New Approaches to the Life Cycle Costs Philosophy of the Railway Vehicles

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Abstract: This paper deals with the topical problems of the Life Cycle Costs in connection with the railways vehicles. The Life Cycle Costs (LCC) philosophy has already entered the third decade. This philosophy contributed towards the new relationship's comprehension between railway vehicle producers' and railway vehicle users' sphere. This leads together to the technical-economical solution convenient for the both sides.

Low operational costs could be reached using a well-designed and structured maintenance program. This is due to the proper technical analysis of critical components that leads to low costs of maintenance and a superior reliability without increasing the capital investment.

UNIFE (Union of Railway Industry) contributed towards the practical usage of the LCC philosophy in the railway vehicles manufacturers and user sphere.

This paper presents both topical experiences with the LCC models for the railways vehicles and also procedures during Life Cycle Costs calculations.

In conclusion the authors present their own experiences with the UNIFE LCC modules in the terms of railway operation in the Czech Republic and also a date structure essential for the module work.

Key Words: Life Cycle costs; Fail-safe; Railway vehicles; Reliability; Maintenance; Failure rate

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1 Introduction

The Life Cycle Costs (LCC) philosophy has already entered the third decade. This philosophy contributed towards the new relationship's comprehension between railway vehicle producers' and railway vehicle users' sphere. This leads together to the technical-economical solution convenient for the both sides.

Low operational costs could be reached using a well-designed and structured maintenance program. This is due to the proper technical analysis of critical components that leads to low costs of maintenance and a superior reliability without increasing the capital investment.

2 Calculation of Life Cycle Costs - LCC

All costs entries for final life cycle costs calculation must be identified and defined. Typical LCC model works with purchase costs, generating costs, maintenance costs and with other important customer costs e.g. documentation, education and so on.

Typical costs are:

- purchase costs
- investment in workroom equipment
- investment in spare parts investment in documentation
- investment in education
- investment in documentation

3 Optimization of contributions and costs in fail-safe specification

With high requirements to fail-safe of object we must increase costs for development and production. High fail-safe of object faces to low operating and maintenance costs. Consequently, beneficial optimization of requirements to fail-safe for minimization of whole vehicle life cycle is made.

3.1 Object Life Cycle Costs optimization

In connection with modern opinion for vehicle (RCM) is evident [2], that important parts of railway vehicles has exponential probability distribution of failures. Every distribution is described by one parameter – failure rate λ. One parameter λ_C for whole vehicle is important for description of above mentioned optimization.

Along observation dependence of production costs to fail-safe, enclosures are written below:

- even object designed without fail-safe need some costs and has some undefined fail-safe

- with requirements to fail-safe development and generating costs increased
- development and production of object with extreme high fail-safe needs extreme high costs

Total costs C_S for development, purchase and maintenance of object are expressed:

$$C_S = C_P + C_{PM} + C_{RM} \tag{1}$$

C_P – development costs,
C_{RM} – repair maintenance costs,
C_{PM} – preventive maintenance costs

3.2 Development and purchase costs C_P

Development and purchase costs depend on failure rate are:

$$C_P = f(\lambda) \tag{2}$$

Function $f(\lambda)$ is determined by used technologies and a number of produced vehicles, and other specific factors. For example, when the vehicle is designed with low fail-safe, it has failure rate λ_0 and costs H_0 as well. For half failure rate the development costs must be minimal doubly.
Therefore the following development and purchasing costs are assumed:

$$C_P = \frac{H_0}{\lambda} \tag{3}$$

For vehicle with zero failure rate development costs tend to infinity.

3.3 Preventive maintenance costs C_{PM}

Vehicle with zero failure rate has zero preventive maintenace costs, otherwise for $\lambda = \lambda_0$ costs will be $k . \lambda_0$ (maximal). In half failure rate we have also half costs, and C_{PM} will be:

$$C_{PM} = k.\lambda_0 . \frac{\lambda}{\lambda_0} = k.\lambda \tag{4}$$

Therefore, total summary life cycle costs (described as a function of failure rate) are:

$$C_S(\lambda) = \frac{H_0}{\lambda} + k.\lambda + A + A.\beta\lambda \tag{5}$$

Solving the extremal problem, we get optimal failure rate (λ_{opt}). It follows from the formula above:

$$\frac{dC_S(\lambda)}{d\lambda} = -\frac{H_0}{\lambda^2} + k + A.\beta \qquad \frac{H_0}{\lambda^2} = k + A.\beta$$

$$\lambda_{opt} = \sqrt{\frac{H_0}{k + A\beta}} \tag{6}$$

This is optimal failure rate (λ_{opt}) for whole life cycle of vehicle (figure 1.).

