LCC-analysis for Switches and Crossings – a case study from the Swedish railway network

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ABSTRACT

Banverket (the Swedish Rail Administration) plans to achieve a lower operation and maintenance cost for infrastructure through a better understanding of the life cycle cost. It is easier to propose changes in the design and maintenance strategy for its assets through quantified values of cost instead of just failure rates and the number of inspection remarks. This paper makes an attempt to analyze the LCC-values of S&Cs (switches and crossings) on Swedish railway track. The scope of the paper is to explore the possibility of using LCC as a decision tool for an infrastructure manager.

The S&C cost data from Banverket were collected for the LCC-analysis as a part of the case study. A cost model based on the acquisition phase and the operation and maintenance phase has been developed and tested. In this model the LCC-values of three types of S&Cs are compared. The model can also be used to find cost drivers, as well as to perform sensitivity analysis to find parameters that have a large influence on the result. The model has been built with the assumption that a multiple type of maintenance action is undertaken for each subsystem. Within the model, there is a possibility of defining periodical maintenance intervals besides the annual maintenance cost. The LCC-value may be presented as an annuity cost, which enables a comparison between assets that have different technical lifetimes.

The cost drivers are the inspection cost and the periodical maintenance costs of subsystems, such as the costs for crossing and switch blade replacement, welding and tamping. The sensitivity analysis confirms that the most important parameter to have control of is the frequency of periodical preventive maintenance.

Keywords: Switches and crossings, LCC, railway

Mathematical symbols and abbreviations

$[\rightarrow]$	–	Conditional statement, if the statement is true, assign the value after the arrow
$\|$	–	Used in conditional statement, interpreted as Boolean AND
λ_{ij}	–	Failure intensity for action i and unit j [year^{-1}] (this is a function of time)
C_A	–	Cost of acquiring an asset [€]

C_{Eij} – Maintenance equipment cost for action i and unit j [€/h]
C_{Delay} – Unavailability cost per hour [€/h]
C_I – Cost for investment in maintenance equipment [€]
C_{IN} – Cost for installation of asset [€]
C_L – Man hour cost for labour [€/h]
CO – Operational cost [€]
C_{Pij} – Spare parts cost for action i and unit j [€]
CP_{PM} – Periodical preventive maintenance cost (typical interval of 5 – 30 years) [€]
$CPPM_E$ – Yearly cost for use of maintenance equipment for periodical preventive maintenance [€/year]
$CPPM_M$ – Cost for man hours performing periodical preventive maintenance [€/h]
$CPPM_S$ – Cost for spare parts used for periodical preventive maintenance [€]
C_Y – Yearly cost for maintenance [€/year]
CY_{CM} – Yearly cost for corrective maintenance [€/year]
$CYCM_E$ – Yearly cost for use of maintenance equipment for corrective maintenance [€/year]
$CYCM_M$ – Yearly cost for man hours performing corrective maintenance [€/year]
$CYCM_S$ – Yearly cost for spare parts used for corrective maintenance [€/year]
CY_{PM} – Yearly cost for preventive maintenance [€/year]
$CYPM_E$ – Yearly cost for use of maintenance equipment for preventive maintenance [€/year]
$CYPM_M$ – Yearly cost for man hours performing preventive maintenance [€/year]
$CYPM_S$ – Yearly cost for spare parts used for preventive maintenance [€/year]
f_{ij} – Maintenance frequency for action i and unit j [$year^{-1}$] (this is a function of time)
I – Index for maintenance actions
INT – Calculates the integer value of the function
j – Index for units/subsystems
LCC – Life cycle cost [€]
LCCA – Acquisition cost [€]
$LCCA_E$ – Acquisition cost for equipment [€]
$LCCA_I$ – Installation cost at the acquisition [€]
LCCO – Ownership cost [€]
LSC – Life support cost [€]
LUC – Unavailability cost [€]
LCT – Termination cost (disposal cost) [€]
m – Maintenance actions between 1 and m are treated as annual maintenance actions
m_1, m_2 – Maintenance actions between m_1 and m_2 are treated as periodical preventive maintenance
MAT_{ij} – Mean action time for action i and unit j (preventive maintenance) [h]
MLT_{CM} – Mean logistic time for corrective maintenance [h]
MLT_{PM} – Mean logistic time for preventive maintenance [h]
MRT_{ij} – Mean repair time for action i and unit j (corrective maintenance) [h]
$MTDT_j$ – Mean train delaying time for unit j [h]
n – Number of units/subsystems
n_L – Number of workers to perform the maintenance

