Bridge Life Cycle Cost Optimization

Analysis, Evaluation & Implementation

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Thesis Idea/Starting Points

- In Fact, Implementation of a bridge design proposal decision is generally require that several alternatives to be considered. Many factors contribute to an agency's decision to select a particular option.
- Although initial project costs may dominate this decision. Initial agency costs, however, tell only part of the story.
- Some projects have exceeded all cost estimates but still it has been possible to fulfill them with success.

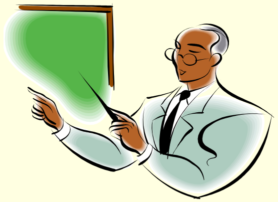
- Bridges are required to provide service for many years. Thus the investment decision should consider not only the initial activity, but also all future activities that will be required to keep that bridge in service condition.

Research Questions/Objective

- What is the optimum bridge design proposal?
- What are the factors that affect the decision making?
- How can we achieve and fulfill this target?
- How can we formalize & facilitate the bridge LCC optimization process?

- *Each involving parties has his own considerations and interests*

Individual Answers

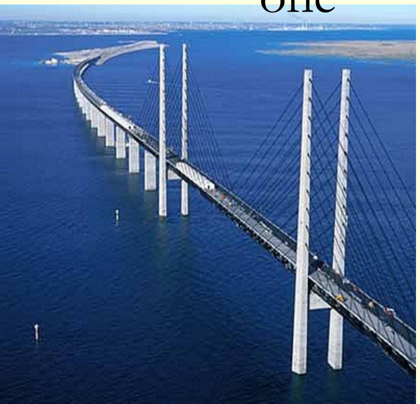


- **Bridge Owner/Agency:** The best bridge design is the one which meets project performance requirements at the lowest costs

- **Bridge Users:** The best bridge is the one which provide the highest level of traffic flow and safety conditions

- **Environmentalists:** Which gave the minimum environmental distortion

- **Social viewers & Neighbors:** The most beautiful/quiet one



- **The Optimum Bridge:** The one which fulfill all involving parties requirements & Interests with the lowest Life Cycle Costs

Thesis Structure

- Introduction
  - General
  - Bridge LCCA Principle
  - Feedback
- Agency Cost
  - Basic methodology
  - Feedback
- User Cost
  - Basic methodology
  - Developed computer program
  - Demonstration Example
- Aesthetical & Cultural Value
  - General
  - Basic methodology
  - Developed computer program
  - Demonstration Example
- Environmental Impact
  - General
  - Basic methodology
  - Demonstration Example
- Conclusion
  - Discussion
  - Future research

Unique Integrated bridge LCCA system

- Bridge life cycle cost components:-

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

- Bridge LCC Formalization ?!

System Formalization

$$LCC = C_{AG} + C_{USER} + C_{RACV} + C_{REI}$$

Where:-

- C_{AG} Is the corresponding ***Ag**ency cost*.
- C_{USER} Is the corresponding ***User** cost*.
- C_{RACV} Is the corresponding ***R**elative **A**esthetical and **C**ultural **V**alue cost*.
- C_{REI} Is the corresponding ***R**elative **E**nvironmental **I**mpact cost*.

Where:-

$$C_{RACV} = k_{AES} C_{AG}$$

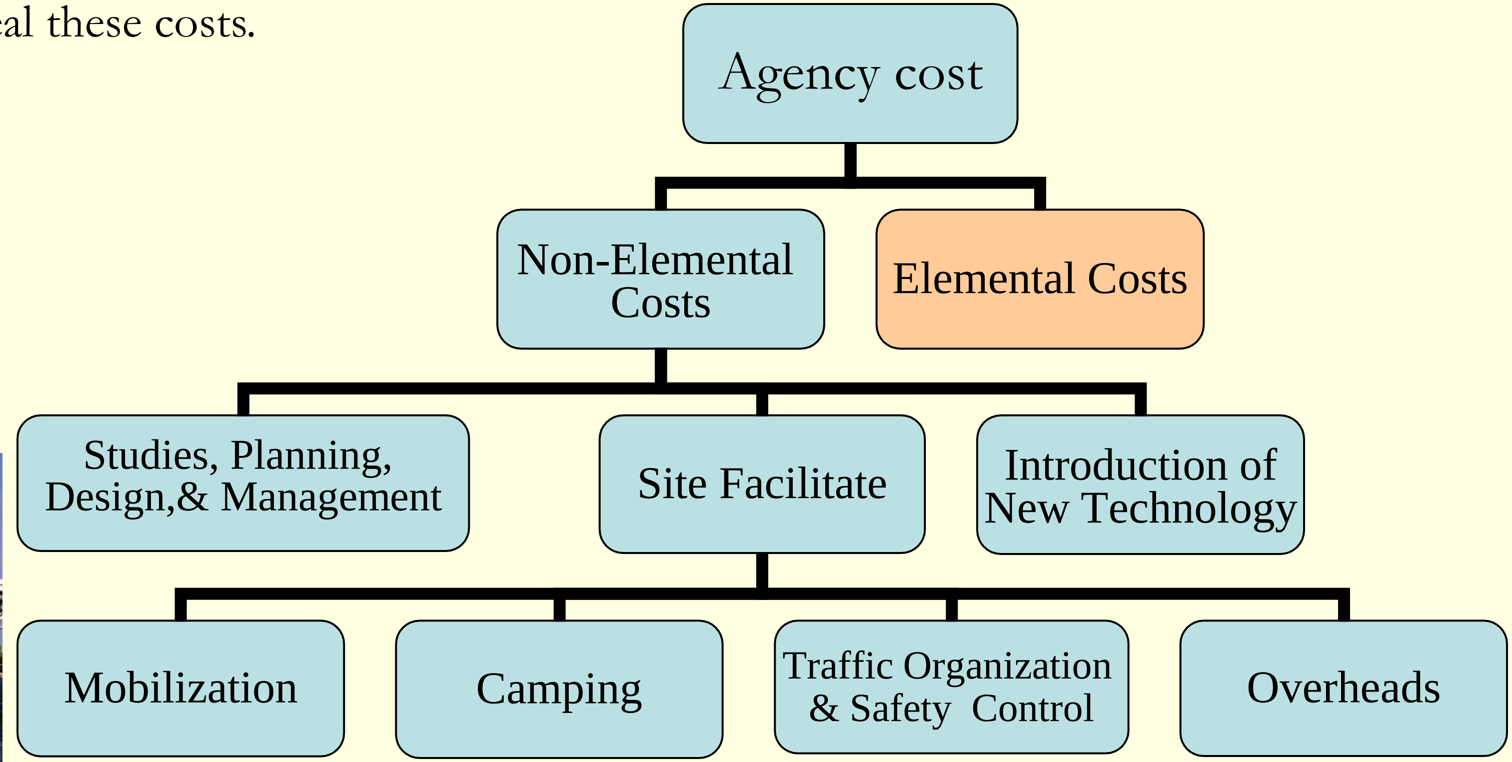
k_{AES} Is the aesthetical and cultural coefficient. Range from +0,30 To -0,30

