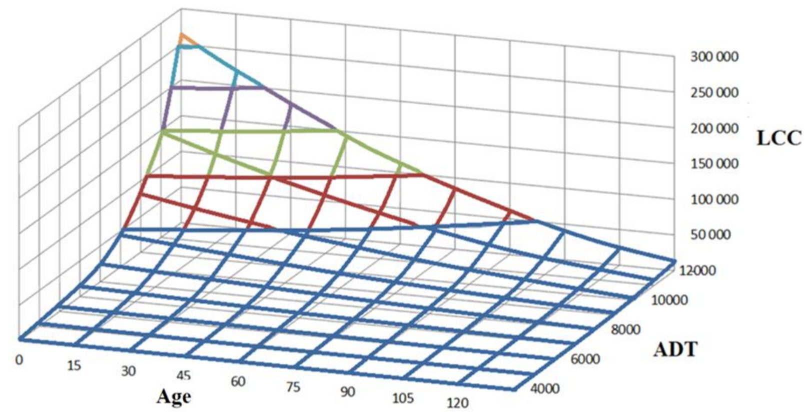
Closing Seminar
14-15 May, 2012
Malmö

NordFoU

DESIGN OF SHORT-SPAN BRIDGES WITH REGARD TO LIFE CYCLE COSTS



Master thesis carried out at COWI – Göteborg, for Chalmers University of Technology, autumn 2011

Niklas Larsson & Dan Nilsson 2012-05-15

OUTLINE

Bridge Life Cycle Optimisation

- Background
- The LCC concept
- Basis for analysis (input data for analysis)
- Analysis
  - Results
- LCC approach for new bridges
- Conclusions

BACKGROUND

Bridge Life Cycle Optimisation

1. Sweden's public procurement act
   - Usually the alternative with the lowest investment cost is chosen

2. In 2009, 74% of Sweden's budget for infrastructures was used for operation, maintenance and repair (OMR)

3. Methods developed to estimate costs over time
   - Life Cycle Cost Analyses (LCCA)

- *Could a solution that is more expensive today, be the financially most favourable over time?*

PURPOSE/AIM

Bridge Life Cycle Optimisation

- **Purpose:**
  - *To find an approach on how to use the LCC-analysis as a decision-making tool in design when planning new bridges*

- **Aim:**
  - To compare two LCC cases
    - *Case 0 – Today's standard execution of detailing*
    - *Case 1 – Alternative detailing solutions*

SCOPE

Bridge Life Cycle Optimisation

- Decision-making of detailing solutions
- 3 *common* short-span bridge types (road) was considered
  - Concrete, steel and timber
- Swedish conditions
  - Urban environment
- Extreme conditions were to be omitted
  - As generally applicable as possible

ETSI

METHOD

Bridge Life Cycle Optimisation

- Start-out point: The LCC concept
  - Literature studies
- Selection of 3 bridge types
- Statistical compilation on typical problems from the **BaTMan** database
  - Alternative approach: Compilation based on interviews with experienced bridge managers

METHOD

Bridge Life Cycle Optimisation

- **Comparative LCC-analysis**
  - By using computer softwares
    - *WebLCC/BroLCC (was under development by the ETSI project during the thesis)*
    - *BridgeLCC (US developed)*
    - *Vännen07 (Swedish, Trafikverket)*
  - Evaluation of the impacts alternative detailing solutions had to the LCC
    - *Identification of sensitivity factors*
- **Develop a method on how to use LCC, based on the conclusions drawn from the analysis**

Bridge Life Cycle Optimisation

THE LCC CONCEPT

- **General**
  - **Equation:** $LCC = \sum_{n=0}^{L} \frac{B_n}{(1+r)^n}$
    - *LCC= Present value of the life cycle cost*
    - *n= Age of which the present value is discounted from*
    - *B_n= Sum of all costs and incomes at age n*
    - *r= Discount rate (usually 4 % in Sweden)*
    - *L= Service life*
  - An LCC becomes useful first when it is compared to another LCC

