INV cost/m²

\[ Y = 458.37X - 904726 \]
\[ R^2 = 0.9189 \]
BSMs’ LCPs based on Real repair Records

Based on 288 Replacement actions performed between 1980 and 2010

Appendix B introduces rough life-cycle plans (LCPs) for the various bridge structural members (BSMs) of Swedish bridges.
Procurement within Public Agencies

Public Procurement Act, based on EU Procurement Directives.

Enquiry documentation is the collective documentation that:

• Describes what is to be procured,
• What requirements are placed on the tenderer
• and the subject of the procurement,
• as well as how the tenders will be evaluated.
The Concept of the Lowest LCC Bid

- The lowest LCC bid should be used as the contract award criterion under D-Bs, instead of the lowest INV bid

- Two inappropriate ways to apply the lowest LCC bid award criterion.

  1. Request contractors to supplement bids with life-cycle plans (LCPs) and LCM cost calculations:
     
     A. Some contractors may underestimate LCM costs of their designs because they will not usually be obligated in the long run.
     
     B. Most contractors are not familiar with actual LCM costs of designs, since they are usually incurred by the bridge procurers.
     
     C. The LCP and LCM costs for a proposal prepared by a contractor could be strongly questioned by other contractors.

  2. The other inappropriate way is for the agency to analyze LCCs of contractors’ bids and use the results to select a contractor,
     
     A. The results may easily be adjusted to provide a desired answer and
     
     B. Different analysts might generate different results.
Proposal (A) is associated with the least (EAC) which promotes it to be the most life-cycle cost-effective proposal.