USE OF THE LCC ANALYSIS TO SELECT A TECHNICAL SOLUTION OF POWER DRIVE FOR APPLICATION AT RAILWAYS

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The paper addresses identification and analysis of individual costs of a life-cycle of engines for railways that meet required emission limits according to STAGE III.B.A cost analysis ofa life-cycle is an effective tool, which allows for observation of various options of technical solutions. The result of an LCC analysis is the basis on which a decision is made about selecting a technical solution of power drive of locomotives and efficiency of the solution with one or three combustion engines. The result is also preparation of a life-cycle costs identification method for specific locomotive engines and initial evaluation of advantages, specifically disadvantages of the solution.

KEYWORKS

costs, life-cycle costs (LCC), locomotive engine, power drive

1 INTRODUCTION

Managers need information to make decisions regarding manufacturing and organizational planning, i.e. formation of products' assortment, determination of maximum cost per production unit, required production output in order to cover fixed costs, expenses within organizational units etc. [Matusevska 2015]. Life cycle analysis presents an effective tool for comprehensive assessment of costs. The goal of management of life-cycle costs of a product is to maximize the product's value when summarizing costs for the producer, user and the company [Simanova 2016]. Management of life-cycle costs in the broad term focuses on three main areas of management of life-cycle costs: costs to the company (the producer), user costs, and costs to the society [Sujova 2016a].

Management of life-cycle costs consists of an approach that leads to sustainable development and effective use of company's resources. The life-cycle cost analysis method, LCC, provides a base for complex evaluation of costs of a product from its conception until termination of its life- cycle. Life-cycle costs were defined by the IEC in 1989 as total costs to a user of a specific system or equipment for its purchase and installation, as well as costs for use and maintenance during its life-cycle. The life-cycle can be a so called maximum life-cycle of a product, which includes a period of conception, development, and preparation for production, production, use and disposal [Westkaempfer 2002]. The EN 60300-3-3 norm is a good tool for monitoring and qualification of amounts for various costs, which are absorbed by the user and which are considerably affected by the products' quality (especially by reliability of production). The above mentioned norm is recommended for work with information on life-cycle costs. Its purpose is to optimize results in various phases of the life-cycle or a specific technical system, by dividing costs into six groups:

- costs for concept development and a parameter setting phase,
- costs for a draft phase and system development,
- costs for evaluation of a (production) system,
- costs for system installation at user's facility,
- costs for system use and maintenance, and
- costs for liquidation of a system.

One should monitor especially the first three costs, to be able to uncover (e.g. with the use of the model of process costs) how to possibly lower costs, which at first sight are covered by system development, however in the end are absorbed by the user as part of the final sale price. Experience has shown that a developer can influence costs of the life-cycle by up to 90%, especially in the pre-production phases [Nenadal 2008].

The research is based on a company that deals with repair and restoration of locomotives. A common problem with use of locomotive engines is very low percentage of use of their installed power and long term work with low and partial loading. As a result came an idea to divide required nominal power of the locomotive into several smaller engines. The work entails economic evaluations of efficiency of both solutions by using the life-cycle costs analysis. The research is part of a solution of a project subsidised by the KEGA no. 011TU Z-4/2017 project „Integration of progressive information technologies and soft-skills in education programs focusing on management of production processes".

2 LIFE-CYCLES COSTING CONCEPT AND REQUIRED INPUTS

The life-cycle costing concept can be used for various different purposes including selection among options, determining cost drivers, formulating contractor incentives, choosing the most beneficial procurement strategy, assessing application of new technology, forecasting of future budget needs, strategic decision-making and design trade-offs, providing objectives for program controls, deciding to replace aging equipment, improving understanding of basic design associated parameters in product design and development, optimizing training needs, and comparing logistical concepts. A life-cycle costing project can only be accomplished effectively if the required information is available. Nonetheless, the professionals involved in conducting life-cycle cost studies should seek information on general items such as those listed below prior to the start of the project under consideration [Venkannavar 1999]:

- Estimate goal
- Time schedule
- Required data
- Involved individuals
- Required analysis format
- Required analysis detail
- Treatment of uncertainties
- Ground rules and assumptions
- Analysis constraints
- Analysis users
- Limitations of funds
- Required accuracy of the analysis

Nonetheless, the specific data required to conduct life-cycle cost studies for an item include useful life, acquisition cost, periodic maintenance cost, transportation and installation costs, discount and escalation rates, salvage value/cost, taxes (i.e., investment tax credit, tax benefits from depreciation, etc.), periodic operating costs (e.g. energy cost, labour cost, insurance, cost of materials, and cost of supplies) [Sujova 2016b].