ETSI

THE LCC CONCEPT

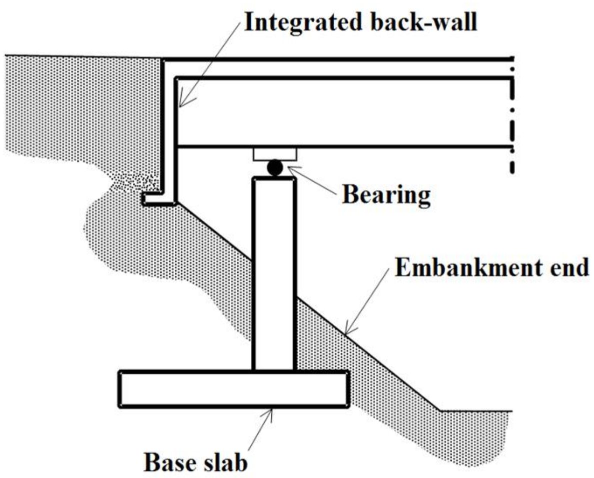
Bridge Life Cycle Optimisation

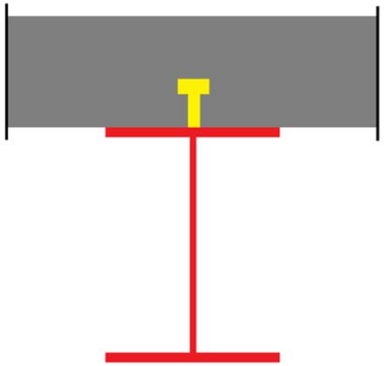
- **Applications in bridge engineering**
  - Bridges = large systems of "products" to be considered
    - *Need for simplifications and assumptions*
  - Bridges usually do not generate any income
    - *In Sweden, infrastructural projects are justified when the benefits (traffic) exceeds the costs*
  - For LCC-analysis to become a recognized decision-making tool in bridge engineering, 3 conditions need to be fulfilled:
    1. *Widely accepted model(s) – **Yet to be developed***
    2. *Reliable input data, and source (database) – **BaTMan (Swe)***
    3. *Changes in the way today's procurements are processed – **Yet to be implemented***

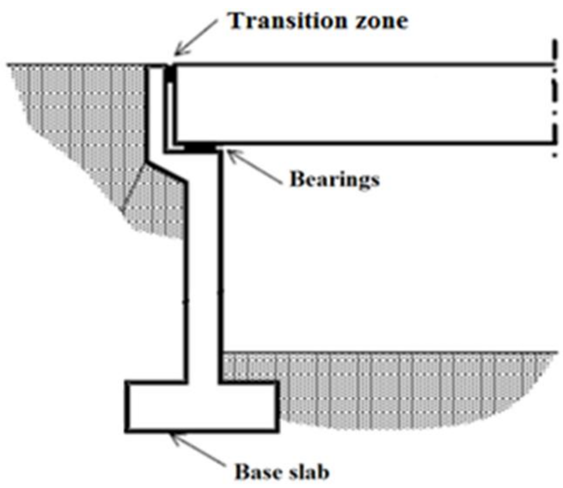
BASIS FOR ANALYSIS
- Bridge types

Bridge Life Cycle Optimisation

Back-wall bridge (concrete)	Composite steel bridge (Steel/concrete)	Transversally post-tensioned Glulam slab (Timber)







“

BASIS FOR ANALYSIS

- Information gathering on common problems

Bridge Life Cycle Optimisation

- **BaTMan**
  - An inquiry was formed and delivered to Trafikverket
    - *The inquiry was too extensive and time consuming to extract*

- **Alternative approach** (interviews)
  - Performed with experienced bridge- managers & engineers at:
    - *Trafikverket*
    - *COWI*
    - *etc.*

ETSI

BASIS FOR ANALYSIS

- Back-wall bridge (concrete)

Bridge Life Cycle Optimisation

Problems	Alternative solutions
1. Settlements at back-wall • Need for extra asphalt	**1. Instalment of link plate** • Reduces settlements
2. Edge beam replacement • Reinforcement corrosion	**2. Using stainless steel reinf.** • No need for replacement
3. Bearing replacement (rubber) • Wears out within ~30 years	**3. Sliding bearings (steel)** • No need for replacement
4. Cone erosion • Storm water runs down the slope	**4. Extension of edge beams** • Diverts the water to the road embankment

BASIS FOR ANALYSIS
- Composite bridge (steel/concrete)

Bridge Life Cycle Optimisation

Problems

- *1-4 from the back-wall applies*

5. **Wearing of the protective painting**
   - Need for repainting ~25th year
6. **Corrosion in bolted joints**
   - Due to relative movements

Alternative solutions

- *1-4 from the back-wall applies*

5. **Pre-emptive washing of steel girders**
   - Need for repainting ~35th year
6. **Welding of joints**
   - No relative movements

ETSI

BASIS FOR ANALYSIS

- Transversally tensioned Glulam slab (Timber)

Bridge Life Cycle Optimisation

Problems

- *3 also applies (Bearings)*

7. **Durability of protective painting (panel)**
   - Re-appliance ~8th year
8. **Moisture damage to end timber**
   - Inaccessible to monitor
   - Expensive to remedy

Alternative solutions

- *3 also applies (Bearings)*

7. **Using impregnated timber**
   - No need for re-application
8. **Installation of moisture indicators**
   - Provide a measure to monitor
     - Avoids expensive damages

ETSI

ANALYSIS

Bridge Life Cycle Optimisation

1. **LCC-analysis case 0**
   - Analysis with regard to conventional design
2. **LCC-analysis case 1**
   - Analysis with regard to alternative design
3. **Comparison/evaluation of results**
   - Identification of sensitivity factors

ANALYSIS
- Assumptions case 0

Bridge Life Cycle Optimisation

Costs Time-interval Duration:

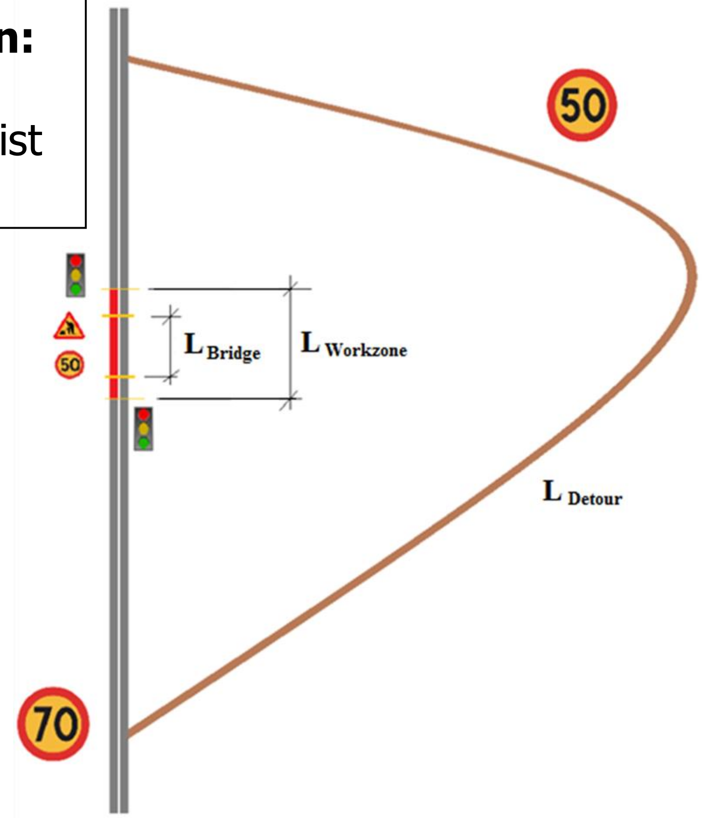
- BaTMan's price list
- Interviews

General (bridge):

1 span
20 meter long
7 meter wide (2 lanes)
80 year service life

Traffic conditions:

Size of workzone	= 50 m
ADT	= 6'000
Normal speed	= 70 km/h
Reduced speed	= 50 km/h
Length detour	= 7 km



ANALYSIS

- LCC-results, case 0

Bridge Life Cycle Optimisation

Back-wall bridge (Case 0)

Activity	BroLCC			BridgeLCC			Vännen07		
	OMR-costs	Traffic	Tot. LCC	OMR-costs	Traffic	Tot. LCC	OMR-costs	Traffic	Tot. LCC
Edge beam replacement	39 925	7 610	**47 535**	41 522	7 914	**49 436**	41 182	-	**41 182**
Bearings (rubber)	9 529	41 392	**50 921**	9 910	44 290	**54 200**	10 834	-	**10 834**
Cone erosion	8 870	-	**8 870**	9 225	-	**9 225**	12 149	-	**12 149**
Settlement repairs	79 677	5 695	**85 372**	82 865	5 923	**88 788**	82 865	-	**82 865**
Sum			**192 698**			**201 649**			**147 030**

Composite steel bridge (Case 0)

Activity	BroLCC			BridgeLCC			Vännen07		
	OMR-costs	Traffic	Tot. LCC	OMR-costs	Traffic	Tot. LCC	OMR-costs	Traffic	Tot. LCC
Edge beam replacement	39 925	7 610	**47 535**	41 522	7 914	**49 436**	41 182	-	**41 182**
Bearings (rubber)	9 529	41 392	**50 921**	9 910	44 290	**54 200**	10 834	-	**10 834**
Cone erosion	8 870	-	**8 870**	9 225	-	**9 225**	12 149	-	**12 149**
Settlement repairs	79 677	5 695	**85 372**	82 865	5 923	**88 788**	82 865	-	**82 865**
Repainting of girders	204 701	-	**204 701**	212 889	-	**212 889**	280 121	-	**280 121**
Gap corrosion	7 941	-	**7 941**	8 259	-	**8 259**	9 686	-	**9 686**
Sum			**405 340**			**422 797**			**436 837**

Transversally tensioned Glulam slab (Case 0)

Activity	BroLCC			BridgeLCC			Vännen07		
	OMR-costs	Traffic	Tot. LCC	OMR-costs	Traffic	Tot. LCC	OMR-costs	Traffic	Tot. LCC
Bearings (rubber)	9 529	41 392	**50 921**	9 910	44 290	**54 200**	10 834	-	**10 834**
Repainting of panel	9 344	-	**9 344**	9 555	-	**9 555**	9 717	-	**9 717**
Damaged end timber	10 553	277 408	**287 961**	10 976	274 688	**285 664**	11 455	-	**11 455**
Sum			**348 226**			349 419			**32 006**