3.4 Repair maintenance costs C_{RM}

Repair maintenance costs C_{RM} following formula expectably described:

$$C_{RM} = A.e^{\beta\lambda} \tag{7}$$

This costs can be detected only in operate vehicle, but according to contemporary knowledge formula (4) can be used.
Exponent β is small ($\beta << 1$), thus Maclaurin's serie may be calculated to $e^{\beta\lambda}$:

$$C_{RM} = A.(1 + \frac{\beta\lambda}{1!} + \frac{\beta\lambda^2}{2!} + ...) \tag{8}$$

As a consequence of equality, we state the following result:

$$C_{RM} = A + A.\beta\lambda \tag{9}$$

4. Calculation for new vehicles

Now we try to do the general calculation with specifications for tenders to new vehicles.
Failure rate is ranged from 6 to 10 failures on 1000000 km (stopping fault; $t_{stop} > 15$ min).
For 1000000 km: $\lambda_{opt} \in (6;10)$.

Repair maintenace costs and preventive maintenance costs are usually presented together. Therefore, summation k + Aβ is $0{,}3 \cdot 10^6$ € to 1000000 km (thi is 300 € to 1000 km – ordinary required value). For $\lambda_{opt} = 10$ we can calculate value H_0 [€/1000000 km].

$$10 = \frac{H_0}{3.10^5} \quad \Rightarrow \quad H_0 = 30.10^6 \ \text{€}/\ 1000000\ \text{km}$$

Costs at 30000000 € are very high, but this calculation corresponded with designed covered dist during life 1000000 km.

Fundamental part of this costs is the generating costs. Therefore, producer must decide, which part must be used for design and development, and which part of costs must be used for production. Important aspects of decision process are ranged of production set and potential production for other customers.

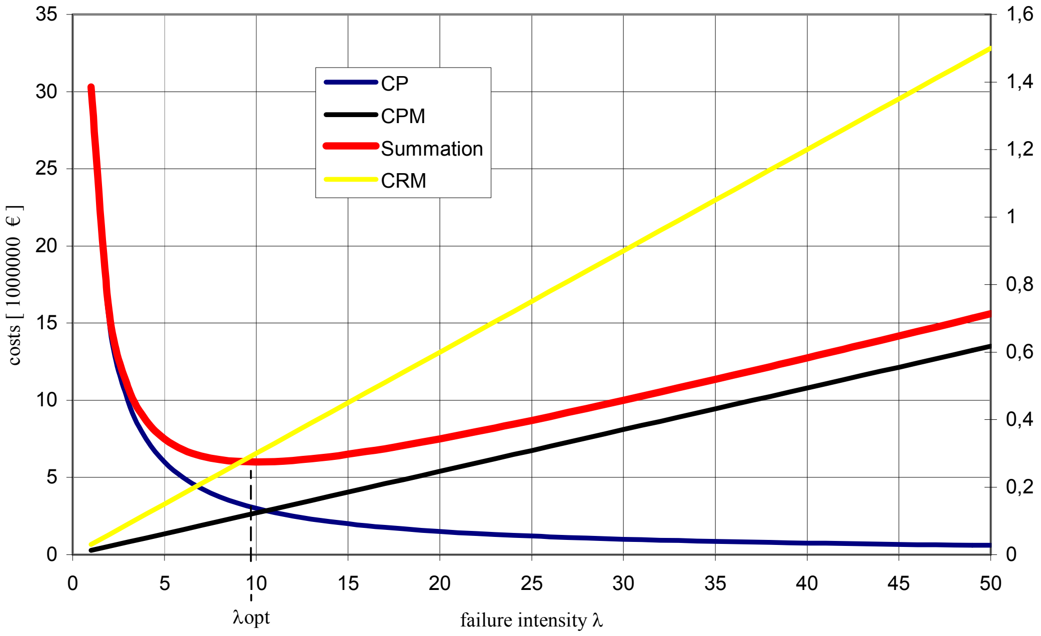


Figure 1: Total life cycle costs and λ_{opt}

5. UNIFE Initiative

UNIFE (Union of Railway Industry) contributed towards the practical usage of the LCC philosophy in the railway vehicles manufacturers and user sphere. UNIFE in CITM commission create working group for RAMS.