$$C_{REI} = k_{EI} C_{AG}$$

k_{EI} Is the environmental impact coefficient. Range from 0,0 To +0,20

1- Agency Cost

- Agency costs are all costs incurred by the project's owner or agent over the whole bridge life or study period.
- Agency costs are relatively easy to estimate since historical data on similar projects reveal these costs.



Agency/Elemental Cost

- Elemental costs include all bridge components life-cycle cost categories which, in KTH we agreed to classify them ascending by there occurrence during the bridge life cycle, with these proposed titles as follow:

  - Investment Cost (Purchasing, Construction, & Installation)
  - Operation & Maintenance Cost
  - Inspection Cost
  - Repair/Rehabilitation & Replacement Cost
  - End of life Management Cost (Demolition and Landscaping)

- *Historical agency data is the best mechanism that can used to feed LCCA inputs.*

Historical Agency Data

❖ Operation & Maintenance Cost

Operation & Maintenance activities					
The Action Name	Recommended Intervals(*Year*)	Average Required Unit Duration			Average Cost % From The Agency Cost
		Value	Unit	From	
Cleaning the bridge of salt	1	0.05	hr/m^2	Bridge Area	,05
Cleaning & rodding of the drainage system	1	0.2	hr/m	Bridge Length	
Maintenance of parapets,gardrail& railings	1	0.5	hr/m	Bridge Length	
Maintenance of surface finish and laning	1	0.5	hr/m^2	Bridge Area	
Dehumidification, electricity and maintenance	1	0.5	hr/m^2	Bridge Area	
Protection against scour	1	0.2	hr/m^2	Bridge Area	
Improvement of painting	10	2	hr/m^2	Bridge Area	

❖ Inspection Cost

Inspections activities					
The Action Name	Recommended Intervals(*Year*)	Average Required Unit Duration			Average Cost % From The Agency Cost
		Value	Unit	From	
General inspection	1	0.05	hr/m^2	Bridge Area	0,15 (*Concrete Structures*) 0,20 (*Steel Structures*)
Major inspection	3	0.1	hr/m^2	Bridge Area	
Special inspection	6	0.2	hr/m^2	Bridge Area	

❖ End of life Management Cost (Demolition and Landscaping)

End of life Management (Demolition and Landscaping) activities					
The Action Name	Recommended Intervals(*Year*)	Average Required Unit Duration			Average Cost % From The Agency Cost
		Value	Unit	From	
Prestressed concrete bridges	100	0.025	day/m^2	Bridge Area	9
Convential reinforced concrete bridges	80	0.04	day/m^2	Bridge Area	10
Steel Structures	70	0.02	day/m^2	Bridge Area	8
Timber Bridges	50	0.015	day/m^2	Bridge Area	6

Bridge Breakdown Components

No.	Component / Activities	Type / Include	No.	Component / Activities	Type / Include
1	**Foundation**	Foundation slab Foundation plinth Rock filled box timber caisson Caisson Timber grillage Pile Backfill Erosion protection Sheet pile wall Rock anchor bolt	6	**Bridge equipment**	Bearing and Hinge Expansion joint Parapet Railing Guardrail Insulation, water proofing Drainage system Lightening, Electrical work and Accessories
2	**Slope and Embankment**	Embankment, embankment end, backfill Soil reinforcement and slope protection	7	**Surface layers**	Pavement (asphalt etc.) Insulation, water proofing Epoxy sealing Others
3	**Substructure**	Lower front wall Bridge seat Upper front wall Pier Footing slab for pier Counterfort Wing wall Supporting wall	8	**Earthworks**	Excavation soil Excavation rock Soil filling Others
4	**Superstructure**	Slab and deck Beam Truss Arch, Vault Arch spandrel wall Cable system Pipe, Culvert	9	**Construction**	Scaffolding Temporary constructions Bridge construction Transportation of workers Other activities
5	**Secondary load-bearing structure**	Secondary load-bearing beam, cross beam Secondary load-bearing truss, Wind bracing Edge beam	10	**End of Life Management**	Demolition Landscaping Waste management (incl. recycling and recovery)

2- User Costs

- **Definition:**

  Costs incurred by users of the bridge as a result of deteriorated conditions on the bridge, resulting from construction, maintenance, inspection, rehabilitation, and demolition activities, leading to an increase in the vehicles trip time which is translated into user delay costs, additional vehicle operating costs and increase risk and accident costs.

