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METHOD FOR EFFECTIVENESS ASSESSMENT OF ROLLING STOCK INVESTMENTS USING LCC (LIFE CYCLE COST) ANALYSIS

Abstract

The article concerns the application of LCC (Life Cycle Cost) life cycle analysis as a method of assessing the effectiveness of investments in rail transport. On the basis of general guidelines contained in professional literature and international standards, including PN-EN 60300-3-3:2017-07, the LCC calculation method for rail transport is presented. This method can be used to assess the effectiveness of various variants of purchasing new vehicles, as well as to compare the costs of their modernization.

Keywords: effectiveness assessment, LCC analysis, rail transport

1. Methods for effectiveness assessment of investments in rail transport

Legal conditions in the field of rail transport in Poland allowed for the dynamic development of private business entities dealing with rail transport of cargo and passengers. In recent years, the railway market has seen a lot of interest in the purchase of new passenger transport vehicles: electric locomotives, traction units, as well as the modernization of old rolling stock for freight transport, mainly of diesel locomotives. Due to the very high costs associated with investments related to the purchase or modernization of rail vehicles, these projects should be carefully analyzed in terms of feasibility and cost-effectiveness. The effectiveness assessment of investment projects related to railway means of transport has the character of a relative, microeconomic calculus – performed from the railway enterprise (railway carrier, manufacturer, modernization contractor), which incurs

certain investment expenditures on the purchase or modernization of rolling stock, operating costs and benefits from the implemented transport services. Conducting a reliable assessment of effectiveness requires comparison of several investment variants that correspond to specific technical solutions[1]. The selection of the methods of researching the effectiveness of investment projects developed so far and applied in practice depends on the individual characteristics of the undertaking[2]. Based on the experience gained during the implementation of research and development works for Polish rail carriers[3], the following methods may be used to assess the efficiency of rolling stock:
– Cost-Benefit Analysis;
– Life Cycle Cost Analysis.

These are the methods recommended in international standards, including: in the UIC 345 Environmental specifications for new rolling stock, in the PN-EN 60300-3-3 standard:2017-07 Reliability management. Part 3-3: Application Guide – Life cycle cost estimation, recommended by the World Bank and the United Nations Industrial Development Organization (UNIDO).

2. The proposed method of LCC life cycle cost analysis

Numerous methods of calculating the lifecycle cost are proposed in the literature and in the proposed standards[4]. The choice of the right model depends on the resources available, the input data available, the time horizon that the analysis includes, the accuracy of the calculations and the object being analyzed. As examples of selected LCC calculation methods, set chronologically from 1969, you can mention:
– the Kaufman method[5];
– the Harvey method[6];
– the Fabrycky and Blanchard method[7];

1 G. Dębniewski, H. Pałach, W. Zakrzewski, *Mikroekonomia*, UWM Publisher, Olsztyn 2000.
2 M. Sierpińska, T. Jachna, *Ocena przedsiębiorstwa według standardów światowych*, PWN, Warsaw 1994.
3 Analysis of investment effectiveness of the acquisition project by PKP Cargo S.A. new electric multi-system locomotives for international freight services. Paper No. M-8/297/2012, Cracow University of Technology, Institute of Rail Vehicles, Cracow 2013; Feasibility study for the project of modernization of the EU07 series electric locomotive for international freight transport. Paper No. M-8/493/2015/P, Cracow University of Technology, Institute of Rail Vehicles, Cracow, November 2015.
4 H.P. Barringer, *A Life Cycle Cost Summary*, International Conference of Maintenance Societies, Perth, Australia 2003; H.P. Barringer, D.P. Weber, *Life Cycle Cost Tutorial*, Fifth International Conference on Process Plant Reliability, Houston, USA 1996; I. Dziaduch, *Modele szacowania kosztu cyklu życia: przegląd literatury*, Logistyka 2010, 2 (CD); P. Hokstad, K. Oien, J. Vatn, *Life Cycle Cost Analysis in Railway Systems*, SINTEF Safety and Reliability, Norway 1998; D.G. Woodward, *Life cycle costing – theory, information acquisition and application*, International Journal of Project Management 1997, 6, p. 335–344.
5 R.J. Kaufmann, *Life Cycle Costing: Decision Making Tool For Capital Equipment Acquisition*, Journal of Purchasing 1969, August.
6 G. Harvey, *Life-cycle costing: a review of the technique*, Management Accounting 1976, October.
7 W.J. Fabrycky, B.S. Blanchard, *Life Cycle Cost and Economic Analysis*, Prentice Hall, Englewood Cliffs, New Jersey 1991.

