FINNISH BRIDGE LIFE-CYCLE-COST GUIDELINE

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ABSTRACT

Infrastructure owners have recently put efforts to better estimate life cycle costs (LCC) and do life cycle assessment (LCA). In Finland, a design guideline is recently prepared and taken in use by the Finnish transport agency. This guideline harmonises estimation of LCC at the bridge design or at the bridge renovation stage. LCC is dealt as its wide meaning including agency costs, user costs and society's costs. Indirect costs are dealt by assigning monetary values to non-monetary quantities, including traffic delays, environmental burden and risks. Used methodology is logical extension of standard quantity take-off and cost estimation of bridges. Present value calculation with multiple discount rates is used. Guideline gives sufficient and comprehensive unit data for preparing LCC-estimates to e.g., compare various design variants. It also instructs owner to choose discount rates and weighting factors for the cost types depending on view-point of the analysis. In longer view, one is looking possibility to include LCC-efficiency as part of the quality ranking in bids, to promote usage of sustainable structures and detailing. This paper describes the methodology used in the guideline and discusses of the outcome of the case studies.

1. INTRODUCTION

Bridges are long-term investments and expensive components of the road network. In most countries and owning agencies dealing with high number of bridges, computer based bridge management systems (BMS) are used to maintain information of the bridge stock, and to optimize the usage of money available for the maintenance. BMS, when run over the decades, gives theoretical bases of the statistically approvable and mutually reliable LCC-estimation. Aside with BMS, experts' personal views to issues like estimated service-life of various structural parts, surface structures and accessories are important.

Taking Finnish transport agency's bridges as an example, concrete and steel road bridges have 100 years life-time target. To achieve this, a bridge is thoroughly renovated 2 to 3 times, while keeping the primary load-bearing structure in use. Individual renovation can cost up to 60 % of the construction costs. It also causes indirect costs to users and society in terms of traffic delays, environmental burden, etc. It is meaningful to put efforts to optimize LCC in addition to the construction costs. Certain design and repair solutions, even though being more expensive to use, are known to be lifetime efficient. One of the hindrances of wide employment of these has been the lack of consistent methods of assessing LCC to study their efficiency at the design stage.

In recent years, bridge and other infrastructure owners have become more aware of indirect costs caused to the third parties. When dealing with bridges on busy traffic corridors, obviously the disturbance caused to traffic during construction and maintenance is a significant source of indirect costs. Injuries and fatalities caused by accidents;

including traffic accidents participating by bridge structures and accidents at construction and maintenance works; are another example. General awareness related to environmental burden affects all disciplines, including the bridge engineering.

Finnish Transport Agency has prepared 2009-2011 the guideline, which harmonises estimation of LCC and LCA at the bridge design or renovation design stage. It employs general methodologies of the Nordic ETSI research project (2006-2011) [1, 2].

2. METHODOLOGY OF THE LIFE-CYCLE-COST GUIDELINE

LCC guideline is authored as a bridge design guideline. By following the instructions given, bridge designer or other bridge expert will produce an extended LCC-estimate. The word extended means here that the LCC-estimate covers relevant direct and indirect costs of the bridge owning organisation (agency), users and society (Fig. 1). Indirect costs; including traffic delays, environmental impacts and risks; are put in monetary values to allow comparison and analysis.

	Direct costs	Indirect costs
Agency	• Construction ($K_{T,1}$) • Maintenance ($K_{T,2}$) – routine maintenance – operating – repairing – Dismantling	• Risks ($K_{T,3}$)
Users		• Traffic delay costs ($K_{K,1}$) • Risks ($K_{K,2}$)
Society		• Environmental ($K_{Y,1}$) – noise & vibration – waste & contamination – global stressors • Risks ($K_{Y,2}$)

Figure 1 - Breakdown and symbols of present value of cost types.

The guideline is an extension of the standard quantity take-off and cost estimate procedures of new bridges. Each title in the cost estimate is augmented by additional data needed in LCC. In addition to construction, LCC-estimates cover desired review period, which is typically 100 years. One prepares simple schedule of the significant maintenance operations and compute their costs and durations. Standard present value calculation is used with multiple discount rates (0 %, 1%, 2 % and 5 %). This basically allows cost occurring later in the future to be weighted less than those occurring soon. Present value calculation is applied to all cost types, including environmental costs and risks. Here, using non-zero discount rate to long term stressors, like the Global Warming Potential (GWP) within environmental costs, means that there might be some unforeseen potential of improving the efficiency in reduction of the stressors in the future. The present value of the cost occurring at year count *n* is

$$K = \frac{1}{(1+i)^n} K_0 \qquad (1)$$

where K = present value of cost; i = discount rate and K_0 = cost at day's price of preparing the LCC estimate.