NPVF – Net present value factor $(1+r)^{-t}$
p_{ij} – Probability that a failure will lead to a train delay
r – Discount rate
S&Cs – Switches and crossings
t – Index for time [years]
t_l – Technical lifetime for S&Cs [years]
TLT – Technical lifetime for a subsystem [years]

1 INTRODUCTION

Banverket (the Swedish Rail Administration) manages an infrastructure consisting of 13,000 km of track with about 12,000 switches and crossings (S&Cs). The cost of maintenance and reinvestment is on average €26,000/km of track/year.

Life cycle cost (LCC) analysis has been used since the late ’60s and has its roots in the American defence industry [1] as a tool for decision making by assessing the total cost of acquisition, ownership and disposal of a product [2].

This study has been undertaken to analyze the LCC-values of S&Cs in the Swedish railway network. By presenting quantified values, one can gain a better understanding of the type of changes in the design and maintenance strategy that can be planned to lower the life cycle cost.

The scope of this article is to explore the possibility of using LCC as a decision tool for an infrastructure manager.

The article is based on data retrieved from maintenance databases in use for the Swedish rail network. The data may differ considerably from that for other railways. The equations for dependency on the traffic load have not been validated, but are general and therefore possible to adapt to other circumstances. The cost for operation has not been included in the model and it is considerable in the northern part of Sweden, especially concerning snow removal and heating.

Railway infrastructure and particularly track components are expensive assets with long life spans. This motivates the use of LCC, an engineering economics technique. LCC can, for instance, visualize the importance of good maintenance strategies [3].

There are a few examples of reports assessing the long-term cost for track components within Banverket. Strategies for managing rail cracks and rail breaks, lubrication and grinding of rail have been studied [4,5]. The life cycle cost for tunnels has also been discussed and analyzed by Banverket [6,7]. Rail life and grinding strategies have been modelled in economic terms [8]. The author is not aware of any more reports showing the use of LCC within Banverket.

S&Cs contribute to about 13% of the maintenance budget for Banverket [9]. The life length of S&Cs on the main track is in general 40 years and, therefore, in the reinvestment plan, it is necessary to calculate for more than 200 new S&Cs per year. A cost-benefit analysis based on life cycle costing could be a good tool for finding which S&Cs need to be replaced. Life cycle costing can also be used in the design stage or when choices between different types of S&Cs must be made. In the European project Innotrack, life cycle costing and RAM-analysis have been used as a foundation for making choices. Banverket is involved in this European project as one of 8 infrastructure managers. The Association of American Railroads has presented a report on LCC for railroad turnouts [10]. Any other research on the life cycle cost of S&Cs has not been found by the author.

2 LCC METHODOLOGY

The life cycle of an asset can be subdivided into 6 phases according to (IEC 60300-3-3) [2]:

1. concept and definition

2. design and development
3. manufacturing
4. installation
5. operation and maintenance
6. disposal

The owner of an asset can consider 3 stages [11] for LCC-analysis:

1. development
2. operation
3. phase-out

These 3 stages have been used in this case study. Cost can be attributed to each stage by information available at Banverket. The life cycle costing model (LCC-model) is based on three S&C-types used in Sweden.

For the asset owner, the cost connected with the development stage is the acquisition and installation cost, while the development is carried out by the vendor. These costs are normally fixed. The S&Cs can be described by different levels. Level I is the superstructure carrying the load, and level II is the superstructure and the mechanical parts with the driving and locking devices. Level III is the total system with the signalling and interlocking system, see Figure 1. Only level II is used in the operation phase of the LCC-model. In Figure 2 the S&Cs are decomposed into subsystems and units.