Bridge User Cost

- Construction & Installation
- Operation & Maintenance
- Inspection
- Repair, Replacement & Rehabilitation
- Demolition & landscaping

- Traffic Delay Cost
- Vehicle operation Cost
- Accident Cost
- Failure cost

User Costs/Formalization

$$T = T_{WZ} - T_o \quad , \quad T_o = \frac{L}{v_o} \quad , \quad T_{WZ} = ???$$

- The duration travel delay time in case of work zone *(T)* is strongly associated with the traffic flow condition, the hourly traffic distribution,

$$Bridge\,User\,Cost = TDC + VOC + AC + FC$$

- **Traffic Delay Cost (TDC)**

$$TDC = \sum_{t=0}^{T_E} T \times ADT_t \times N_t \times (r_T w_T + (1 - r_T) w_P) \frac{1}{(1+r)^t}$$

- **Vehicle Operation Cost (VOC)**

$$VOC = \sum_{t=0}^{T_E} T \times ADT_t \times N_t \times (r_T O_T + (1 - r_T) O_P) \frac{1}{(1+r)^t}$$

- **Accident Cost (AC)**

$$AC = \sum_{t=0}^{T_E} ADT_t \times N_t \times (A_n - A_a) \times \left[(C_F \times P_F) + (C_I \times P_I)\right] \frac{1}{(1+r)^t}$$

Logical Assumed Values

- The value of *w*
  - The value of one hour of travel time per vehicle should be equal to the average hourly wage for average employee in the considered country.
  - The recommended values according to Sweden 2009 are:
    - $ 14,0 /hr for passenger cars.
    - $ 28,0/hr for other vehicles.
- The value of *O*
  - The average hourly vehicle operating cost, include fuel, engine oil, lubrication, maintenance, and depreciation.
  - The recommended values according to Sweden 2009 are:
    - $ 9,5 /hr for passenger cars.
    - $ 21,5/hr for other vehicles.

- The Value of average cost per accident
  - The recommended values according to Sweden (SRA) 2009 are:
    - $1,500,000 for fatal deaths crush
    - $ 160,000 for serious injury crush

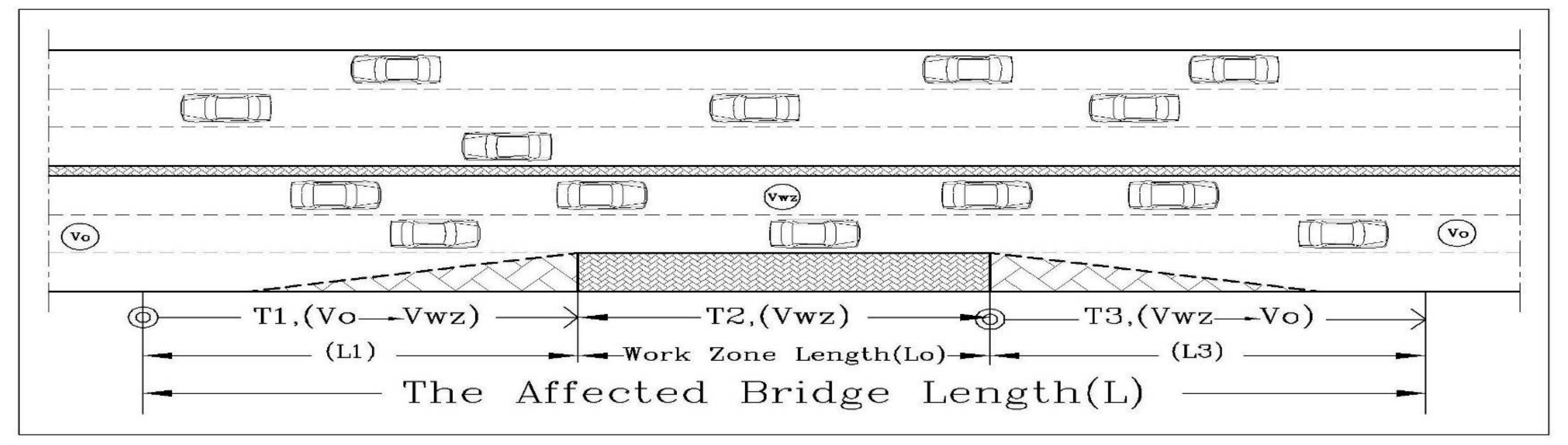
User Costs/Traffic Flow

- Traffic Flow Conditions
  - Unrestricted flow conditions:
    Where the traffic volume is below the work zone capacity
  - Forced flow conditions:
    Where the traffic volume exceeds the work zone capacity “Queue” situation
  - Circuity flow condition:
    where traffic is forced to utilize a detour

Hour		Distribution Factor(%ADT)		Hour		Distribution Factor(%ADT)	
From	To	Interstate	Other	From	To	Interstate	Other
0	1	1.70%	0.90%	12	13	5.70%	5.70%
1	2	1.40%	0.50%	13	14	5.90%	5.90%
2	3	1.30%	0.50%	14	15	6.30%	6.60%
3	4	1.30%	0.50%	15	16	6.90%	7.70%
4	5	1.40%	0.90%	16	17	7.20%	8.00%
5	6	2.10%	2.30%	17	18	6.60%	7.40%
6	7	3.70%	4.90%	18	19	5.30%	5.50%
7	8	4.90%	6.20%	19	20	4.40%	4.30%
8	9	4.90%	5.50%	20	21	3.80%	3.60%
9	10	5.20%	5.30%	21	22	3.40%	3.00%
10	11	5.50%	5.40%	22	23	2.90%	2.30%
11	12	5.80%	5.60%	23	24	2.40%	1.50%