2.1. Service life of structural parts

One of the key unit data, service life of structural parts, can be based on the statistical data originating from bridge inspections. Inspection data is stored into the Finnish BMS, the Bridge Register [3]. The Bridge Register has been in use about 30 years indicating that information is available of condition changes (deterioration rate) of main structural parts. In the Finnish bridge stock, where bridges are basically in good condition, majority of the repair operations invoke in from the failures found in visual bridge inspections. Estimated service life of a structural part, which is tabulated as unit data in the guideline, is related to the trained and homogenized view of bridge inspectors to report repair-needing damages. If the coverage of BMS is insufficient for the purpose; as it often is when dealing with estimates for several decades forward, special recipes of concrete or new products; expert views, theoretical deterioration models and reasoned guesses could be used in addition.

The theoretical bases of specifying the service life of a structural part is illustrated in Fig. 2. Estimated service life is strongly related to a confidence level. For example at Fig. 2, edge beam have service-life at least 30 years 80 % sure and as much as 54 years as average (50% sure). If one inquires maintenance expert his/her view of the estimated service life, the answer might be around 30 years or less, because he/she had worked mainly with problematic bridges that needs repair.

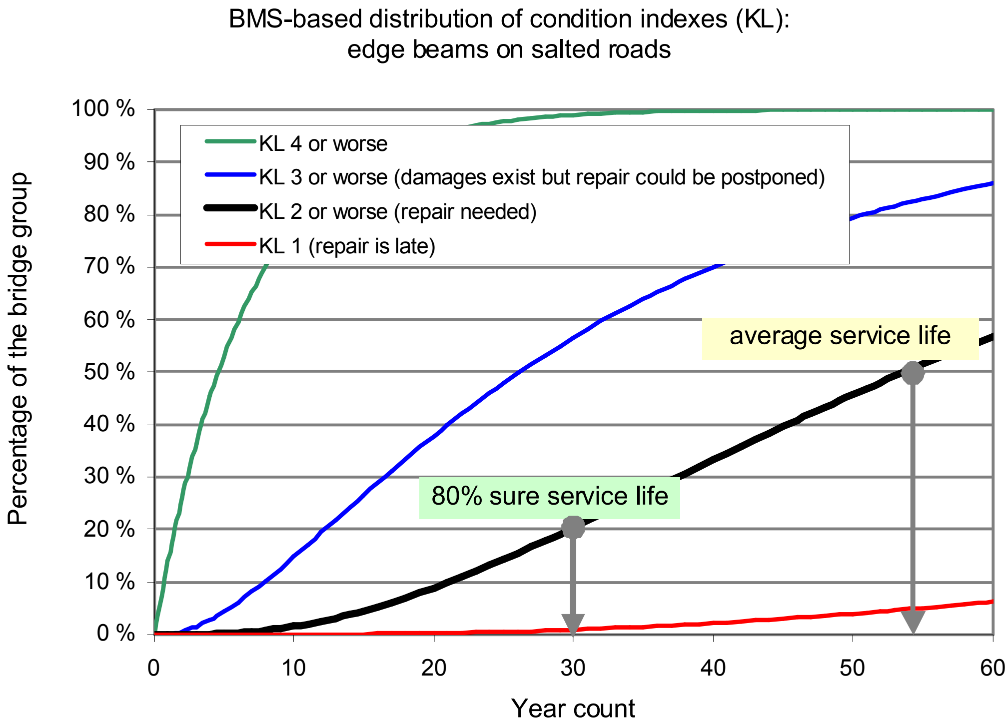

Figure 2 – Example of theoretical service life and related risk definitions.

One of the strengths of the methodology of the guideline lies in the systematic handling of risks. For example, when setting a service life of 30 years for the edge beam in Fig. 2, one at the same time set 20 % risks that this service life is not reached. Here, one identifies a risk with probability 20 % that edge beam renovation needs to advance; and set the risk consequence so that the risk value is in line with overall money needed by the agency to edge beam renovations. If one set 25 year service life instead, the risk probability could be decreased to reach the same overall cost.