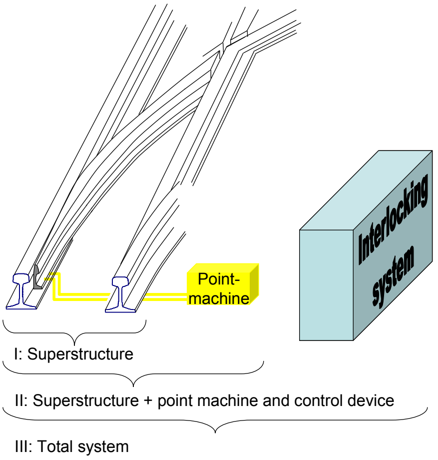

Figure 1 Decomposition of an S&C into different levels

For each subsystem different maintenance activities are possible. A maintenance activity is described by the frequency and the unit cost. For a few subsystems, the operation cost (such as the cost for heating and snow and leaf removal) can be added. In the phase-out stage the disposal cost and the cost for possible restoration and further use in a low traffic area can be considered.

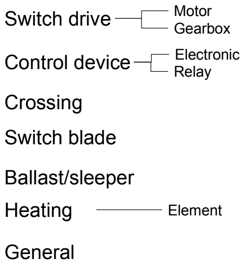

Figure 2 Decomposition of an S&C into subsystems and units

2.1 Product breakdown structure (PBS)

The product breakdown structure is used to allocate the cost, maintenance rate, repair time, etc. at a level where parameters for repair and replacement can be identified.

2.2 Cost breakdown structure

The cost breakdown structure enables the analyst to find the cost driving elements and also simplifies the work involved in setting up correct equations. The breakdown shown in Figure 3 is an adaption of that used in IEC 60300-3-3 [2] and Wååk [12]. The equations used in the cost breakdown structure are summarized in equation (1) – (5). The operational cost, C_O, and the termination cost have been set to zero in the model. Three features not normally used in LCC-calculation have been introduced.

- Several maintenance rates can independently be attributed to each subsystem.
- The preventive maintenance has been separated into annual preventive maintenance and periodical preventive maintenance.

- The yearly costs are not constant, but functions of time. An application factor that normally is used has been substituted by Σ(NPVF*CY).

The reason for doing this is explained in the discussion.

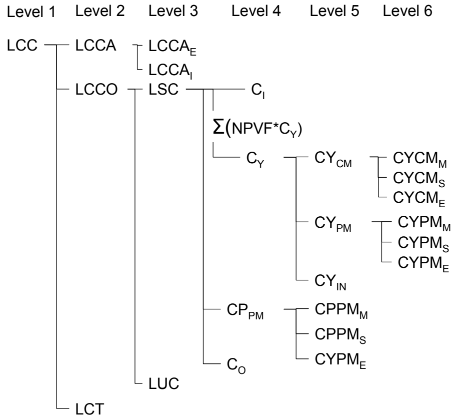

Figure 3 Cost breakdown structure adapted of that used in EN IEC 60 300-3-3 [2]

Acquisition cost $LCC_A = C_A + C_{IN}$ (1)

Annual cost for corrective maintenance

$$CY_{CM}=\sum_{i=1}^{m}\sum_{j}^{n}\lambda_{ij}*\left(C_L*n_L*(MRT_{ij}+MLT_{CM})+C_{Pij}+C_{Eij}\right) \quad (2)$$

Annual cost for preventive maintenance

$$CY_{PM}=\sum_{i=1}^{m}\sum_{j}^{n}f_{ij}*\left(C_L*n_L*(MAT_{ij}+MLT_{PM})+C_{Pij}+C_{Eij}\right) \quad (3)$$

Periodical preventive maintenance cost CP_{PM}=

$$\sum_{t=0}^{t1-1}\sum_{i=m1}^{m2}\sum_{j=1}^{n}\begin{bmatrix} t<t_1-t_{ep}\big|INT\big((t+1)*f_{ij}\big)>INT\big(t*f_{ij}\big)\rightarrow \\ \rightarrow NPVF*C_L*n_L*(MAT_{ij}+MLT_{PM})+C_{P\,ij}+C_{E\,ij} \\ t>=t_1-t_{ep}\rightarrow 0 \\ INT\big((t+1)*f_{ij}\big)=INT\big(t*f_{ij}\big)\rightarrow 0 \end{bmatrix} (4)$$

Consequential cost

$$LUC=\sum_{t=0}^{t1-1}\sum_{i=1}^{m}\sum_{j}^{n}NPVF*\lambda_{ij}*p_{ij}*C_{Delay}*MTDT_j \quad (5)$$

2.3 Maintenance breakdown structure

The maintenance of a subsystem can be conducted in several ways and the cost associated with a subsystem depends heavily on the type of maintenance action. Banverket's maintenance actions are registered in two databases (Bessy and 0felia). Table 1 lists typical maintenance actions used by Banverket. The model developed in this paper uses the activities written with bold letters.