Basic structure of software LCC model from UNIFE is described at figure 2.

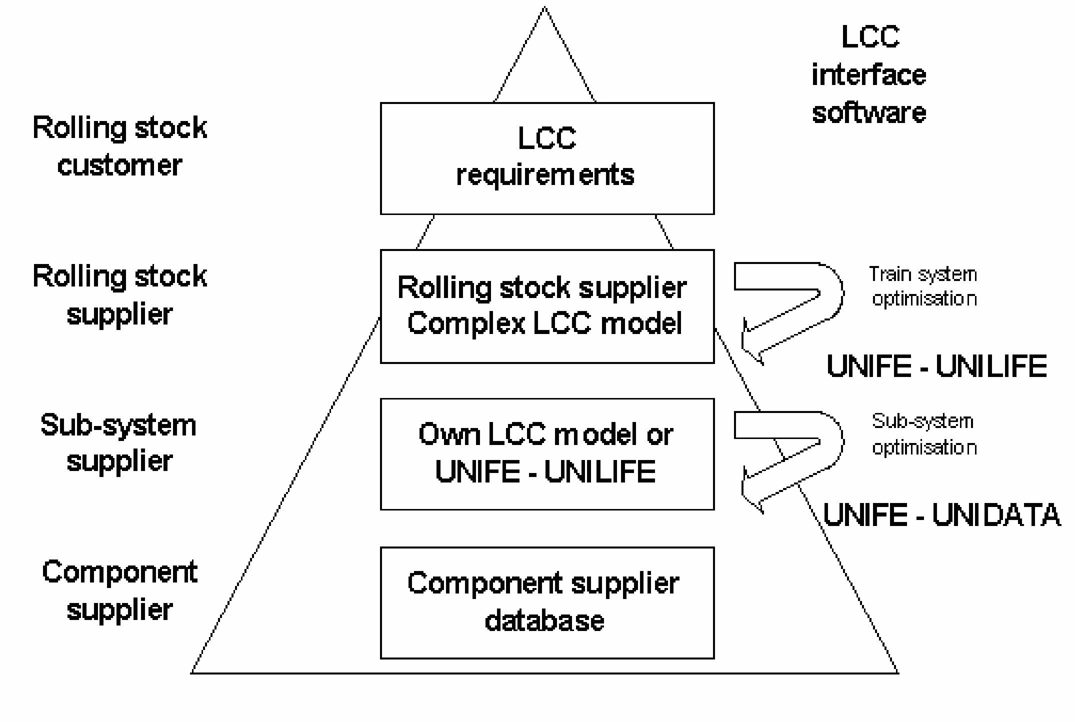


Figure 2: UNIFE – UNIDATA LCC model

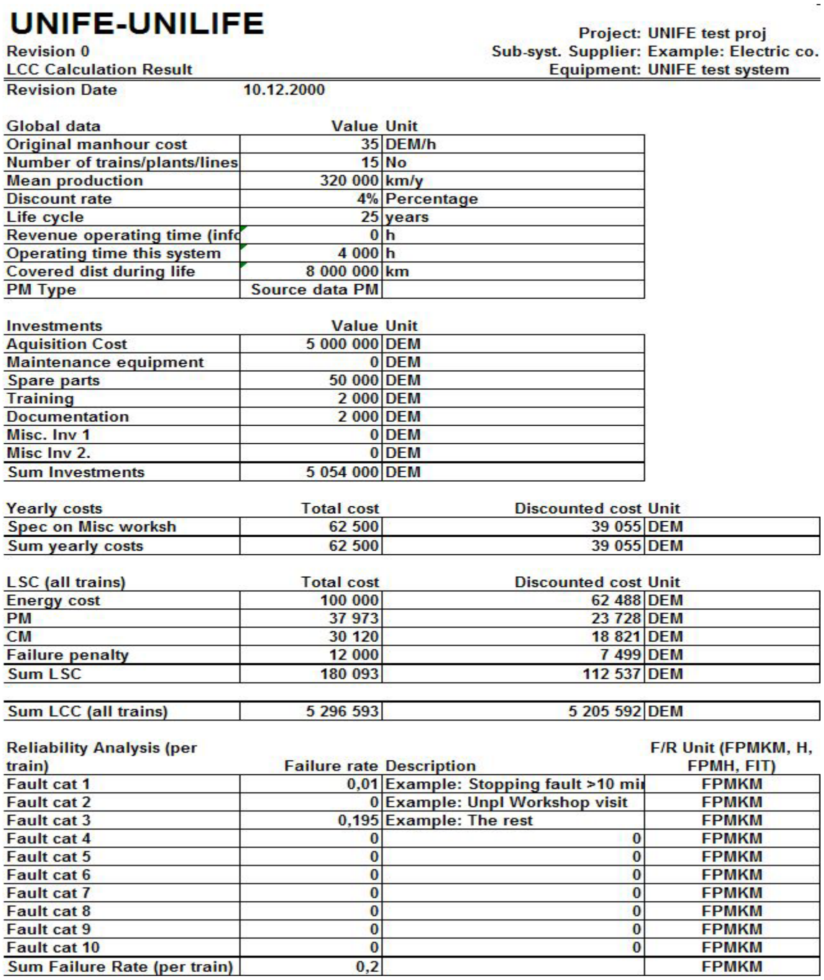
6. Module UNIFE LCC

Basic components are two modules, module *Unidata.xls* and *Unilife.xls*. In *Unidata.xls* module are collected data for life cycle costs calculations.
Really life cycle costs are calculated in module *Unilife.xls* (figure 3).

Necessary conditions and expectations for justification:

- for using intervals and costs are needed system of preventive maintenance
- data of inherent reliability from suppliers and from own databases are needed

Next important part is economical shell to maintenance processes.



UNIFE-UNILIFE

Revision 0
LCC Calculation Result
Revision Date 10.12.2000

Project: UNIFE test proj
Sub-syst. Supplier: Example: Electric co.
Equipment: UNIFE test system

Global data	Value	Unit
Original manhour cost	35	DEM/h
Number of trains/plants/lines	15	No
Mean production	320 000	km/y
Discount rate	4%	Percentage
Life cycle	25	years
Revenue operating time (info	0	h
Operating time this system	4 000	h
Covered dist during life	8 000 000	km
PM Type	Source data PM	

Investments	Value	Unit
Aquisition Cost	5 000 000	DEM