2.2. Content of the unit data

Extended LCC-estimates need, and are based on, extensive set of unit data. These should cover issues like unit costs of construction; unit costs of maintenance operations; unit costs for indirect cost types; duration of construction; type and duration of typical maintenance operations; projected traffic volume; service life; production of environmental stressors etc.

Unit data in the guideline is provided in a table format (Fig. 3). Data is related to theoretical quantities, which are derivable from drawings or other design deliverables of the bridge. The level of detail, the numbering system and the title structure are the same than used in the quantity take-off and cost estimates for new bridges. This ensures that LCC-aspects of no important cost-producing design solution or a detail are ignored from the analysis.

Information of construction and maintenance operations are shown in needed number of rows below the title. In the simplest case, two rows in enough: first row showing data for the construction and the second for the renewal operation. Any unit value in the table is shown as a base value and the next rows showing factors altering the base value. This allows more detailed presentation of issues affecting the LCC. Factors altering the base value could be many: including type of construction, type of maintenance operation, exposure class, traffic volume, type of surface treatment, type of concrete, location of the bridge, difficulty of soil conditions etc. In addition, the guideline includes rules of taking into account recycling and reuse to reduce environmental burden.

Risks are tabulated separately for the agency, the users and the society. Example of the unit data is shown in Fig. 4. Identified risks include those on whose costs evidence has been obtained in the past, or which could be envisaged.

High number of different type risk are tabulated; including excess of costs, excess of duration of operations, collisions, collapses, malfunction of new materials, malfunction of unforeseen structural details, obsolescence, injuries, fatalities, bad bridge aesthetic, loss of functionality, crimes, etc.

Design solution or a detailing can affect the risk probability and/or the consequence. Taking an annual number of fatal traffic accidents in Finland as an example, roughly one accident is claimed to be related to collision to bridge piers or abutments. From about Finland’s 10’000 relevant bridges (underpasses and flyovers) one can set the normal annual risk probability around 1/10’000. Computational cost of one fatal traffic accident to the society has computed elsewhere and is around 2 Million euros. This gives risk value for a single bridge during the 100 years review period around 20’000 euros. If traffic barriers are used to protect the vehicles hitting the bridge structures, the risk probability in LCC-estimate could evidently be reduced. If crash cushions are used, the consequence might drop from cost of one fatal accident to the cost of an injury. This example is for demonstrating the methodology only, and ignores many factors, like effect of traffic volume etc., that might make the traffic barriers and the crash cushions more attractive.

A	B	C	D	E	F		G	H	I	J	K	L	M	N	O
Number	Title	Unit	Operat. year	Operat. delay max y	Unit costs €/yks	% constr. costs	Duration t/unit	Traffic % duration	Routine maint. €/y	Env L_{CNE} t/unit	Noise % duration	Vibration % duration	Contamin. % duration	Waste t/unit	Remarks
1000	MAA-, POHJA- JA KALLIO RAKENTEET														
1100	OLEVAT RAKENTEET JA RAKENNUSOSAT														
1120	POISTETTAVAT, SIIRRETTÄVÄT JA SUOJATTAVAT RAKENTEET														
1120	Poistettavat, siirrettävät ja suojattavat sillat														kierrätys ja uusiokäyttö voidaan ottaa huomioon
	- betonirakenteet	m3	-	-	-	60 %	0,01		-	-	60 %	-	60 %	0,8	
	- kivirakenteet	m3	-	-	-	50 %	0,01		-	-	50 %	-	20 %	-	
	- puurakenteet	m3	-	-	-	50 %	0,01		-	-	20 %	-	20 %	0,8	
	- teräsrakenteet	t	-	-	-	60 %	0,01		-	-	20 %	-	20 %	2,1	
	- muut rakenteet	pcs	-	-	-	50 %	0,01		-	-	20 %	-	20 %	0,1	
	* lisä kestoon kierrätyksestä						+20%								
1300	PERUSTUSRAKENTEET														
1310	MAANVARAISET PERUSTUKSET														voidaan jättää ottamatta huomioon siltaan peruslaatat kts. 4207
1320	PAALUPERUSTUKSET														
1321	Lyöntipaalut														
1321.1	Betonipaalut	m													
	:1 korjaaminen	m	70	+20	-	200 %			-	-	60 %	60 %	60 %		
	* käyttö kärki tuettu 100 v	*	+60												
	* ei käyttö kärkituettu														
	* veden vaikutus W1	*	-10												
	* veden vaikutus W2	*	-20												
1321.2	Teräspaalut	m													
	:1 korjaaminen	m	70	+20	-	200 %			-	-	60 %	60 %	60 %		
	* käyttö kärki tuettu 100 v	*	+60												
	* ei käyttö kärkituettu														
	* veden vaikutus W1	*	-10												
	* veden vaikutus W2	*	-20												
	* suolauksen vaikutus S4	*	-20												
1321.3	Puupaalut	mtr													
	:1 korjaaminen	mtr	50	+20	-	100 %			-	-	60 %	60 %	60 %		
1324	Kaivettavat paalut														