– the D.G. Woodward method[8];
– the Life Cycle Environmental Cost Analysis (LCECA) method[9];
– the method according to PN-EN 60300-3-3:2017-07[10].

On the basis of general guidelines included in professional literature and international standards, an attempt was made to develop a comprehensive method for identifying and assessing the lifecycle cost for rail transport means. The methodological basis of the algorithm is compliant with the requirements of the PN-EN 60300-3-312 standard. This method includes a total of six stages, which are described in points 2.1 ÷ 2.6 and can be used both for LCC assessment of a specific vehicle and for a comparative analysis of many variants related to their purchase or modernization.

2.1. Development of assumptions, input data and the purpose of the analysis

Stage 1 in the proposed method involves the development of assumptions, the collection of source materials, the preparation of input data and the definition of objectives to be provided by the analysis. In the case of a variant analysis consisting in the comparison of various possible solutions, the stage includes the detailed identification of the variants to be analyzed. The input data concerns:
– identification of technical parameters of the vehicle;
– identification of the conditions, time and intensity of the vehicle operation, e.g. average daily working time, mileage and transport performance performed during the year;
– analysis of requirements resulting from the vehicle maintenance documentation, e.g.: measures of the interval between preventive services, scope of inspection and periodical repairs;
– assumptions regarding the discount rate being the basis for calculations and others.

As examples of LCC analysis aims, you can indicate[11]:
– comparative assessment of total costs or operating costs of various types of new vehicles offered by suppliers and selection of the optimal variant from the point of view of the carrier's needs;
– comparative assessment of various variants of vehicle modernization (various assemblies and components used for modernization: combustion engine, steering, braking system, ergonomics solutions for the driver's cab, etc.);
– identification of dominant costs having the greatest impact on LCC in order to direct development work.

8 D.G. Woodward, *Life Cycle Cost…*
9 S.K. Durairaj, S.K. Ong, A.Y. Nee, R.B.H. Tan, *Evaluation of Life Cycle Cost Analysis Methodologies*, Corporate Environmental Strategy 2002, 1, p. 30–39.
10 PN-EN 60300-3-3:2017-07 – Reliability management. Application Guide – Estimating the Life Cycle Cost.
11 M. Szkoda, *Evaluation of economic efficiency of rail vehicles with the use of the LCC analysis* [in:] *Problems of Maintenance of Sustainable Technological Systems*, PAN, Warsaw 2012, p. 234–248.

2.2. RAMS analysis

Stage 2 is to perform a reliability analysis of RAMS (Reliability, Availability, Maintainability, Safety) for all identified variants. A detailed description of the RAMS analysis and indicators allowing a quantitative description of reliability for railway transport means is presented in PN-EN 50126-1:2018-02. Railway applications – Specification and demonstration of reliability, availability, maintenance compliance and security (RAMS) – Part 1: Process general RAMS. According to the requirements of the standard, the assessment of the reliability of rail transport means should be an integral part of the LCC calculation process. The choice of reliability indicators depends on the level of detail and the purpose of the analysis. As a basic set of indicators applicable to rail transport means[12]:

- mean number of failure in a given operation period MNF [failures/period];
- mean time between failures MTBF [hours];
- technical availability A;
- mean time to repair MTTR [hours].

In the proposed method, vehicle reliability characterized by RAMS indicators is the basis for building the cost model (Figure 1).