ANALYSIS

- Assumptions case 1

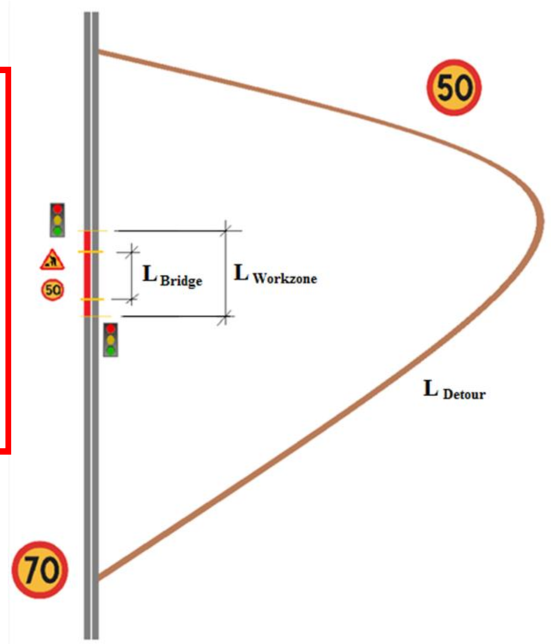
Bridge Life Cycle Optimisation

General (bridge):

1 span
20 meter long
7 meter wide (2 lanes)
80 year service life

Costs
Time-interval
Duration:

- BaTMan's price list
- Interviews



Traffic conditions:

Size of workzone	= 50 m
ADT	= 6'000
Normal speed	= 70 km/h
Reduced speed	= 50 km/h
Length detour	= 7 km

Cost differences

ANALYSIS

- Comparison and evaluation

Bridge Life Cycle Optimisation

Back-wall bridge (Comparison case 0 and case 1)														
Activity		BroLCC				BridgeLCC				Vännen07				
		OMR-costs	Traffic	Tot. LCC	Difference	OMR-costs	Traffic	Tot. LCC	Difference	OMR-costs	Traffic	Tot. LCC	Difference
Edge beam	Case 0	39 925	7 610	47 535	- 12 465	41 522	7 914	49 436	- 10 564	41 182	-	41 182	- 18 818
	Case 1	60 000	-	60 000		60 000	-	60 000		60 000	-	60 000	
Bearings	Case 0	9 529	41 392	50 921	- 39 079	9 910	44 290	54 200	- 35 800	10 834	-	10 834	- 79 166
	Case 1	90 000	-	90 000		90 000	-	90 000		90 000	-	90 000	
Cone erosion	Case 0	8 870	-	8 870	- 39 130	9 225	-	9 225	- 38 775	12 149	-	12 149	- 35 851
	Case 1	48 000	-	48 000		48 000	-	48 000		48 000	-	48 000	
Link Plate	Case 0	79 677	5 695	85 372	- 20 659	82 865	5 923	88 788	- 17 484	82 865	-	82 865	- 23 233
	Case 1	105 629	402	106 031		105 854	418	106 272		106 098	-	106 098	

Composite steel bridge (Comparison case 0 and case 1)														
Activity		BroLCC				BridgeLCC				Vännen07				
		OMR-costs	Traffic	Tot. LCC	Difference	OMR-costs	Traffic	Tot. LCC	Difference	OMR-costs	Traffic	Tot. LCC	Difference
Edge beam	Case 0	39 925	7 610	47 535	- 12 465	41 522	7 914	49 436	- 10 564	41 182	-	41 182	- 18 818
	Case 1	60 000	-	60 000		60 000	-	60 000		60 000	-	60 000	
Bearings	Case 0	9 529	41 392	50 921	- 39 079	9 910	44 290	54 200	- 35 800	10 834	-	10 834	- 79 166
	Case 1	90 000	-	90 000		90 000	-	90 000		90 000	-	90 000	
Cone erosion	Case 0	8 870	-	8 870	- 39 130	9 225	-	9 225	- 38 775	12 149	-	12 149	- 35 851
	Case 1	48 000	-	48 000		48 000	-	48 000		48 000	-	48 000	
Link Plate	Case 0	79 677	5 695	85 372	- 20 659	82 865	5 923	88 788	- 17 484	82 865	-	82 865	- 23 233
	Case 1	105 629	402	106 031		105 854	418	106 272		106 098	-	106 098	
Cleaning Steel	Case 0	204 701	-	204 701	33 444	212 889	-	212 889	44 222	280 121	-	280 121	101 410
	Case 1	171 257	-	171 257		168 667	-	168 667		178 711	-	178 711	
Gap Corrosion	Case 0	7 941	-	7 941	- 42 059	8 259	-	8 259	- 41 741	9 686	-	9 686	- 40 314
	Case 1	50 000	-	50 000		50 000	-	50 000		50 000	-	50 000	