A Tile numbering
B Title as appearing in the standard titling system for infrastructures
C Unit (m, m^2, m^3, kg, etc.) of the quantity
D Year for a maintenance operation
E Number of years the maintenance operation could be postponed
F Unit costs per quantity. For maintenance operations, this could be given as unit of money or as percentage of the construction costs
G Multiplier for duration of the construction or maintenance operation
H Percentage of time the operation causes traffic disturbance
I Annual cost of routine maintenance
J Multiplier for production of combined environmental stressor per quantity
K Percentage of time the operation causes harmful noise
L Percentage of time the operation causes harmful ground vibration
M Percentage of time the operation causes contamination near the site
N Multiplier of waste production per quantity
O Remarks

Figure 3 – Table presentation of unit data.

A	B	C	D	E	F	G	H	I	J	K
Number	Description	Risk probability				Risk consequences				Observations
		uit	reduced level[1]	normal level	increased level[2]	unit	reduced level[1]	normal leve	increased level[2]	
4200.T1	TIENPITÄJÄN RISKIT									
4200.T11	Rakentaminen									
4200.T111	Rakennusajan piteneminen									
	- tavanomaiset siltatyypit	-	0,05	0,1	0,2	rak.kust.	10 %	10 %	10 %	[1]hyvät perustusolosuhteet
	* rak. korkeasuhdanteen aikana	*	+0,025	+0,05	+0,1					[2]huonot perustusolosuhteet
	- erikoiset siltatyypit	-	0,05	0,1	0,2	rak.kust.	10 %	10 %	10 %	[1]vastaavia siltoja rakennettu ≥ 5 kpl 10 v aikana [2]vastaavia siltoja rakennettu 0-1 kpl 10 v aikana
4200.T112	Kustannusten ylittyminen									
	- tavanomaiset siltatyypit	-	0,1	0,2	0,2	rak.kust.	10 %	10 %	15 %	[1]rakentaminen taantuman aikana
	* suun. ja rak. lupakasittelyja kesken ennen aloittamista					*	+5%	+5%	+5%	[2]rakentaminen korkeasuhdanteen aikana
	- erikoiset siltatyypit	-	0,05	0,1	0,2	rak.kust.	10 %	10 %	10 %	[1]vastaavia siltoja rakennettu ≥ 5 kpl 10 v aikana [2]vastaavia siltoja rakennettu 0-1 kpl 10 v aikana
4200.T113	Sillan romahtaminen	-	0,0005	0,001	0,002					[1]listeyssillat ilman rakentamisen aikaista liiken.
	* suurin jännemitta ≥ 50 m	*	+50 %	+50 %	+50 %					[2]pääkuormat tai tulvat mahdollisia kuormia telineille
	* aineettomat kustannukset									
	L < 100 m	*				€	50 000	50 000	50 000	
	L ≥ 100 m	*				€	100 000	100 000	100 000	
4200.T12	Ylläpito									
4200.T121	Suunniteltua nopeampi peruskorjaustarve									
	- reunapalkkien uusimiset	-	0,15	0,2	0,3	korj.kust.	10 %	10 %	10 %	[1]vastaavia rakenteita ollut käytössä ≥ 30 v [2]vastaavia rakenteita ollut käytössä < 10 v (rakenne & materiaali & eristys & pinnoitus)
	- kannen pintarakenteiden uusimiset	-	0,15	0,2	0,25	korj.kust.	10 %	10 %	10 %	[1]vastaavia rakenteita ollut käytössä ≥ 30 v
	* KVL > 10000	*	+0,05	+0,05	+0,05					[2]vastaavia rakenteita ollut käytössä < 10 v (tyyppi & työtapa & materiaalit)
	* vesipiikkauksen käyttö betonikannen yp kunnostuksessa	*	-0,05	-0,05	-0,05					
	* silta kokonaan suljettu liikenteeltä uusimisen yhteydessä	*	-0,05	-0,05	-0,05					
	* eristystöiden suhteen epäedullinen vuodenaika	*	-0,1	-0,1	+0,1					
	* muodonmuutosten tai liikennetärinän suhteen herkkä kansi	*	+0,05	+0,05	+0,05					teräskantiset teräsillat, avattavien siltojen läpät, hoikat betonisillat