Maintenance equipment	0	DEM
Spare parts	50 000	DEM
Training	2 000	DEM
Documentation	2 000	DEM
Misc. Inv 1	0	DEM
Misc Inv 2.	0	DEM
Sum Investments	5 054 000	DEM

Yearly costs	Total cost	Discounted cost	Unit
Spec on Misc worksh	62 500	39 055	DEM
Sum yearly costs	62 500	39 055	DEM

LSC (all trains)	Total cost	Discounted cost	Unit
Energy cost	100 000	62 488	DEM
PM	37 973	23 728	DEM
CM	30 120	18 821	DEM
Failure penalty	12 000	7 499	DEM
Sum LSC	180 093	112 537	DEM

Sum LCC (all trains)	5 296 593	5 205 592	DEM

Reliability Analysis (per train)	Failure rate	Description	F/R Unit (FPMKM, H, FPMH, FIT)
Fault cat 1	0,01	Example: Stopping fault >10 mi	FPMKM
Fault cat 2	0	Example: Unpl Workshop visit	FPMKM
Fault cat 3	0,195	Example: The rest	FPMKM
Fault cat 4	0	0	FPMKM
Fault cat 5	0	0	FPMKM
Fault cat 6	0	0	FPMKM
Fault cat 7	0	0	FPMKM
Fault cat 8	0	0	FPMKM
Fault cat 9	0	0	FPMKM
Fault cat 10	0	0	FPMKM
Sum Failure Rate (per train)	0,2		FPMKM

Figure 3: LCC calculations in unilife.xls module

The most of this procedures are successfully using in Institute of Transport, VSB – Technical University of Ostrava, and our experiences are offered by authors to specialists community .

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