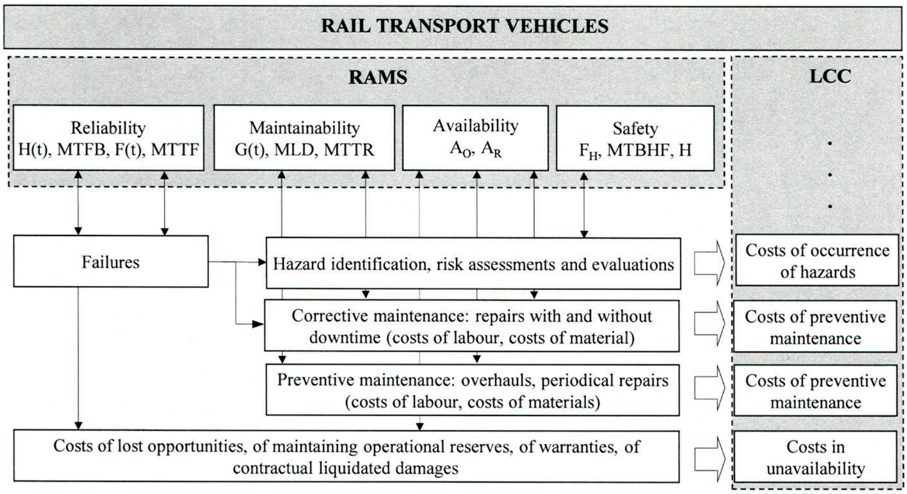

Figure 1. Relation between RAMS and LCC of railway transport means
Source: own elaboration based on: PN-EN 60300-3-3:2017-07 – Reliability management. Application Guide – Estimating the Life Cycle Cost

The results of the conducted analyzes prove that the reliability characteristics of rail vehicles have a significant impact on the costs of use and maintenance[13].

[12] M. Szkoda, *Analiza niezawodności lokomotywy spalinowej serii SM48*, Logistics 2012, 3, p. 2203–2211.

[13] Life cycle cost analysis (LCC) of the ST48 series 15D/A diesel locomotive. Paper No. M-8/494/2015/P, Cracow University of Technology, Instute of Rail Vehicles, Cracow, July 2015; Assessment of the efficiency of modernization of SM42 series locomotives operated by KOLPREM Sp. z o.o. based on the life cycle cost analysis (LCC). Paper No. M-8/648/2015/P, Cracow University of Technology, Institute of Rail

In most studies regarding this issue, losses caused by the unreliability of the vehicle are treated as a determinate amount, specific costs of switching off the vehicle or costs of repairs. In fact, there are also losses associated with the direct effect of disability, resulting, for example, from the loss of benefits arising during the period of the vehicle's unserviceability, the cost of contractual penalties, costs associated with the loss of the company's reputation and prestige or loss of customers. In the monograph[14], the author presented calculation formulas for selected categories of costs depending on the characteristics of RAMS, which depend primarily on the availability of a reliability database.

2.3. Development of the LCC cost model

The LCC cost model created in stage 3 consists in distinguishing the features of the vehicle and transforming them into numbers relating to costs. In order to get a realistic model it is recommended to reflect the characteristics of the analyzed variant, including expected usage scenarios and maintenance strategies.

The model should be simple enough to be easy to interpret and allow for future use, upgrades and modifications. It should be defined in such a way that allows the assessment of specific LCC elements independently of the others. The development of the cost model may include:

- defining the Costs Breakdown Structure (CBS);
- defining the product breakdown structure (PBS);
- defining of cost elements.

One of the above-mentioned tasks in the construction of the LCC model is defining the cost division structure. It involves the decomposition of cost categories at the highest level, i.e. purchase costs, operating costs and liquidation costs for component costs[15]. According to the PN-EN 60300-3-3:2017-07 standard, each cost category should be divided until the lowest level of the so-called cost element. The cost element is a value that cannot be expressed as the sum of other costs. It is defined by means of mathematical formulas containing functions, constant values and indicators, e.g.: failure intensity, mean time between failures, labor consumption of current repairs and others. The concept of defining cost elements in multidimensional space was proposed for the first time in the program of the Ministry of Defense of the United States Integrated Logistics Support (DOD Directive 4100.35 from 1968) and in PN-EN 60300-3-3 from 2017.