A Number related to title
B Title and description of a risk
C Unit related to definition of the risk probability
D Probability for reduced risk level
E Probability for normal risk level
F Probability for increased risk level
G Unit (€, % construction costs, etc.) related to definition of the risk consequence
H Consequence for reduced risk level
I Consequence for normal risk level
J Consequence for increased risk level
K Observations and rules for applying reduced and increased risk level

Figure 4 – Table presentation of risks.

2.3. Preparation of the extended life-cycle estimate

Preparation of the extended LCC guideline starts from augmenting a cost estimate of the bridge by information of the maintenance operations. For this purpose, one has to plan for scheduling the maintenance operations (Fig. 5). This plan is based to unit data of structural parts (Columns D and E in Fig. 3). One can combine various smaller operations to be done during a major renovation operation. The guideline includes rules of setting a penalty, if the operation is postponed and thus affecting to envisaged costs, operation duration or risks. In Finnish conditions, it's usually the service life of the deck water proofing that schedules the main renovation operations.

Operation	Abbreviation	Year count
Bridge design and construction	R	0
Maintenance repair 1	Y1	15
Renovation 1	P1	30
Renovation 2	P2	60
Maintenance repair 2	Y2	80
Bridge is used till the end in intensified control	L	90
Dismantling	L	100
Routine maintenance	-	Every year
Road maintenance	T	-

Figure 5 – Simple maintenance plan within a LCC-estimate.

On roads with high traffic volume one has to plan for optimized strategy on minimizing the traffic delay costs, i.e., to minimize the duration of the operation that harm traffic. In practise, one make plan of how many lanes are in use for traffic or if a traffic rerouting is used. One computes typical duration in days of the operation, which is smaller or equal than sum of task durations within in the operation (Fig. 6). Overall duration also affects other issues like noise, vibration and the risk of traffic accidents.