2.4 Parameters

Each stage is described with a certain number of parameters.

Development

The pre-investment has so far been considered to be equal for all the cases and has therefore been set to 0. It is possible that an S&C with a new design would need a test period and this could be treated as a pre-investment cost.

The cost for investment was assumed to be the price for a new system given by Banverket, Spare Part Support (Materialservice). The cost for installation was requested from the entrepreneur or vendor.

2.4.1 Operation

The most important operation cost for S&Cs in Sweden is the heating and snow removal cost. This cost is treated as equal for different S&Cs and therefore normally set to zero. In certain cases where improvement of the heating system is considered, this is an essential cost.

Table 1 Maintenance action for S&Cs in use by Banverket. Activities in bold letters are headings used in the model.

Action	Corrective Maintenance	Preventive Maintenance
Replacement	**28.0%**	**9.4%**
Adjustment	**14.8%**	**45.8%**
Checking	12.2%	
Lubrication	10.2%	
Snow clearance	7.4%	
Repair	**7.2%**	**0.4%**
Rinsing	7.1%	
Cleaning	5.0%	0.4%

Restart	3.1%	
Minimal repair	2.2%	
No action	1.5%	
Not specified	0.4%	0.1%
Removal	0.3%	0.0%
Restart	0.3%	
Advice	0.2%	
Speed restriction	0.1%	
According to notes		9.8%
Tightening		8.7%
Grinding		**7.9%**
Building up weld		**7.3%**
Complement		4.0%
Bolt replacement		3.3%
Tamping		**1.7%**
Lubrication		0.4%
Visual inspection		0.3%
Lifting		0.2%
Lock		0.1%
Plan for action		0.1%
Action needed		0.0%
Alignment		0.0%
Removal of vegetation		0.0%

The maintenance training cost and the cost for investing in maintenance equipment, C_I, have been set to zero.

The data used to describe the maintenance can be grouped into some general parameters and 8 sheets with values. Table 2 describes which type of data should be gathered, and one sheet with values for the LCC-model is shown in Figure 4, which contains data on the preventive maintenance rate (times per year). Each sheet is based on 12 subsystems/units and 9 possible actions. A primary assessment has been carried out using data taken from Banverket's maintenance systems [13]. A second assessment has been performed by interviewing people involved in maintenance activities. It is important in this stage that the case has been described and that the traffic volume and type of track have been specified. The values that are the most critical are discussed in the section "*Sensitivity analysis*" and written in bold print in Figure 4.

2.4.2 Phase-out

There are three possible outcomes concerning how the asset is treated after the operation and maintenance phase.

- The technical life length is sufficient to keep the system in use for a certain period.
- The asset is reconditioned and moved to a low frequency track.
- The asset is taken out and disposed of.

Table 2 Type of input data needed for the model (X – single values, XXX – sheet with values)

Parameter	**Corrective maintenance**	**Preventive maintenance**	**General**
Frequency of maintenance activities	XXX	XXX	
Man hour time per action	XXX	XXX	
Logistic delay time	X	X	
Equipment cost per action			XXX
Spare part cost per action			XXX
Man hour cost			X
Train delay time per action	XXX		
Cost for train delay time	X		
Frequency of train stopping failure	XXX		

In each case it is possible to give a value for the asset. In the first case a value proportional to the investment cost and the life length used can be calculated. In the other two cases a fixed cost can be used.

Action / Subsystem	Adjustment	Replacement norma	Replacement large	Repair	Repair, welding	Other
Switch drive	**1.933**	0.013	**0.033**	0.246		0.117
- motor		0.000				
- gearbox		0.000				
Control device	**0.663**			0.000		0.063
- electronic		0.002				
- mechanical		0.004				
Crossing	**0.917**		**0.071**	0.154	**0.710**	**0.896**
Switch blade	0.283		**0.108**	0.088		0.233
Ballast/Sleeper				0.021		
Heating	0.033					0.033
- element		0.000				
General	0.15	0.025		0.029		0.100

Figure 4 A sheet for values of frequency of predetermined maintenance for the S&C UIC60-760-1:15 based on figures in Banverket's database (for a mixed traffic line with 10 MGT/year). The values in bold print are the most critical (discussed in the section "Sensitivity analysis").