2.1 Design and Calculation of Life-Cycle Costs

Costs for development of a primary system represent user's total one-time investment. The main portion of this cost could consist of accruing costs. System maintenance costs in use can be divided into one-time and running yearly costs. The first subgroup can include: costs for user documentation, initial training, cost of minimal inventory of supporting materials and spare parts, purchase of maintenance tools, if necessary, and more. Running costs spent during operation include: fuel and energy, salaries of operators and maintenance staff, other costs for repair and maintenance, selected parts of other expenses, and other. Third group of user costs includes loses caused by system failure, including costs for finding replacement technology, loss of production and more (Figure 1) [Nenadal 2002].

Cost items include all costs that arise from conception until the end of a life-cycle. These cost items should be structured so that they make it easier to identify potential connections between them with the goal to set the correct amount for a product's life-cycle. This should be possible by performing a product life-cycle analysis. The final stage of the calculation is definition of calculation of life-cycle costs [Freiberg 2011].

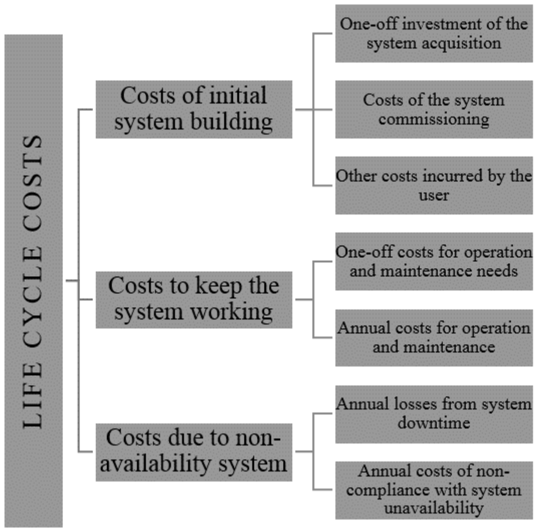

Figure 1. Basic life-cycle cost structure [Nenadal 2002]

The final stage comprises of eight steps:

- Establish a production profile: regimes of operation for the product's entire life-cycle are defined as part of this step.
- Determine used factors: while the production profile monitors a time frame during which the machine will be used or will not be in use, used factors show how will the machine react in different operational regimes (continuous, intermittent, etc.).
- Identify all cost items.
- Set all critical cost parameters: to set parameters that influence costs of the product's life-cycle. For example, the period between breakdowns, repair, general repair, scheduled maintenance, etc.
- Calculate all costs in current prices.
- Decrease common costs to adjust for inflation.
- Recalculate all costs.
- Summary of all recalculated costs.

We realize that it is important to perform a product life-cycle analysis in the design and product development phases. Since it is hard to predict how various construction and development alternatives will affect the costs, which arise as part of the production and pre-production phases of the product's life-cycle, room to influence costs in the design phase of the product's life-cycle diminishes. In the design phase and during production, it is not possible to determine production or operational characteristics of the product, maintenance needs, volume of production, logistics or other factors [Freiberg 2011].

2.2 The Key Influence of the Design and Development Stages on Product Life-Cycle Costs

The greatest opportunity for reducing life-cycle costs and improving product parameters and performance can be identified in the initial stages of the product life-cycle (the design and development phases). The costs incurred during these stages are not so high when compared to the overall life-cycle costs of the product. However, decisions taken during these phases have a considerable impact on costs during the manufacturing and operational stages. At the manufacturing stage, and even more so at the operational stage, any modifications and attempts to influence manufacturing and operating costs are considerably limited. This is well illustrated in Figure 2,[Wrobel 2008].

The importance of implementation of a life-cycle cost analysis at the product design and development stages is obvious. However, an effective analysis requires suitable instruments for evaluation of economic aspects of various technical solutions company [Simanova 2013]. The extensive space for influencing product life-cycle costs at the design and development stages is reduced by the fact that it is difficult to predict how various design and development alternatives will affect the costs incurred during the manufacturing and operational stages of the product's life-cycle. At the design and development stages it is not yet possible to specify the manufacturing and operational features of the product, maintenance policies, production volume, logistical solutions, etc.