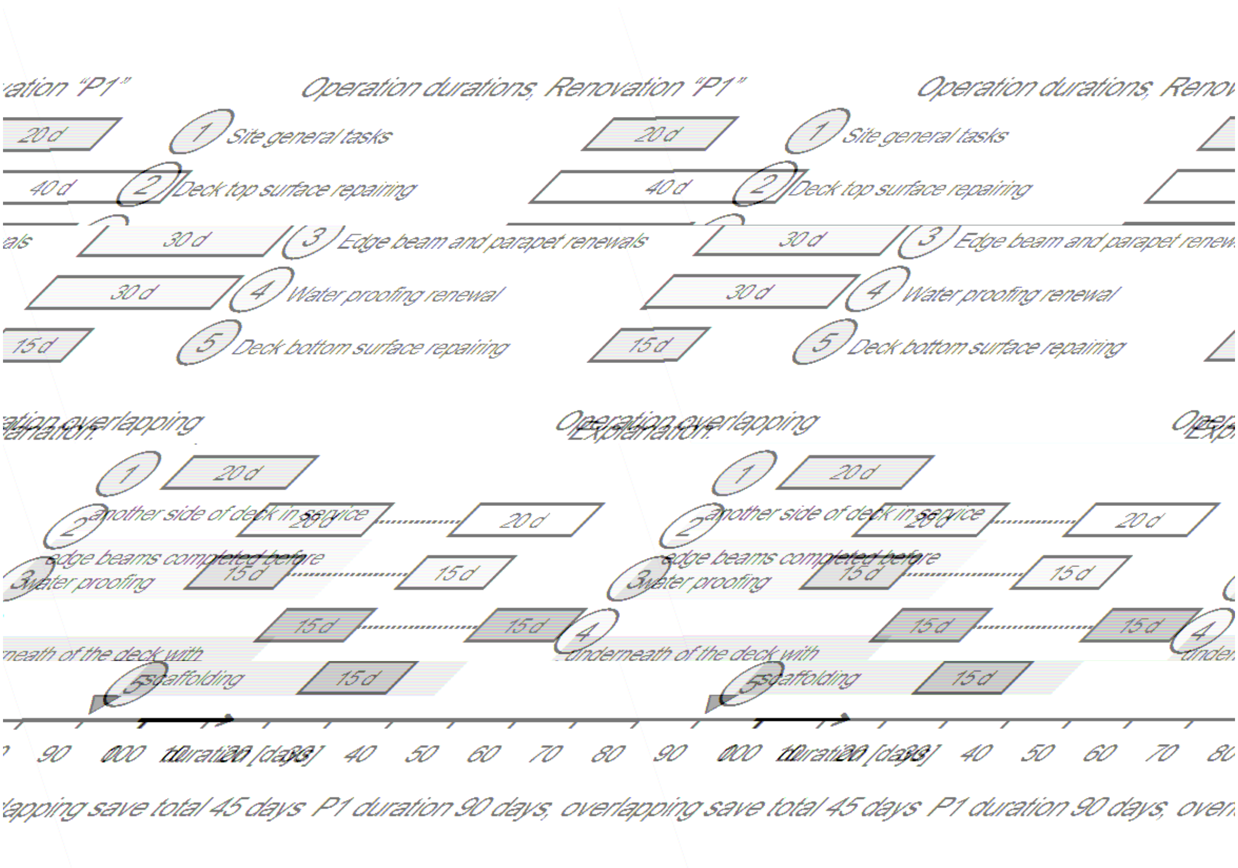

Figure 6 – Overlapping of various tasks to calculate duration of the operation.

While conventional cost estimate for bridge construction is about 5 to 10 pages document, the LCC-estimate is about 3 to 4 times that in page count. The results of the LCC could, and are, summarized to one page (Fig. 7). Rest of the LCC-estimate document is for review and computational use.

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Suunnitelman numero R15/12470 kö €