2.4.3 General parameters

The general parameters include the discount rate, the calculation period and boundary conditions such as the maintenance strategy for tamping and grinding. In Table 3 some general parameters are shown.

2.5 Reference solution

The reference solution is the solution that is assumed to be the normal choice.

Banverket prefers to use the EV-UIC60-760-1:15 or a larger S&C when replacing cross-over S&Cs on most main tracks. The location is assumed to be at a meeting station on a double track line with 4 S&Cs and the station is used for cross-over traffic (with 1-2% usage), see Figure 5. The station is situated 100 km from the nearest maintenance service team. The technical lifetime is set to 40 years.

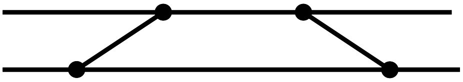

Figure 5 A cross-over station with 4 S&Cs

Table 3 General parameters used in the study

Parameter	Value
Discount rate	4%
Calculation period	35,40 and 45 years
Traffic	Mixed traffic line 10 MGT/year
Track	Double
Grinding frequency	40 MGT
Use of deviating track	2%
End period when no periodical maintenance is performed	20% of maintenance interval
Logistic delay time for corrective maintenance	3 h
Logistic delay time for preventive maintenance	1 h
Cost of train delay	€53/minute

2.6 Alternative solutions

Two different alternative solutions are discussed.

A) EV-BV50-600-1:15 with a technical lifetime of 35 years

B) EVR-UIC60-760-1:15 with a movable frog and a technical lifetime of 45 years

The EV-BV50-600-1:15 is an S&C with lighter rail (50 kg/m instead of 60 kg/m) and a smaller radius for deviating track (600 m instead of 760 m). This should normally lead to a lower investment cost, faster deterioration and a shorter lifetime than for the EV-UIC60-760-1:15 S&C. The EVR-UIC60-760-1:15 has the same dimension as the reference solution and has a movable frog. This S&C has a higher investment cost, but a lower cost for maintaining the crossing.

2.7 Input value with distribution

In many cases there is an uncertainty in the input value of the LCC-model. This uncertainty can be handled by using distributions instead of single values. Some of the possible distributions used for LCC are the triangle, square, half-circle and normal distributions, shown in Figure 6 [14].

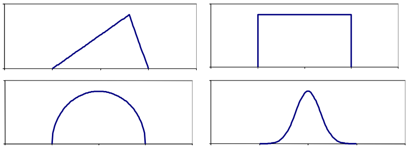

Figure 6 Distributions used in Monte Carlo simulations. A) Triangle, B) Rectangle, C) Half-Circle, D) Normal distributions

3 RESULTS

In this section the cost drivers for the reference solution are discussed, and a sensitivity analysis for the reference solution is presented. The alternative solution is compared to the reference solution.

3.1 Reference solution

In a previous study it was concluded that the cost for maintaining an S&C is about €900/MGT [15]. That would give a life support cost (LSC) in the order of €185 k. The reference solution has an LSC of €191 k. Figure 7 shows the LCC subdivided into cost elements (with the cost elements CYCM, CYPM and CYIN summed up for the total lifetime of the S&C). The cost for preventive maintenance dominates over that for corrective maintenance, and in Figure 8 more details from the preventive maintenance actions (CPPM, CYPM and CYIN) are shown. The dominant activities are periodical preventive maintenance, adjustment and inspections. The subsystems that cause most of the preventive maintenance cost are the crossing, switch blade, rail, switch device and ballast (need of tamping) subsystems, see Figure 9.