Transversally tensioned Glulam slab (Comparison case 0 and case 1)														
Activity		BroLCC				BridgeLCC				Vännen07				
		OMR-costs	Traffic	Tot. LCC	Difference	OMR-costs	Traffic	Tot. LCC	Difference	OMR-costs	Traffic	Tot. LCC	Difference
Bearings	Case 0	9 529	41 392	50 921	- 39 079	9 910	44 290	54 200	- 35 800	10 834	-	10 834	- 79 166
	Case 1	90 000	-	90 000		90 000	-	90 000		90 000	-	90 000	
Timber Panel	Case 0	9 344	-	9 344	4 511	9 555	-	9 555	4 689	9 717	-	9 717	4 713
	Case 1	4 833	-	4 833		4 866	-	4 866		5 004	-	5 004	
Damage End Timber	Case 0	10 553	277 408	287 961	285 961	10 976	274 688	285 664	283 664	11 455	-	11 455	9 455
	Case 1	2 000	-	2 000		2 000	-	2 000		2 000	-	2 000	

ANALYSIS

- Comparison and evaluation

Bridge Life Cycle Optimisation

- **Only 3/8 alternative solutions were favourable**
  - Unexpected!
  - Further investigation by iteration:
    - *What would make the alternative solutions favourable (assuming the activity-pricing was correct)?*

- **Identification of sensitivity factors (2)**
  1. ***ADT*** *(Average Daily Traffic)*
     - *Critical ADT*
  2. ***Age of the bridge when an activity occur***
     - *Critical age for the occurrence of an activity*

LCC APPROACH FOR NEW BRIDGES
- TrafficWizard2011

Bridge Life Cycle Optimisation

- Excel toolbox was developed
- Insert input data concerning:
    - *Traffic condition*
    - *LCC-conditions*
- Generates tables and graphs where the following can be read out:
    - *Critical ADT*
    - *Critical age*

Input data

Traffic conditions		
ADT	6 000	
Size of the workzone	50	m
v_norm	70	km/h
v_red	50	km/h
c_car	140	SEK/h
c_heavy	320	SEK/h
Proportion heavy	10%	

LCC-conditions		
Age for occurrens:	60	
Discount Rate:	4%	
Duration_work	28	days
Cost of activity (case 0)	420 000	SEK
LCC (case 0), age for activity	41522	SEK
Alternative LCC (case 1):	60 000	SEK
Dif. in LCC case 0 and 1	18478	SEK