		Rakenta-minen	Kunnossapito								Elinkaarikustannusten nykyarvo			
			ylläpidon kustannukset, nykyarvo				hoidon ja käytön kustannukset, nykyarvo							
			kust.	1 %	2 %	5 %	kust.	1 %	2 %	5 %	kust.	1 %	2 %	5 %
1	TIENPITÄJÄN SUORAT KUSTANNUKSET													
	Kustannukset (i=100, 2000=1000)	514 000	799 000	473 000	297 000	95 000	48 900	30 800	21 100	9 700	1 361 900	1 017 800	832 100	618 700
	- kustannustason indeksikorjaus	202 516	314 806	186 362	117 018	37 430	19 267	12 135	8 313	3 822	536 539	401 013	327 347	243 768
	Yhteensä, pyöristettynä	717 000	1 114 000	659 000	414 000	132 000	68 000	43 000	29 000	14 000	1 898 000	1 419 000	1 160 000	862 000
	(i=139,4, 2000=100, ALV0)													
	% rakentamisen kustannuksista	100 %	155 %	92 %	58 %	18 %	9 %	6 %	4 %	2 %	265 %	198 %	162 %	120 %
2	TIENPITÄJÄN EPÄSUORAT KUSTANNUKSET													
	Kustannukset (i=100, 2000=1000)													
	- riskit	15 500	163 000	103 300	70 200	30 500	6 400	4 000	2 800	1 300	184 900	122 800	88 500	47 300
	- *yhteensä*	*15 500*	*163 000*	*103 300*	*70 200*	*30 500*	*6 400*	*4 000*	*2 800*	*1 300*	*184 900*	*122 800*	*88 500*	*47 300*
	- kustannustason indeksikorjaus	6 107	64 222	40 700	27 659	12 017	2 522	1 576	1 103	512	72 851	48 383	34 369	18 636
	Yhteensä, pyöristettynä	22 000	227 000	144 000	98 000	43 000	9 000	6 000	4 000	2 000	258 000	171 000	123 000	66 000
	(i=139,4, 2000=100, ALV0)													
	% rakentamisen kustannuksista	3 %	32 %	20 %	14 %	6 %	1 %	1 %	1 %	0 %	36 %	24 %	17 %	9 %
3	KÄYTTÄJIEN KUSTANNUKSET													
	Kustannukset (i=100, 2000=1000)													
	- ajokustannukset	9 800	137 400	87 300	57 400	19 400	-	-	-	-	147 200	97 100	67 200	29 200
	- riskit	400	5 100	3 200	2 100	700	10 000	6 300	4 300	2 000	15 500	9 900	6 300	3 100
	- *yhteensä*	*10 200*	*142 500*	*90 500*	*59 500*	*20 100*	*10 000*	*6 300*	*4 300*	*2 000*	*162 700*	*107 000*	*74 000*	*32 300*
	- kustannustason indeksikorjaus	4 019	56 145	35 657	23 443	7 919	3 940	2 482	1 694	788	64 104	42 158	29 156	12 726
	Yhteensä, pyöristettynä	14 000	199 000	126 000	83 000	28 000	14 000	9 000	6 000	3 000	227 000	149 000	103 000	45 000
	(i=139,4, 2000=100, ALV0)													
	% rakentamisen kustannuksista	2 %	28 %	18 %	12 %	4 %	2 %	1 %	1 %	0 %	32 %	21 %	14 %	6 %
4	YHTEISKUNNAN KUSTANNUKSET													
	Kustannukset (i=100, 2000=1000)													
	- ympäristökustannukset	112 600	113 300	68 400	43 600	14 000	-	-	-	-	225 900	131 000	156 200	126 600
	- riskit	99 200	320 200	183 300	112 700	34 900	30 200	19 000	13 000	6 000	449 600	331 500	224 900	140 100
	- *yhteensä*	*211 800*	*433 500*	*251 700*	*156 300*	*48 900*	*30 200*	*19 000*	*13 000*	*6 000*	*675 500*	*482 500*	*381 100*	*266 700*
	- kustannustason indeksikorjaus	83 449	170 799	99 170	61 582	19 267	11 899	7 486	5 122	2 364	266 147	190 105	150 153	105 080
	Yhteensä, pyöristettynä	295 000	604 000	351 000	218 000	68 000	42 000	26 000	18 000	9 000	942 000	673 000	531 000	372 000
	(i=139,4, 2000=100, ALV0)													
	% rakentamisen kustannuksista	41 %	84 %	49 %	30 %	9 %	6 %	4 %	3 %	1 %	131 %	94 %	74 %	52 %
5	KAIKKI KUSTANNUSLAJIT YHTEENSÄ													
	Tienpitäjä	739 000	1 341 000	803 000	512 000	175 000	77 000	49 000	33 000	16 000	2 156 000	1 590 000	1 283 000	928 000
	Käyttäjät	14 000	199 000	126 000	83 000	28 000	14 000	9 000	6 000	3 000	227 000	149 000	103 000	45 000
	Yhteiskunta	295 000	604 000	351 000	218 000	68 000	42 000	26 000	18 000	9 000	942 000	673 000	531 000	372 000
	Yhteensä	1 048 000	2 144 000	1 280 000	813 000	271 000	133 000	84 000	57 000	27 000	3 325 000	2 412 000	1 917 000	1 345 000
	(i=139,4, 2000=100, ALV0)													
	% rakentamisen kustannuksista	146 %	299 %	179 %	113 %	38 %	19 %	12 %	8 %	4 %	464 %	336 %	267 %	188 %

A	Construction costs
B	Present value of maintenance cost (0 %, 1 %, 2 % and 5 % discount rates)
C	Present value routine maintenance and operation costs (0 %, 1 %, 2 % and 5 % discount rates)
D	Present value of LCC (0 %, 1 %, 2 % and 5 % discount rates)
1	Rows for direct costs of the agency
2	Rows for indirect costs of the agency
3	Rows for user costs
4	Rows for society's costs
5	Summary of all cost types.

Figure 7 - Summary sheet as a result of the LCC-estimation.