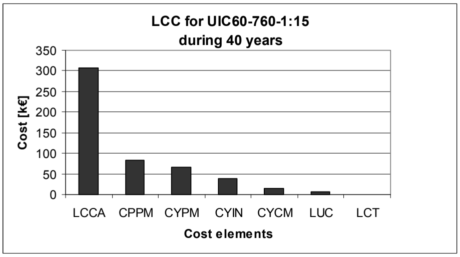

Figure 7 Cost elements of reference solution

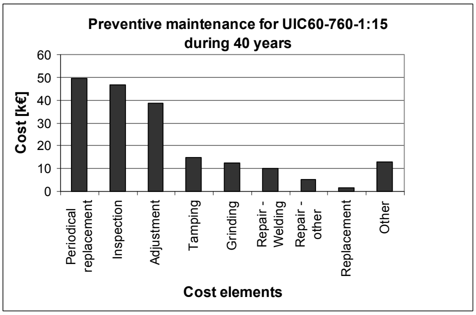

Figure 8 Maintenance activities within the preventive maintenance

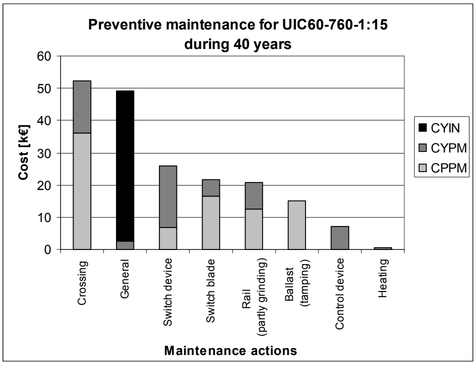

Figure 9 The cost of preventive maintenance divided up into subsystem costs

3.2 Sensitivity analysis

In the sensitivity analysis the parameters are varied to see how great an effect they have on the LCC-value.

In Figure 10 about eight parameters affect the LCC-value to a great extent. For the other parameters even a variation of +100% or -50% will not change the LCC-value by more than 10%. The need for precision of the input parameter is shown in Figure 11. For most of these parameters it is possible to have a good data quality, and it may be difficult to establish sufficiently good data quality for only a few of them. For instance, it is important to have knowledge of the preventive maintenance and the technical life length of subsystems such as the crossing and the switch blade.

As shown in Figure 4, some values can be considered to be more critical concerning the preventive maintenance rate. It is also important to perform a quality check on all the other parameters that are combined with the preventive maintenance rate, for instance the man hour time required to install a new crossing.

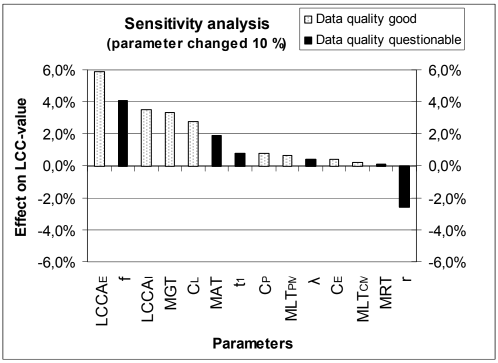

Figure 10 Sensitivity analysis showing the most important parameters

3.3 Alternative solution

A comparison between the UIC60-760-1:15 and the BV50-600-1:15 has been made based on historical data for the UIC60 S&C on Main Line 2 in Sweden (Järna-Arlöv) and the assumption of a 15% higher maintenance cost for the BV-50-design. The BV50 is a Swedish development of the UIC60-design involving the use of a 50 kg/m rail where the traffic volume is lower than 8 MGT/year. The lack of historical data is due to the fact that very few BV50 S&Cs are installed on Main Line 2. The values have so far not been validated by discussions with a Swedish S&C expert, but the total cost level is in accordance with the cost figures taken from the accounting system [15].

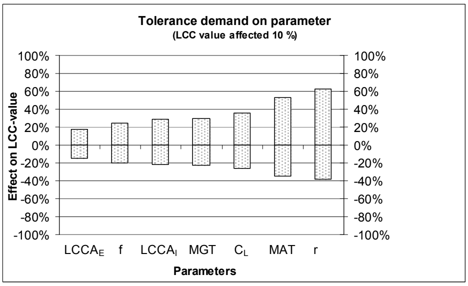

*Figure 11 Tolerance demand on input parameter so that the effect will be less than 10% on the LC*C-value

A comparison between the EV-UIC60-760-1:15 and the EVR-UIC60-760-1:15 (the new S&C with a movable crossing nose) has been made based on historical data for the EV-UIC60-760-1:15 on Main Line 2 in Sweden (Järna-Arlöv) and the assumption of a lower maintenance cost for the EVR-UIC60-760-1:15. The lack of historical data for the EVR-UIC60-760-1:15 is due to the fact that until 2007 only 11 had been in use (none of them on Main Line 2). Another 39 S&Cs have been installed on a new line, but this line has not been in use.

To be able to compare assets with a different technical life length, the LCC-value is divided by the sum of all the NPVFs and is presented as an annuity cost.