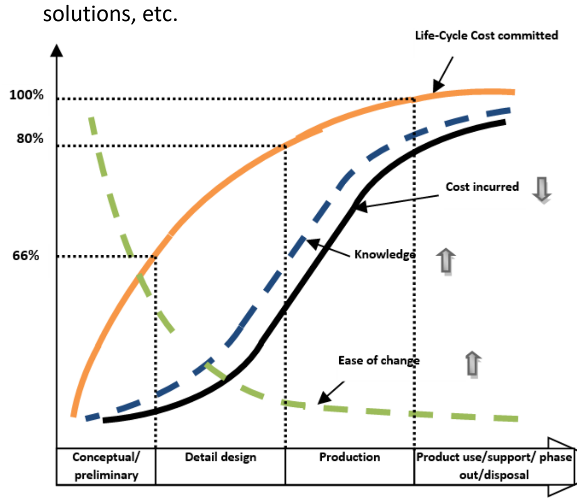

Figure 2. Incurred and planned expenditures along with know-how [Wrobel 2008]

3 METHODS AND MATERIAL

3.1 Concept of Life-Cycle Cost Calculation

Remer [Remer 2010] developed a mathematical model for calculating life-cycle costs for a project where operating costs increase or decrease in a linear manner with time. The life-cycle costis shown to be a function of the investment costs, initial operating costs, operating cost gradient, project life time, interest rate for capital, and salvage value. Life-cycle costs are defined as initial costs, *P*, plus the sum of operating costs, *U*, over the project's life, *n*. Thus,

$$LCC = P + \sum_{j=1}^{n} U_j \qquad (1)$$

Let us assume thatthe operating cost function, *U*, is a uniformly increasing function of time. For the purpose of their development [Remer 2010] they considered discrete step increases in costs rather than a continuous function because the discrete approach more closely matches their actual budgeting and forecasting system. The initial operating cost in year (1)was designed by U_j^0 and the operating cost increases an amount *R* each year. It is necessary to introduce the time value of money for these future operating cost cash flows. There is some discussion at the present time as to whether DSN should discount future cash flows, use a negative discount rate, or ignore discounting and use no time value of money. The present value, P, of a future amount of money, F, is

$$P = F(1+i)^{-n} \qquad (2)$$

Where i is the value of money (interest rate) per year and n is the number of years between P and F. The factor $(1+i)^{-n}$ is referred to as the discounting factor and accounts for the time value of capital. For the no discounting case *i* is zero.

Locomotives need to meet not only demanding technical and safety parameters, but needs to also be economical throughout their entire life-cycle, be reliable, and at lowest possible maintenance costs. Considering the complexity of the machine, which contains a large number of highly technical and complex systems, it is appropriate to focus on one part of the machine, in this case, the engine.

Parts of Costs for Life-Cycle of a Locomotive Engine

Total costs for a life-cycle of and LCC user define Culek [Culek 1996]:

$$C = \sum C = C_a + C_i + C_s + C_m + C_o + C_e + C_l \qquad (3)$$

Where: C_a – acquisition cost, C_i – cost of installation, C_s – cost of salaries, C_m– maintenance costs, C_o – operational costs, C_e – cost of energy , C_l – liquidationcost

3.2 Problem Definition and Possible Solutions

A known problem with operation of locomotives is the low percentage of use of their installed power and long term work with low or partial load.This is caused by the design of the working of a locomotive, pushing, idling at stations, preparation of train cars, drive on neutral, differing weights of train cars, different pulling rations, etc.As indicated above, use of locomotive engines with low loads is not economical [Culek 1996].

One solution to the given problem is to divide the required nominal power of the locomotive into several smaller engines and use these in a locomotive based on actual required power of the locomotive. Which means, use all engines when high power is required and use only some and turn off others when only low power is required.

This kind of solution offers several advantages:

- Better possibilities to set engines in terms of optimal use parameters (set work points in terms of lower measurable use and based on required power add engines that work optimally),
- Extend the life-span of a locomotive in terms of the life-span of its engines, since engine wear is continuous and the time for maintenance is approaching,
- Possibility to easier ensure optimal parameters of use of a locomotive, e.g. one engine can warm up other engines and they then operate in better conditions, which add to increase of engines' life-spans.

Design of an engine with several engines with lower power, however, also brings some disadvantages, such as:

- More pressure on the locomotive's operating system,
- Adding numerous parts to the locomotives,
- A more complicated incorporation ofa multi-engine power unit into a locomotive.

The LCC analysis, comparison of costs for a life-cycle, is an effective tool for comparing a one engine locomotive version (with one high power engine) to a multi engine version [Haragova 2017].