D-factor:	0,009	

ETSI

LCC APPROACH FOR NEW BRIDGES
- Constraints

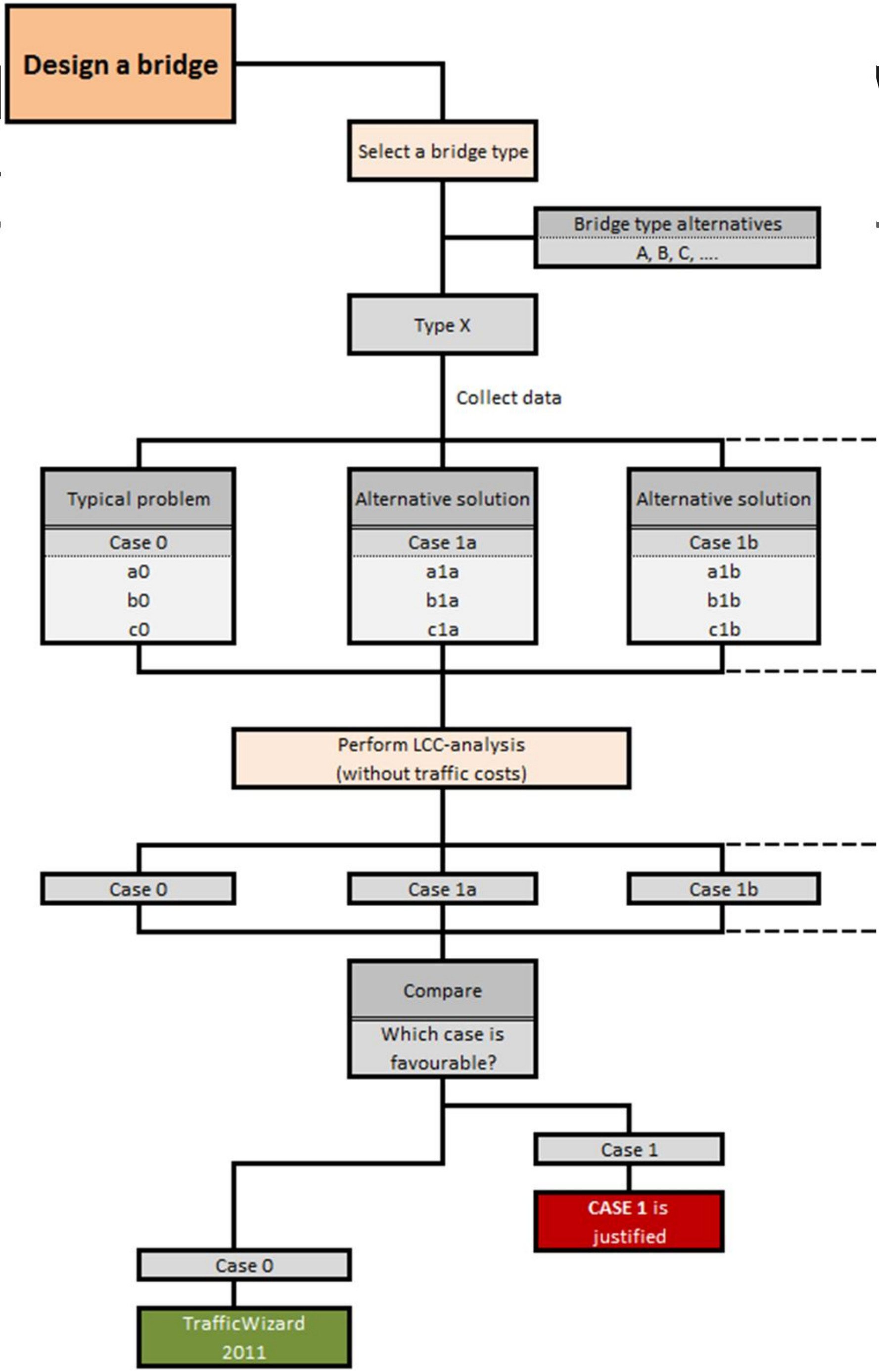
Bridge Life Cycle Optimisation

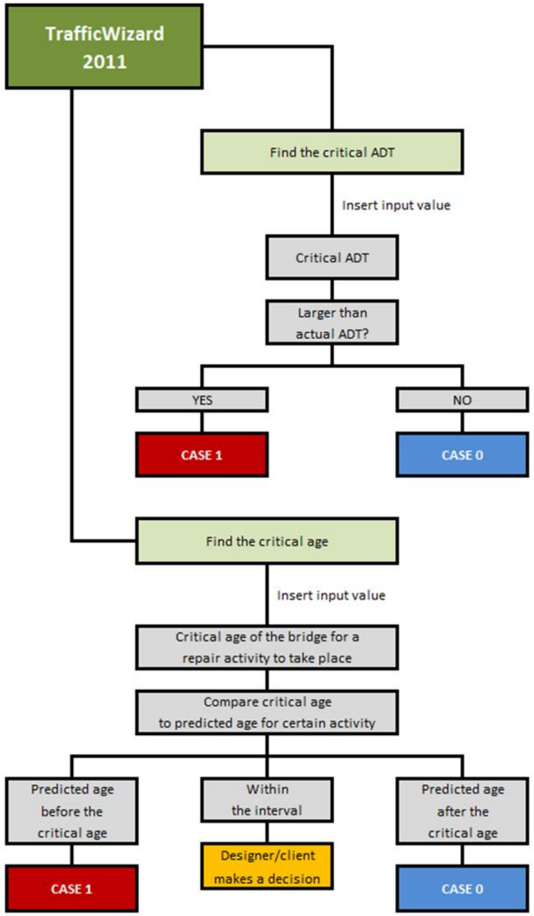
- Only one activity at the time can be analysed
- Only applicable for road bridges
- The bridge has 2 lanes (one in each direction)
- Considers a traffic situation where 1 out of 2 lanes is closed for traffic
- The equation used was only valid for:
  - *ADT > 3,000 vehicles*
  - *Size of the workzone > 30 m*