Annuity factor =

$$\sum_{t=0}^{t1-1}(1+r)^{-t} = \frac{(1+r)-(1+r)^{-(t1-1)}}{r} \quad (7)$$

In Figure 12 the LCC-values for the EV-UIC60-760-1:15, EV-BV50-600-1:15 and EVR-UIC60-760-1:15 are compared. The investment cost for the EV-BV50-600-1:15 is 8% lower and the maintenance cost is higher. The shorter lifetime also affects the annuity value of LCC, so it is 11% higher for the EV-BV50-600-1:15.

The investment cost is 43% higher for the S&C with a movable crossing nose (the EVR-UIC60-760-1:15). In this case the maintenance cost is considerably lower and the technical lifetime longer. The conclusion from this evaluation is that the investment cost is too high to be offset by the lower maintenance cost.

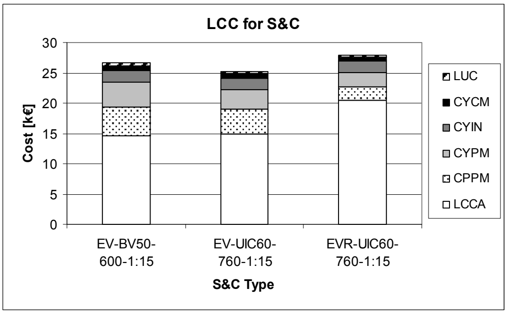

Figure 12 Life cycle cost (annuity cost) for 3 types of S&Cs

3.4 Dependency on traffic volume

The choice of S&C should be the EV-UIC60-760-1:15 according to the example of Figure 12. However, if the boundary condition is dramatically changed, this conclusion may not be correct. For instance, the traffic volume can be higher close to large cities and on heavy haul lines with mostly freight traffic. In Figure 13 the dependency on the traffic volume is shown. For a lower traffic volume it is still best to use the EV-UIC60-760-1:15 S&C, and the EVR-UIC60-760-1:15 should be used when the traffic volume is very high (more than 20 MGT/year).

3.5 Monte Carlo simulation

A Monte Carlo simulation has been performed by building the model in Excel and generating 10,000 individual calculations with a macro. The result has been summarised in histograms. Even in Excel it is possible to trace the probabilistic cost for individual subsystems, but the need for such a detailed understanding is small.

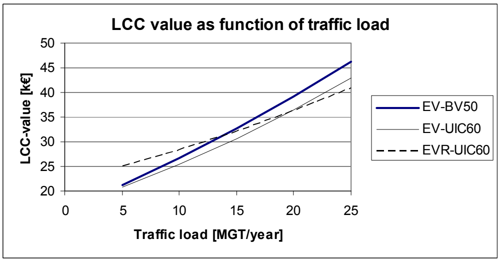

Figure 13 LCC-value as a function of the traffic volume

Figure 14 shows the probabilistic result for the maintenance cost (the annual and periodical preventive and corrective maintenance cost), based on the same model as that used for Figure 12. The solid line represents the result when the base model is used and the dashed line represents the result when the TLT for crossings is changed from 14.1 years to 16.4 years and the total lifetime of the S&C is changed from 35 to 40 years. As the uncertainty for the development of a new crossing material is greater than that for an existing material, the dashed line is based on a two times higher standard deviation in the input data (10% instead of 5%). The result shows that there is no clear benefit for the new material until this uncertainty is clarified.

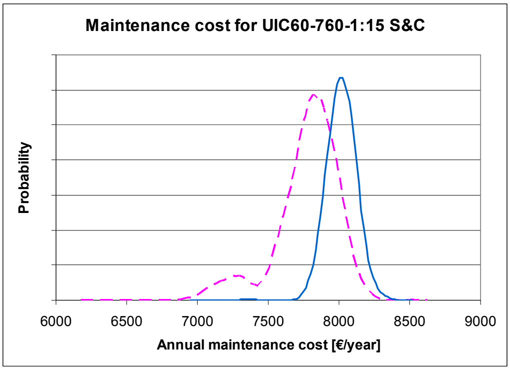

Figure 14 Probabilistic cost for two different designs of a crossing (the TLT is 14.1 years, the solid line, or 16.4 years, the dashed line)

4 DISCUSSION

The LCC-calculation presented in this article is based on the standard IEC 60300-3-3 and has been developed in three fundamental ways.