Traffic Flow Conditions/Bridge Capacity

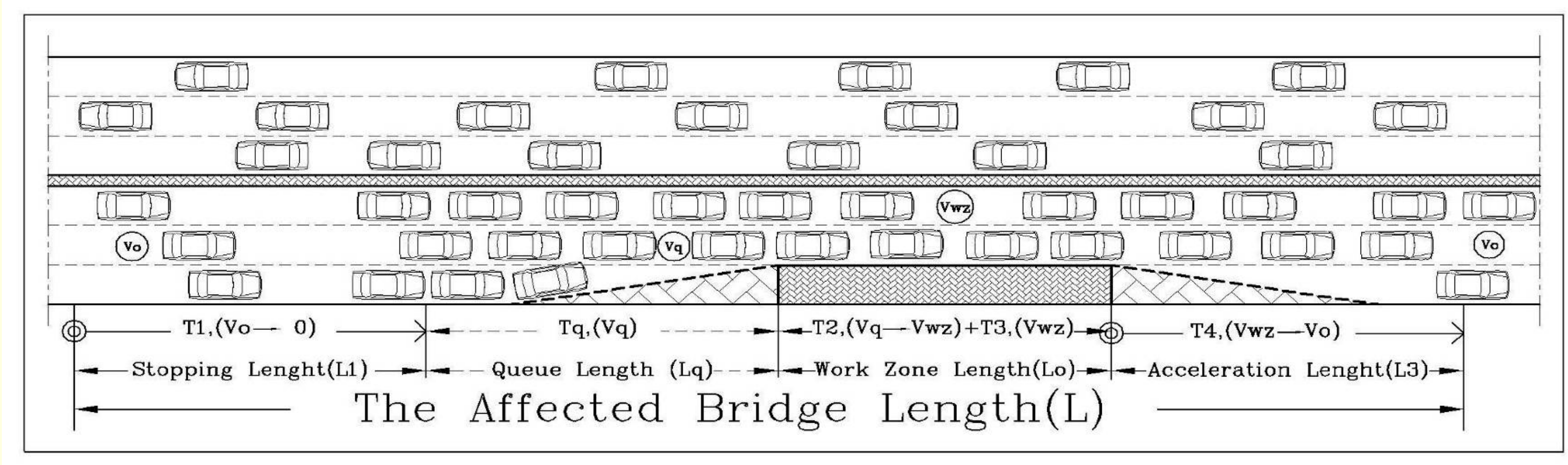
- Unrestricted flow conditions:



Design Speed(km/h)	30	40	50	60	70	80	90	100	110	120
L_1 (*m*)	23.656	35.319	45.246	55.305	65.767	85.192	96.223	108.557	134.759	161.753
L_0 (*m*)	200.000	200.000	200.000	200.000	200.000	200.000	200.000	200.000	200.000	200.000
L_3 (*m*)	0.424	1.019	1.358	1.698	2.037	3.310	3.819	4.329	6.111	8.063
T_1 (*hr*)	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
T_2 (*hr*)	0.008	0.007	0.005	0.004	0.003	0.003	0.003	0.002	0.002	0.002
T_3 (*hr*)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
The Affected Bridge length L (*m*)	224.081	236.337	246.604	257.003	267.804	288.502	300.043	312.886	340.870	369.816
The Travel during work zone T_{wz} (*hr*)	0.009	0.008	0.006	0.005	0.004	0.004	0.004	0.004	0.004	0.004
The Normal Travel time T_0 (*hr*)	0.007	0.006	0.005	0.004	0.004	0.004	0.003	0.003	0.003	0.003
The Travel Time Delay T (*hr*)	0.001	0.002	0.001	0.001	0.000	0.001	0.000	0.000	0.000	0.001
The Travel Time Delay T (*Sec.*)	4.839	6.125	3.706	2.492	1.797	2.247	1.751	1.410	1.688	1.914

Traffic Flow Conditions/Bridge Capacity

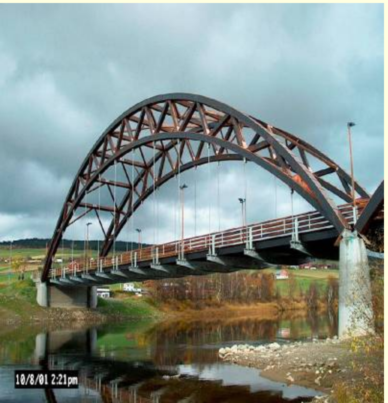
- Forced flow conditions:



Forced Flow Condition										
Design Speed V_0(km/h)	30.00	40.00	50.00	60.00	70.00	80.00	90.00	100.00	110.00	120.00
L_1 (m)	30.03	44.99	63.90	86.23	113.17	142.67	172.75	210.25	252.83	293.31
L_q (m)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
L_0 (m)	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00
L_2 (m)	0.01	0.01	0.03	0.04	0.06	0.07	0.09	0.12	0.14	0.15
L_3(m)	199.99	199.99	199.97	199.96	199.94	199.93	199.91	199.88	199.86	199.85
L_4(m)	0.43	1.04	1.37	1.71	2.05	3.35	3.86	4.37	6.18	8.17
T_1 (hr)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T_q (hr)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T_2 (hr)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T_3 (hr)	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T_4 (hr)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
The Affected Bridge length L(m)	230.46	246.02	265.28	287.94	315.22	346.02	376.61	414.61	459.01	501.48
The Travel during work zone T_{wz}(hr)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
The Normal Travel time T_0(hr)	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
The Travel Time Delay T (hr)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
The Travel Time Delay T (*Sec.*)	7.93	10.20	9.57	10.16	11.34	12.93	14.16	15.71	17.22	18.50