ETSI

Bridge Life Cycle Optimisation

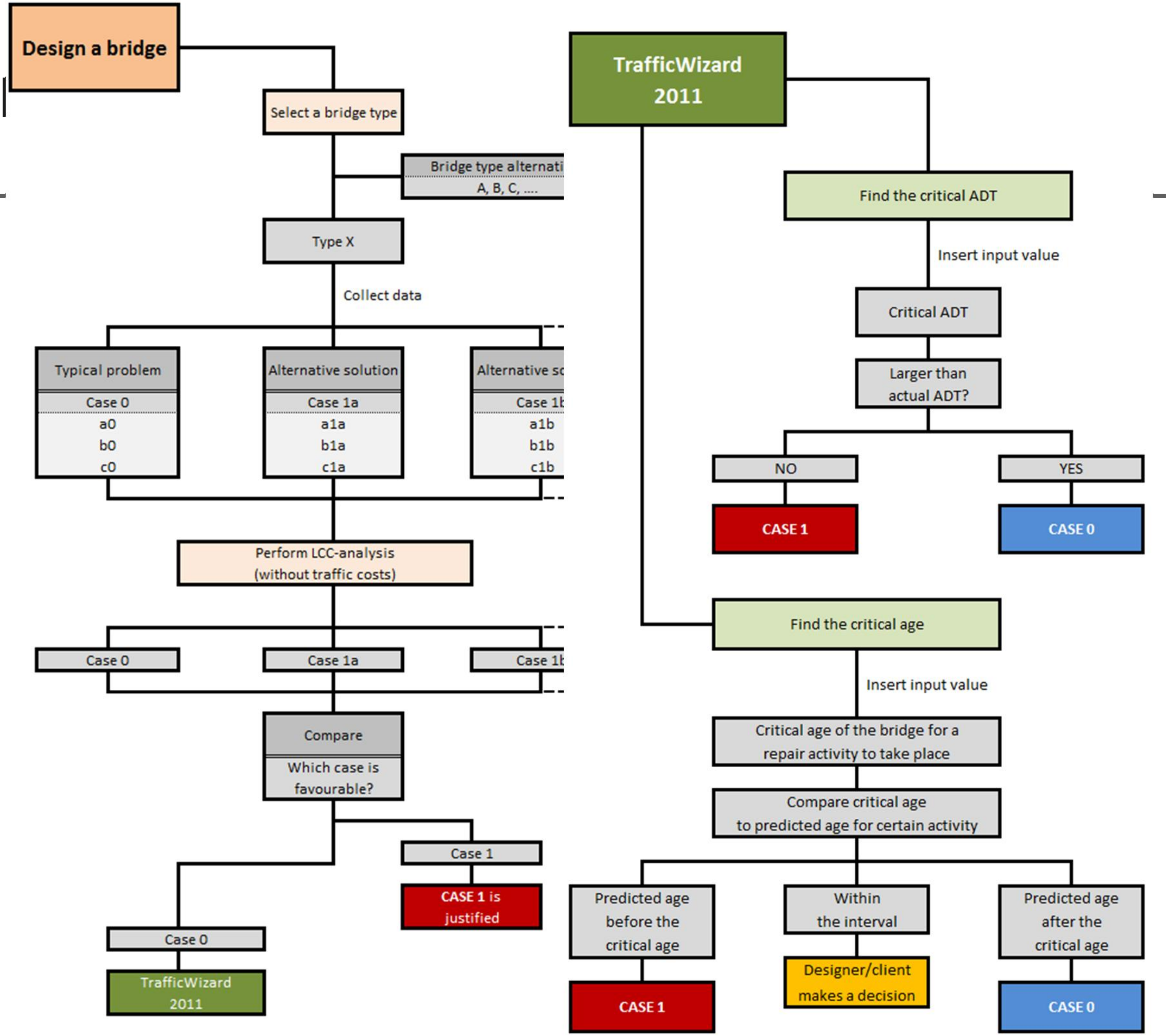
W BRIDGES





ETSI

Bridge Life Cycle Optimisation



LCC APPROACH FOR NEW BRIDGES

- Practical example

Bridge Life Cycle Optimisation

- **Edge beam**
  - *Critical ADT*
  - *Critical age*

Input data

LCC-conditions		
Age for occurrens:	60	
Discount Rate:	4%	
Duration_work	28	days
Cost of activity (case 0)	420 000	SEK
LCC (case 0), age for activity	41522	SEK
Alternative LCC (case 1):	60 000	SEK
Dif. in LCC case 0 and 1	18478	SEK

Traffic conditions		
ADT	6 000	
Size of the workzone	50	m
v_norm	70	km/h
v_red	50	km/h
c_car	140	SEK/h
c_heavy	320	SEK/h
Proportion heavy	10%	