Given Parameters for Analysis:

- Installed power of the locomotive approx. 900 kW
- Solution with 1 combustion engine
- Solution with 3 combustion engines
- Meeting current legislative requirements for combustion engines- emission limits of an engine meeting Stage IIIB regulation

Following are suggested engines, which we have considered as options for a solution for the given exercise or for comparison of a one engine version and a three engine version of a locomotive using the LCC method.

In our work we will be using the following combustion engines:

- One engine version – 1x Caterpillar 3508 B (1x 970 kW)
- Three engine version – 3x TEDOM TD310R6HTA26 (3x 310 kW).

4. RESEARCH RESULTS

4.1 Identification and Analysis of Life-Cycle Costs of Engines for Application at Railways

In our work we are looking at one life-cycle of a locomotive's engines, so called life-cycle costs of an engine until the date of its fist general maintenance check. We have considered two groups of costs as part of the LCC analysis, they are the following [Haragova 2017]:

a) acquisition,
b) maintenance

a) Acquisition Costs

Acquisitioncosts consist of two parts:

- Acquisition cost of individual engines,
- Acquisition related costs (delivery, storage,...)

We have included these costs in our calculation; their numerical values are producers' know-how that is why we are not indicating them.

b) Operational Costs

Under operational costs, we understand fuel costs and maintenance costs.

A picture of operation of a pushing locomotive is an internationally set operational profile. An operational profile shows how and at what load an engine operates during a life-cycle, that is, until the first maintenance check.The operational profile shows that engines of pushing locomotives work the most with load at 15% or less, which is approximately 60% of the total operating time.

b1) Fuel Consumption Costs

We can determine fuel consumption with the help of the operational profile and total characteristics of a combustion engine (Figure 3).

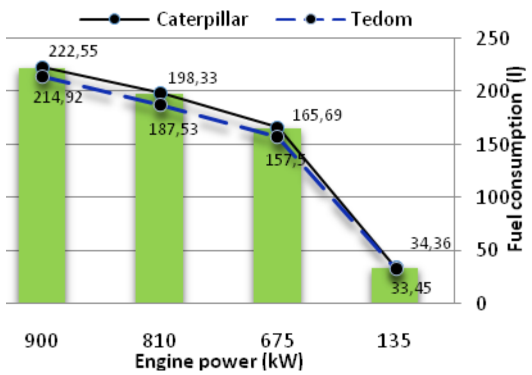

Figure3. Comparison of fuel consumption in relation to engine power

As part of our calculation, we took into consideration calculated, measured, volume of fuel in relation to anticipated operational profiles of engines and current price of fuel, i.e. 1,-€/liter.

b2) Engine Maintenance Costs

Engine maintenance for railways includes lubrication, check and change of operational fluids, change of filers and other preventative work, such as adjustments and repair, to ensure a long life-span and a continuous operation of an engine. When determining maintenance costs, we considered one life-cycle that is until the date of first general maintenance.

4.2 Comparison of Total Costs of Engines During a Life-Cycle

Figures 4 and 5 portray percentages of a portions of costs of the one engine option Caterpillar and the three engine option Tedom during one life-cycle, i.e. up to 40,000 mth. It is clear from the graphs that the biggest part of costs are fuel costs, which on the Caterpillar engine represent 92% and on the Tedom engine represent 94% of total costs.Engine maintenance costs on for the Tedom engines account for only 2% of costs. Maintenance costs of the Caterpillar are higher and represent 5% of total costs. Acquisition costs of the Caterpillar engine are 3% of total costs and acquisition costs of the Tedom engines are 4% of the acquisition costs [Haragova 2017].