Activities affect the Traffic/Computer Application

Work Activities That affect or disturb the Traffic							
The Action Name	Recommended Intervals(*Year*)	Average Required Unit Duration			Affected Traffic		Limitations & Comments
		Value	Unit	From	Over	Under	
Investment (Purchasing, Construction,& Installation)							
Prefabricated Prestressed concrete bridges	100	0.12	day/m^2	The Bridge Area	Yes	Yes	Traffic must detour (Bridge Full Closer)
Convential reinforced concrete bridges	80	0.15	day/m^2	The Bridge Area	Yes	Yes	
Steel Structures	70	0.1	day/m^2	The Bridge Area	Yes	Yes	
Timber Bridges	50	0.12	day/m^2	The Bridge Area	Yes	Yes	
Operation & Maintenance activities							
Cleaning the bridge of salt	1	0.05	hr/m^2	Bridge Area	Yes	No	
Maintenance of parapets,gardrail& railings	1	0.15	hr/m	Bridge Length	Yes	No	
Maintenance of surface finish and laning	1	0.1	hr/m^2	Bridge Area	Yes	No	
Repair, Rehabilitations & Replacement activities							
Deck repair & maintenance	12	0.2	hr/m^2	Bridge Area	Yes	No	
Deck overlay & resurfacing	26	0.4	hr/m	Bridge Length	Yes	No	
Deck replacement	44	1	hr/m^2	Bridge Area	Yes	No	
Expansion joints repair	4	2	hr/m	Bridge Width	Yes	No	
Expansion joints replacement	12	3	hr/m	Bridge Width	Yes	No	
Bridge seat & bearings replacement	40	0.04	hr/m^2	Bridge Area	Yes	No	
Gradrail,railings, parapets & fittings replacement	20	2	hr/m	Bridge Length	Yes	No	
Edge beam impregnation & repair	25	0.5	hr/m	Bridge Length	Yes	No	one closed lane
Edge beam replacements	50	1.5	hr/m	Bridge Length	Yes	No	one closed lane
Superstructure replacements	50	2	hr/m^2	Bridge Area	Yes	No	
Substructure replacement	50	0.5	hr/m^2	Bridge Area	Yes	No	
Painting of steel structure, whole bridge	25	0.2	hr/m^2	Bridge Area	No	Yes	
End of life Management (Demolition and Landscaping) activities							
Prefabricated Prestressed concrete bridges	100	0.12	day/m^2	The Bridge Area	Yes	Yes	Traffic must detour (Bridge Full Closer)
Convential reinforced concrete bridges	80	0.15	day/m^2	The Bridge Area	Yes	Yes	
Steel Structures	70	0.1	day/m^2	The Bridge Area	Yes	Yes	
Timber Bridges	50	0.12	day/m^2	The Bridge Area	Yes	Yes	



- Developed Computer program

Example

3- Bridge Aesthetical & Cultural Value

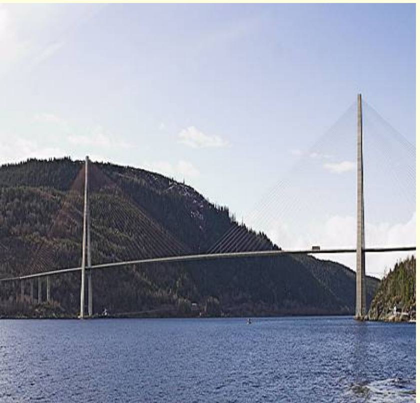
- Bridges are often seen more or less as sculptures and icons which the citizens may relate with the soul of the city.
- Some projects have exceeded all cost estimates but still it has been possible to fulfill them with success
- One of the main aims of bridge projects is to preserve the harmony of the scenery & the surrounding context.
  - So, absolutely there is a hidden value behind the external appearance and the beauty shape of the bridge
  - Firstly, When & How we can decide that the bridge beauty is importance & needed or not !!
- To answer this question, Two things have to be specified first:
  - ✓ Stander Grading System
  - ✓ According to what we can classify the bridge site

Bridge Site Classification

- A four-grade system is used for evaluation of a bridge site:

Class	Explanation	acceptable additional costs
Class I	Very demanding	0…30
Class II	Demanding	0…20
Class III	Remarkable	0…10
Class IV	Ordinary	0

- Evaluated items :
  - Location of the bridge site
  - Viewpoints of local people & Value of the landscape
  - Cultural value of the surroundings
  - Aesthetical demands of the bridge

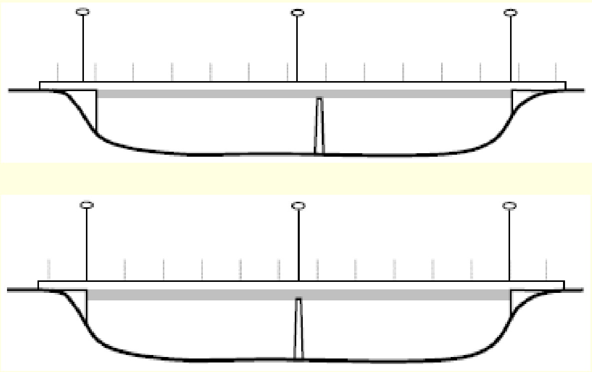


Cost & Aesthetics Can be Complementary

- Bridges of aesthetic merit need not be much expensive than ugly bridges.
- For example, the shape of a parapet, abutment, pier or the design symmetry might have a negligible impact on costs but a significant improvement visually.
- This is not to say that the cheapest bridge is necessarily the ugliest bridge.