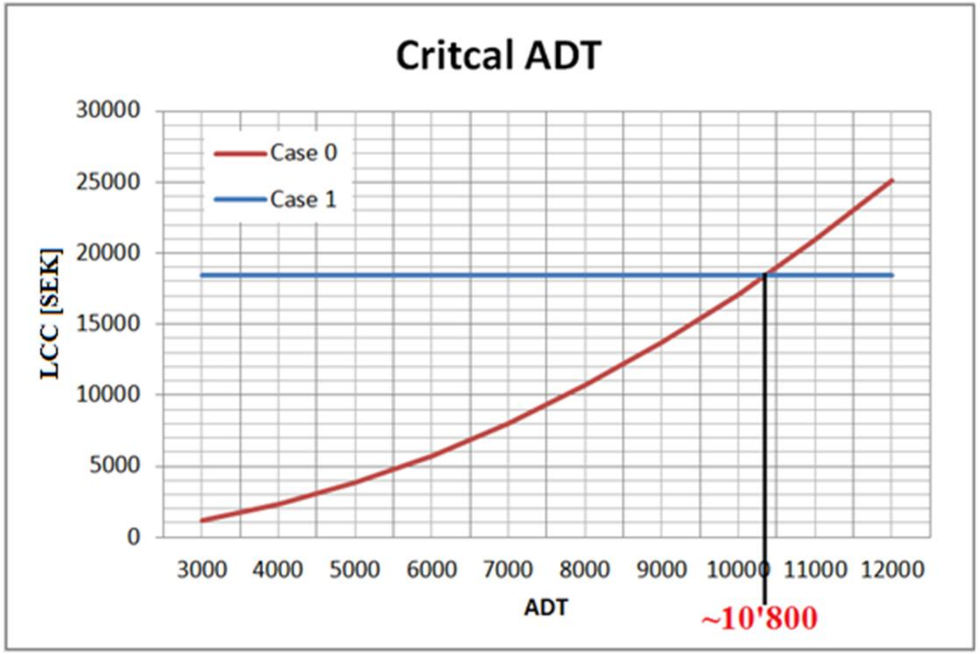
LCC APPROACH FOR NEW BRIDGES

- Practical example, critical ADT

Bridge Life Cycle Optimisation

Input data		
Traffic conditions		
ADT	6 000	
Size of the workzone	50	m
v_norm	70	km/h
v_red	50	km/h
c_car	140	SEK/h
c_heavy	320	SEK/h
Proportion heavy	10%	
LCC-conditions		
Age for occurrens:	60	
Discount Rate:	4%	
Duration_work	28	days
Cost of activity (case 0)	420 000	SEK
LCC (case 0), age for activity	41522	SEK
Alternative LCC (case 1):	60 000	SEK
Dif. in LCC case 0 and 1	18478	SEK
D-factor:	0,009	

Read out the critical ADT



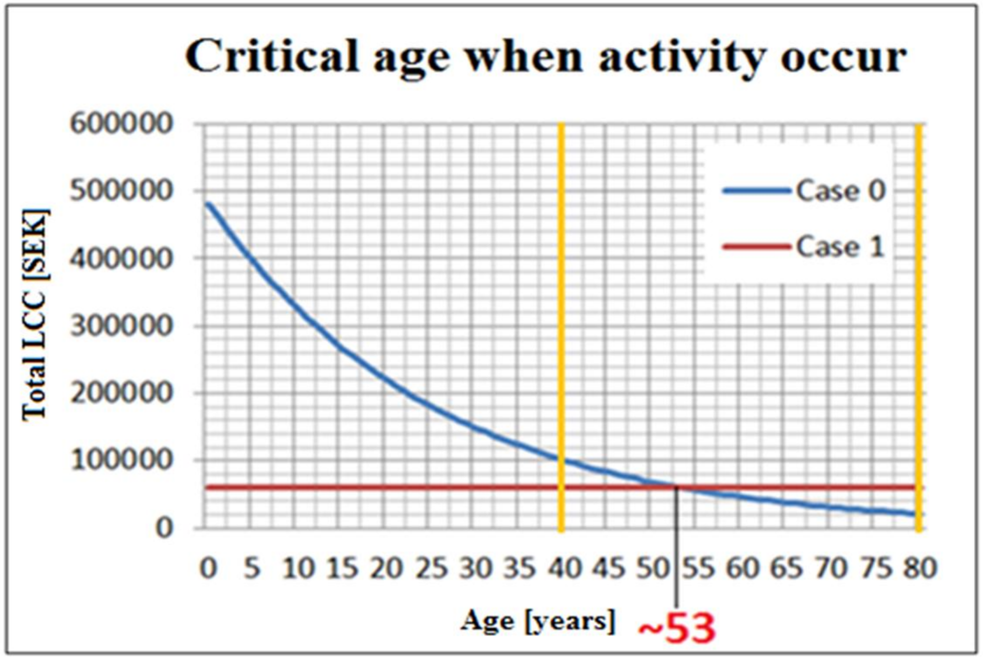
LCC APPROACH FOR NEW BRIDGES

- Practical example, critical year

Bridge Life Cycle Optimisation

Input data		
Traffic conditions		
ADT	6 000	
Size of the workzone	50	m
v_norm	70	km/h
v_red	50	km/h
c_car	140	SEK/h
c_heavy	320	SEK/h
Proportion heavy	10%	
LCC-conditions		
Age for occurrens:	60	
Discount Rate:	4%	
Duration_work	28	days
Cost of activity (case 0)	420 000	SEK
LCC (case 0), age for activity	41522	SEK
Alternative LCC (case 1):	60 000	SEK
Dif. in LCC case 0 and 1	18478	SEK
D-factor:	0,009	

Read out the critical year



CONCLUSIONS

Bridge Life Cycle Optimisation

- To carry out an LCC-analysis a number of assumptions need to be performed, therein lays an uncertainty
  - *This uncertainty is acceptable, as long as the same conditions apply for all activities/alternatives*
- It is unsuitable to run a full scale LCC-analysis at an initial stage
  - *A parametric optimisation is preferable*
- It was <u>not</u> the detailing solutions, conventional or alternative, themselves that was favourable or not, but:
  - *The expected ADT*
  - *When in time the activity occurred*

CONCLUSIONS

Bridge Life Cycle Optimisation

- Method to use LCC as a decision-making tool in design of new bridges was developed:
  - Flow chart
  - TrafficWizard2011

- This method can provide designers with an extended basis to choose the most viable long term design decisions, with regard to life cycle costs

THANK YOU FOR YOUR ATTENTION

NIKLAS LARSSON (niln@cowi.se)
DAN NILSSON (dnnn@cowi.se)