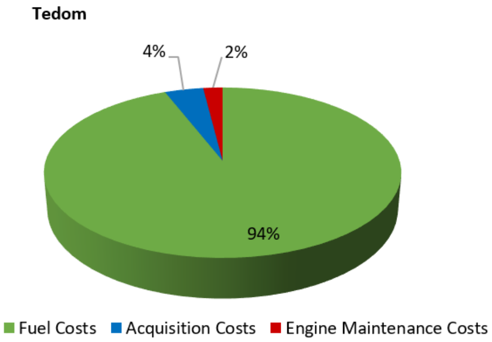

Figure 4. Total costs of three Tedom engines

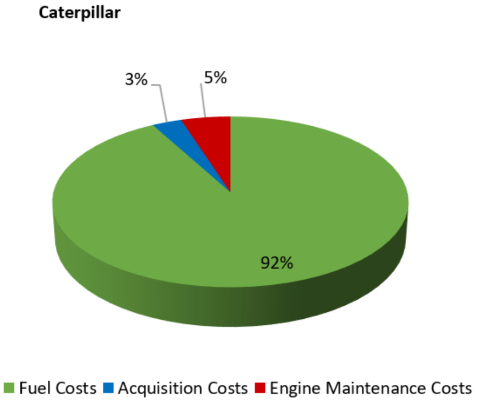

Figure 5. Total costs of Caterpillar engine

The result of the performed LCC analysis is a numerical value and comparison of total costs of engines during a life-cycle (Figure 6). When comparing results from the graph, it is evident that the three engine option is more efficient. In this case a positive operational profile resulted in lower fuel consumption and thereby lowered fuel costs in comparison with the one engine option[Haragova 2017].

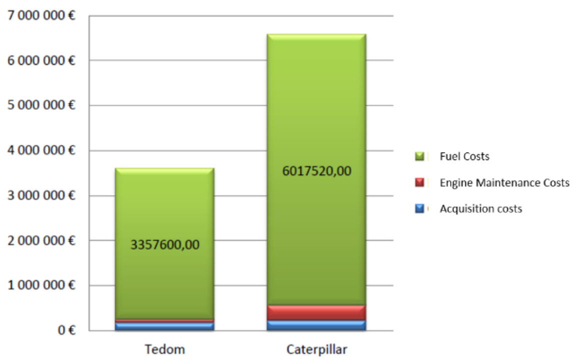

Figure 6. Comparison of total costs of engines (3x TEDOM, 1x Caterpillar) during a life-cycle

4.3 Discussion of Results

The goal of the research was to compare conceptual solutions of a locomotive with a one engine and a three engine version.The thought behind setting this goal, which is also the main point of a thesis, was the fact that load on moving locomotives usually accounts for a large portion of work that is performed when in neutral, that is with low load.Operation of combustion engines with low load is known for its bad economy of engine usebecause it leads to high fuel consumption and is also not recommended in terms of life expectancy and wear of an engine.

For a solution of the given goal, we have decided to use a model of a locomotive with an installed power of approx. 900 kW. In keeping with the current theme, we suggested to use for the locomotive combustion engines that meet limits of current European emission regulations, Stage IIIB. We have chosen to use the LCC analysis, as a means to evaluate the one engine and three engine concepts. The LCC analysis considers costs for the entire life-cycle of equipment, from its acquisition until liquidation.Since life-span and life-cycle of locomotives is determined by general maintenance check, thanks to which they return to operation as if they were new, the life-cycle is a given timeframe between general maintenance checks of a combustion engine.

As seen based on the operational profile of an engine, due to operation of the three engine version of locomotive with low load with only one engine (sufficient in terms of required coverage by the locomotive) and two other engines, Tedom engines reach up to 40,000 hours of use of the locomotive before general maintenance is required. With the one engine version of locomotive, 40,000 hours of work represent close to two general maintenance checks. When comparing options of locomotive design, we have used a common timeframe of 40,000 hours of use of a locomotive.

Based on abovementioned assumptions and performed calculations of acquisition costs, operational and maintenance costs, the three engine version seems more economical.
This simplified model can be extended to life-cycles of other parameters of the locomotive, a more complicated design, a more complicated development of a locomotive, and more. The more parameters are included in the model, specifically the LCC analysis, the more accurate it will be and will provide a better solution for evaluating a problem.

5. CONCLUSION

The main point of the performed research was to calculate and compare life-cycle costs of engines for applications at railways that meet required emission limits.As a methodology for solving the problem we have decided to use the LCC analysis.We have set as one life-cycle time between general maintenance checks of a combustion engine.

Based on performed calculations and analysis, the three engine version of a locomotive is more economical.

Based on results of the research, we have established that the LCC analysis offers information about efficiency of both solutions – one engine and three engine locomotives, and the difference is relatively large.

For the analysis to be even more accurate, it would be necessary to consider other factors and to include other parameters, such as costs of a more complex operational system of a locomotive, its development, costs of triple the number of parameters of a locomotive, e.g. a more complex cooling cycle requiring installation of more electrical components, etc.

The added value of the research was also a process and initial evaluation of advantages, specifically disadvantages of this solution. These set processes can be used for other parts of the locomotives. This study is a source of primary information why development should follow this direction. We have shown processes how to evaluate two options in terms of life-cycle costs.

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