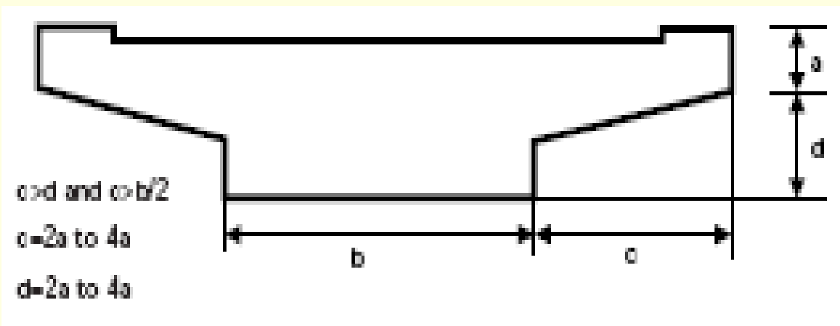
'It is unwise to pay too much. But it is worse to pay too little'

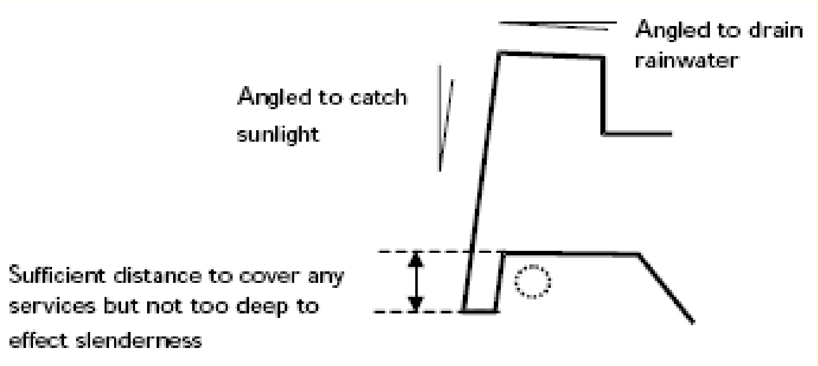
- For aesthetics to be successful, it must first be consider as an integral part of the design. Aesthetics is not something that can be added on at the end

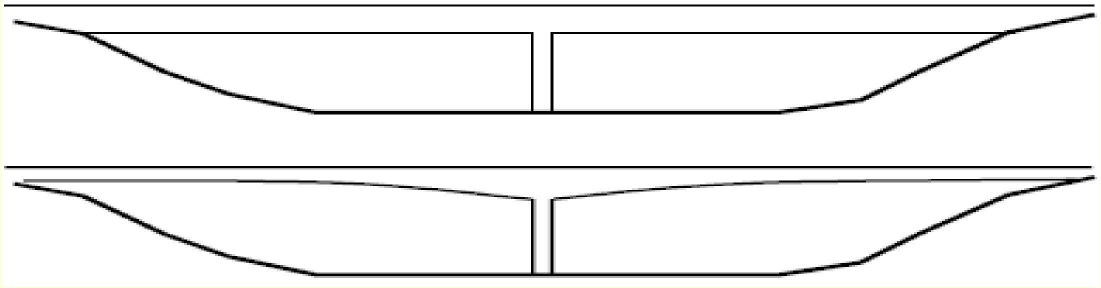


Aesthetical Design Guidelines

- ✓ Intended to sett down considerations and principles, which will help, eliminate the worst aspects of bridge design and encourage the best.







Unique Evaluation System

- Remember what we agreed in the beginning for LCC:

$$LCC = C_{AG} + C_{USER} + C_{RACV} + C_{REI}$$

$$C_{RACV} = k_{AES} C_{AG}$$

k_{AES} Is the aesthetical and cultural coefficient. Range from +0,30 To -0,30

- The system is based on the idea that points given to different things according to a given scheme and the opinion of the evaluators. The *number n of things* to be considered can be freely chosen and each thing can have different *weight wi* of importance.
- The evaluator rule is to give a numerical values or *points pi* on a chosen scale to each thing *i* that is considered.

Developed Computer Program/Example

$$k_{AES} = -a \frac{\sum_{i=1}^{n} w_i p_i}{\sum_{i=1}^{n} w_{i\,\max}\, p_{i\,\max}}$$

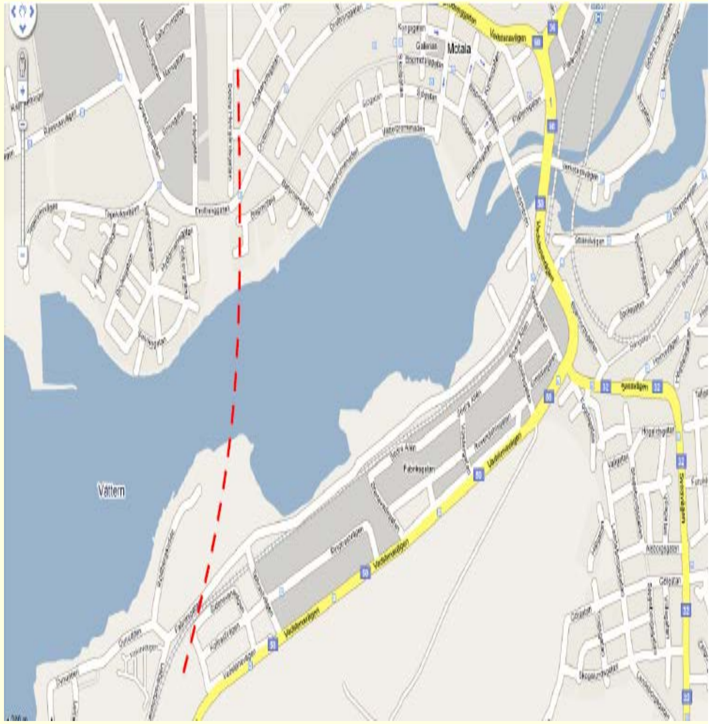
- The scale for *points pi* and the corresponding individual values should be chosen so that an evaluator has enough possibilities to distinguish the different designs or bridges