2.4. Utilization of the results

The guideline proposes weighting factors and discount rates to be used in various types of analysis. Weighting is given by the equation

$$K_{V,j} = \sum_{i=1}^{N_T} w_{T,i} K_{T,i} + \sum_{i=1}^{N_K} w_{K,i} K_{K,i} + \sum_{i=1}^{N_Y} w_{Y,i} K_{Y,i} \qquad (2)$$

where $K_{V,j}$ = present value of the extended LCC in the type of assessment denoted by the subscript j; $w_{T,i}$ = weighting factors for the cost types related to agency costs; $w_{K,i}$ = weighting factors for the cost types related to user costs; and $w_{Y,i}$ = weighting factors for the cost types related to society's costs. Here, the symbols $K_{T,i}$; $K_{K,i}$ and $K_{Y,i}$ are as given in Fig. 1 and are dependent on the chosen discount rate.

As a special case one obtain conventional construction cost estimate by setting $w_{T,1}$ = 1.0 and other weighting factors to zero. Furthermore, in conventional LCC the weighting factors $w_{T,1}$ = 1.0 and $w_{T,2}$ = 1.0 while others are zero.

The used methodology allows various viewpoints to be taken to the same LCC results. Generally speaking, 100 years and more review periods request usage of low discount rate (zero or 1 %) for a LCC-estimation being meaningful. In cost benefit analysis of new infrastructure projects, where bridges are only one component, the review period is shorter. In these cases 2 % and 5 % discount rates may be usable.

In long-terms considerations, when multiple LCC estimates are prepared for different type of bridges one may consider comparing the results against average LCC of similar type bridges in similar type environment. This also forms bases of LCC efficiency classification proposed in the guideline.

3. CASE STUDIES

The test use of the guideline has been implemented in late 2010 by procuring extended LCC estimates from five bridge engineering consultants. Bridges include two slab-frame bridges, cantilevered slab bridge, glue-laminated timber girder bridge and continuous pre-stressed concrete slab-girder bridge. Comments were asked from the usability of the guideline as well as reviewing the results.

Outcome of the test use indicates consistent results between the bridges. On 100 years review period, the ratio of all costs to construction costs is around 4 for 0 % discount rate and around 3 for 1 % discount rate. When considering only agency's LCC, 5 % discount rate produces only 20 % extra to construction costs, indicating the strong influence of the discount rate for long review periods.

The relative contribution of environmental stressors, including GWP and the Acidification Potential (AP), was found to be minor in terms of costs. This is when the unit cost for the weighted sum of these (0,6GWP + 0,4AP) was fixed around 60 euro/t in the guideline. The environmental stressors are mainly dependant on consumption of material (concrete, steel, timber), which is low in ordinary small bridges.

General usability of the guideline was found to be reasonable good and as targeted. Extended LCC-estimates were prepared, first time by the engineer, in around 2…5 working days. Adverse comments originate from the complexity of using the spread-sheet provided as a reference.

4. CONCLUSIONS AND DISCUSSION

The experiences obtained in the development of the guideline and its' test use have been promising. LCC could be estimated and compared at design stage with the same methodology and mutual reliability than construction costs. The detailed breakdown of quantities gives information of overall impacts of individual design solutions including their risk levels. This is considered to be fair for all parties, as it is important to consider extended review period to rank between LCC and LCA efficiency of individual products or design solutions. This is not possible unless bridge maintenance operations are reasonable assumed, scheduled and taken into account.

One of the fundamental benefits of the guideline is that the unit data behind the results, as well as the content of a LCC-estimate itself, are open for review. Any of the unit data could be subjected to criticism and modification proposals if new research, new products etc. become available. If the unit data could be trusted; and the LCC-estimates are checked for errors and consistency; also the comparison between bridge alternatives could be trusted. The unit data is closely related to local environmental conditions and practices applied by the agency, especially those used in bridge inspections and BMS. In Finland, the freeze-thaw cycles of concrete and de-icing salt used for winter road maintenance are the issues influencing strongly the service-life of reinforce concrete parts, the used recipes of concrete and the policy of starting repair operations.

The guideline suggests the way unit data could be acquired and presented in the future: in addition to the construction costs, data is used for typical maintenance schedule, maintenance costs, duration of works, environmental burden, reuse/recycling information and the amount of construction waste.

The long-term target is that extended LCC-estimates could be considers in a quality ranking of bids to further support development and usage of sustainable structures and repair solutions.

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