The structure of the vehicle division consists in the decomposition of the vehicle into systems (subsystems) and components. It is used when the purpose of the analysis is a detailed assessment of costs not only at the level of the vehicle as a system,

Vehicles, Cracow, August 2015; Strategy of renewal of the locomotive park in the enterprise of PKP LHS Sp. z o. o. Stage 1: Modernization of ST44 series locomotives. Paper No. M-8/599/2007, Cracow University of Technology, Institute of Rail Vehicles, Cracow, 2007; Technical and economic study of the renewal of the traction vehicle park operated by PKP CARGO S.A. Paper No. M-8/631/2006, Cracow University of Technology, Institute of Rail Vehicles, Cracow, 2006–2007; Feasibility study for the project of modernization of the EU07 series electric locomotive…

14 M. Szkoda, *Kształtowanie potencjału przewozowego przedsiębiorstw transportu kolejowego*, Monograph, Cracow University of Technology Publisher, Cracow 2017.

15 PN-EN 60300-3-3 – Reliability management…

but also at the level of its elements. The detailed structure of the division of the rail vehicle that can be used in the LCC analysis is described in PN-EN 15380-5:2014-Railway. Classification system for rail vehicles. Part 5: System breakdown structure (Railway applications. Classification system for railway vehicles).

2.4. Analysis of the LCC model

The analysis of the cost model carried out under Stage 4 includes:
- calculation of all cost elements included in the model;
- calculation of total costs within the assumed time horizon, calculation of individual cost categories on an annual basis (in the case of variant analysis for all analyzed variants);
- identification of dominant costs in the LCC.

At this stage, it is also proposed to assess the inaccuracy of the results obtained using a sensitivity analysis or a probabilistic risk analysis. In the first place, the assessment of inaccuracies should include input variables affecting the dominant costs. The description of the inaccuracy assessment related to the variables used as input data for the analysis and the results obtained are presented in the paper[16].

2.5. Review and presentation of results

Stage 5 in the proposed procedure is a review and presentation of results. The review, which is aimed at confirming the correctness of results and applications, includes:
- the purpose and scope of the analysis: were they properly formulated and interpreted;
- the assumptions made during the analysis process: making sure that they are justified;
- the cost model: make sure that it is suitable for the purpose of the analysis and that all necessary cost elements are included.

If it was found that the created model contains any errors, then it is necessary to improve and complete the initial concept. The presentation of the results should contain a clear summary of the results obtained from the calculation for all analyzed variants. In order to select the variant with the highest effectiveness, the presentation should include: comparison of LCC costs, LCC distribution in the assumed time horizon, LCC structure, LCC dominant costs and unit costs expressed as a function of working time, mileage, etc. The decision criterion in relative assessment, when the comparative analysis several variants takes place, is minimizing the LCC value. The variant characterized by the lowest LCC value is considered the most effective.

[16] M. Szkoda, *Niepewność i ryzyko w analizie LCC kolejowych środków transportu*, Logistics 2015, 4, p. 8373–8379.

2.6. Verification of LCC analysis

Verification of LCC analysis results is the last very important stage that requires continuous monitoring, collection and analysis of actual operational data. The railway transport operation phase covers more than 90% of the duration of the entire lifecycle and is a basic source of information. On the basis of the information obtained, an assessment of the accuracy of the calculations made is made. The implementation of the objectives and benefits of the LCC analysis should be monitored from the moment the new or modernized vehicle is put into operation. On the basis of actual data, the RAMS indicators used in the analysis are verified as well as the correctness and accuracy of the cost statements made. Too large discrepancies going beyond the boundaries set out in the contract between the manufacturer, the modernization contractor and the railway carrier form the basis for possible claims, contractual penalties as well as the necessary construction, operational or organizational changes to meet the carrier's expectations.

Conclusions

The LCC analysis, as a tool for assessing alternative options, is in many countries an instrument required legally for the implementation of new investments, making tenders for the provision of services or construction of technical facilities – usually with a high initial value and long-term durability. It concerns railway means of transport. The decision to purchase or modernize rail transport means is influenced not only by the initial cost associated with investment expenditures for the purchase or modernization, but also the costs of use and maintenance throughout the life cycle. The LCC analysis also makes it possible to take into account one of the most important characteristics of railway transport means, that is reliability, characterized by the characteristics of RAMS (Reliability, Availability, Maintainability, Safety).

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