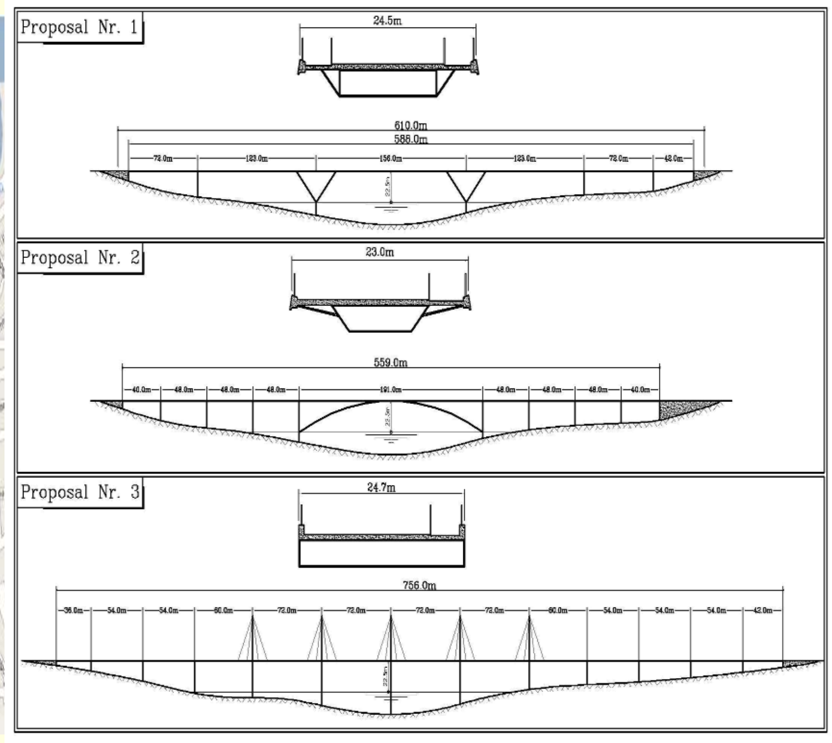
Category	**Explanation**
-2	Poor
-1	Modest
0	Medium
1	Good
2	Excellent

- For the non-dimensional *scaling factor* numerical value of ***a* = 0.30** is recommended as it used also in the *Finnish Road Administration* (*Finnra*).

Example/(Motala Bay, Sweden, 2009)

- Bridge design competition was arranged.
  - 7 Architectural firms were invited to participate.
  - 9 Different proposals were sent in to the SNRA.





Example/(Motala Bay, Sweden, 2009)

- Proposal Number (1):

Example/(Motala Bay, Sweden, 2009)

- Proposal Number (2):

Developed Computer Program/Application

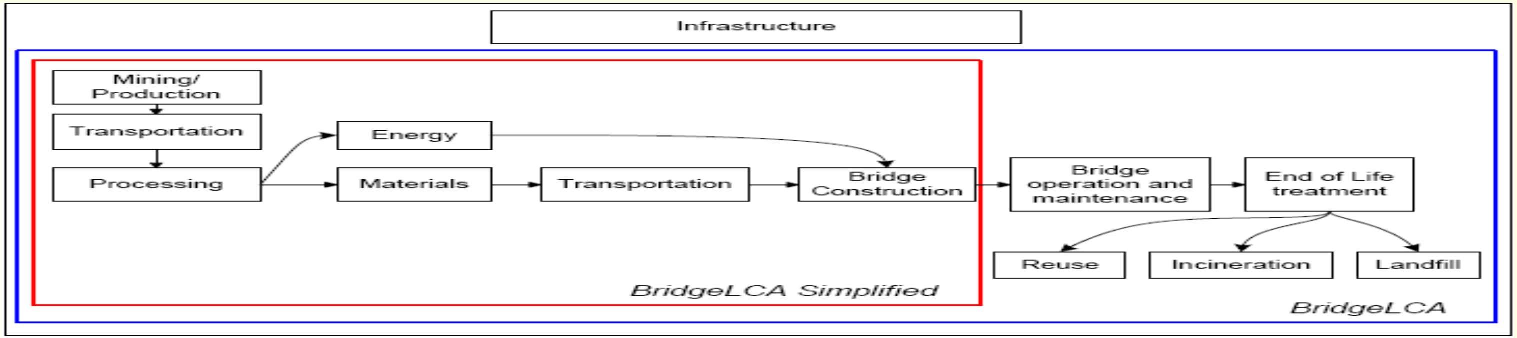
- Proposal Number (3):

Comp. Application

4-Bridge Environmental Impact

- **Environmental Impact Include:**
  - Material resource consumption (The Usage of un renewable materials)
  - Air and water pollutant emissions
  - Solid waste generation
  - Energy use
  - Fuel consumption
  - Emissions from the traffic
- **<u>Life Cycle Assessment(LCA):</u>**

Is an analytical technique for evaluating the environmental consequences attributable to the life cycle of a product or a service.



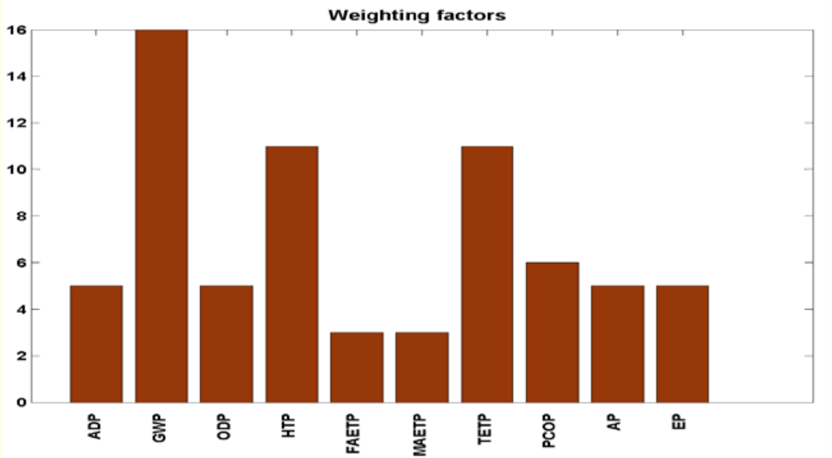
Bridge Environmental Impact Evaluation Steps