- The product breakdown structure has been complemented with several types of maintenance actions.
- The preventive maintenance cost is treated either as an annual cost or as a cost recurring at certain intervals.
- The yearly costs are functions of time.

4.1 Maintenance action

The frequency of maintenance needs can be presented as a mean value of all types of actions, equation (7), and the mean man hours can also be calculated, equation (8). Therefore, it is not necessary to have detailed data in the LCC-model. The reason for keeping the details within the model is to enhance the analytical part, both to find the cost drivers and to ensure that the sensitivity analysis can pinpoint the most critical parameters.

$$f_i = \sum_{j=1}^{n} f_{ij} \quad (7)$$

$$MRT_i = \frac{\sum_{j=1}^{n} \left\langle f_{ij} * MRT_{ij} \right\rangle}{f_i} \quad (8)$$

4.1.1 Periodical preventive maintenance

Grinding, tamping, welding and renewals of switch blades and crossings are not annual costs, especially if the frequency is low during the first 10 years. Consequently, these costs should be treated when they occur and not as an annual cost. At the end of the technical lifetime, larger replacements are normally not carried out, so in Figure 15 and 16 the parameter of the end period, t_{EP}, is used. This parameter makes the model omit a partial renewal late in the asset's technical lifetime. For this article, t_{EP} has been set to 20% of the TLT of the component.

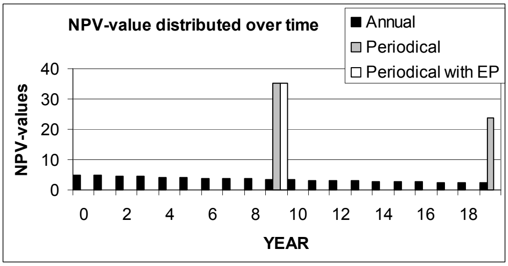

Figure 15 NPV-values of a reinvestment of €50 k calculated in three different ways

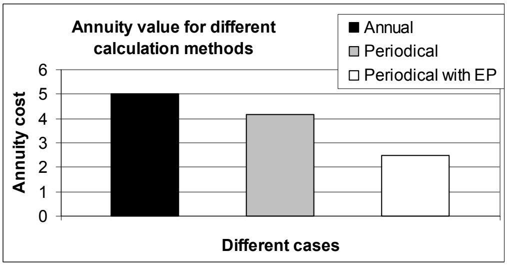

Figure 16 Annuity value for the calculated NPVs in Figure 15

4.2 Validation

The model has so far not been validated by an expert judgement. Instead the model has been compared with cost data from the accounting system Agresso (Nissen 2009B). The model has a reasonable similarity to the cost data for track section 512 and 611, see Figure 17. One input parameter that can be used to adjust short-range planned preventive maintenance and corrective maintenance is the logistic delay time. The number for tamping and grinding is adjusted more to the mean value than to a specific track section.

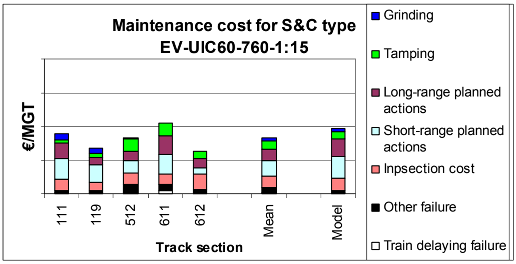

Figure 17 Comparison between cost estimations based on accounting data and the model

4.3 Risk assessment

It is desirable that risk analysis should be undertaken at the same time as the LCC-calculation is made. A solution that is chosen only because it has the best LCC-value cannot be trusted [14]. For the present research, no risk analysis has been performed, as the chosen examples are known S&Cs that are already in use. One example of a known hazard in Sweden is that of a train trying to run over a closed movable crossing nose although it is not trailable, which leads to derailment and high consequential cost.

5 CONCLUSIONS

LCC has proven to be a useful tool both for finding the cost-drivers and for comparing different types of S&Cs. In the analysis, cost-drivers can be found and give an understanding of the parameters that influence the calculation to a great extent. An even better understanding of the costing can be reached by using Monte Carlo simulations.

6 FUTURE WORK

Further studies are needed to investigate whether LCC can be a tool for taking decisions on maintenance strategy and for finding the most important S&Cs to be replaced.

The output and input parameters must be discussed with experts within Banverket to validate the information.

Risk assessment needs to be incorporated with the work of LCC-analysis.

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