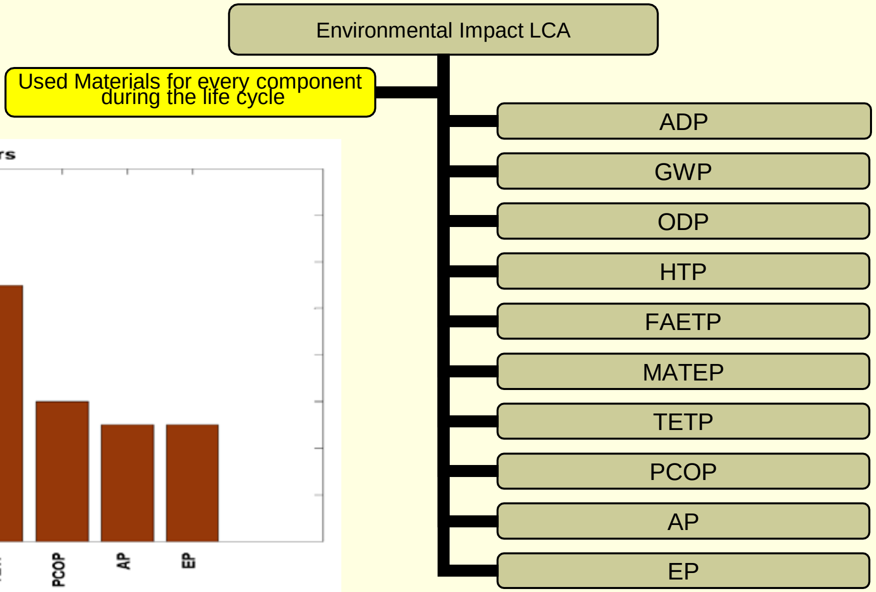
- Tracking the bridge Life cycle phases, estimate the amount of used materials, fuel, energy in the each life cycle stage.
- Provide the computer program LCA which, is developed in the ETSI project stage 2 by ***Johanne Hammervold*** with this amount of materials, directly you can got the amount of emissions

LCA Excel Program

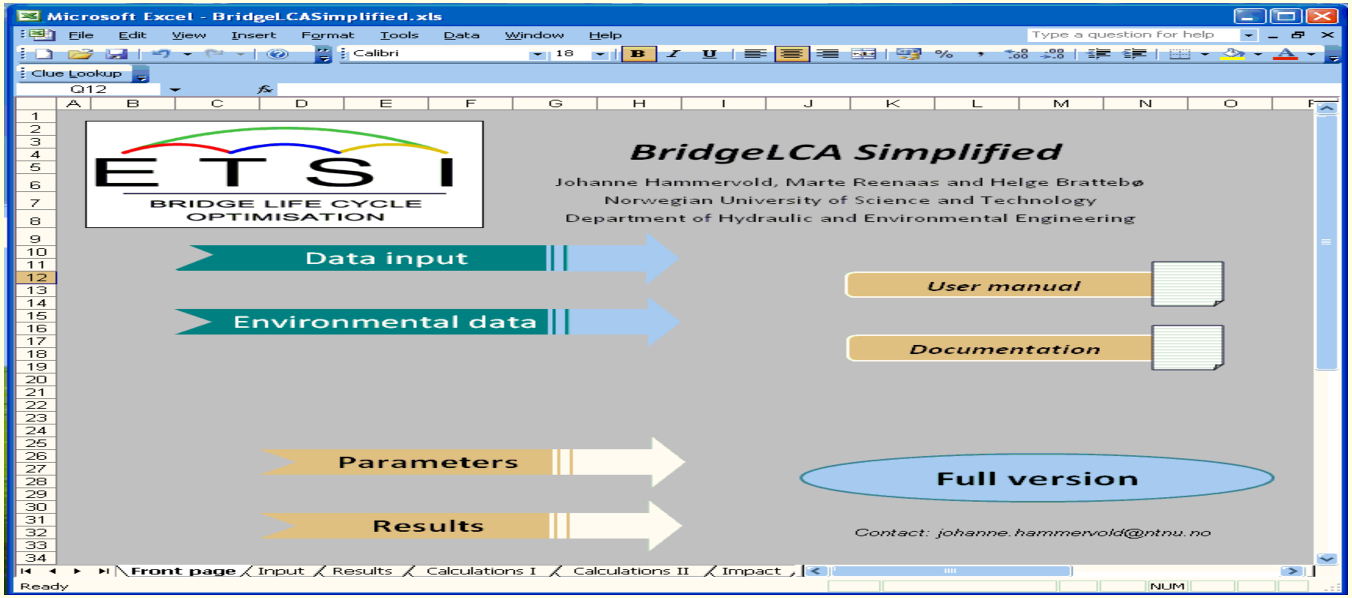
The used Materials ⟷ **The Emissions amounts**

- Using a stander weighting factors for each emission we can assess the total impact and when so, evaluate K_{EI}





Environmental Impact Computer Application



- ✓ Remember again what we agreed in the beginning for LCC:

$$LCC = C_{AG} + C_{USER} + C_{RACV} + C_{REI}$$

$$C_{REI} = k_{EI} C_{AG}$$

k_{EI} Is the environmental impact coefficient. Range from 0,0 To +0,20

- *For more information, See ETSI project Stage 2*

Conclusion

- Conclusion:-
  - ✓ This research demonstrates a unique LCCA system for evaluating the sustainability of bridges, integrating all life cycle aspects like agency cost, user cost, aesthetical and cultural value, and the environmental impact.
  - ✓ The application of this integrated model to bridge design highlighted the critical importance of using the life cycle modeling in order to enhance the sustainability the bridges.

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(The occupied Palestine/The Bleeding Gaza)

For Your Attention

Thank You

Questions?