The Variability Analysis of Current Operation Costs Versus Dependability of a Technical Object

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In the article, the problem of economic dependability assessment of a repairable technical object is described. The definition of life cycle cost as well as the relationship between dependability and LCC are explained. Subsequently, on the basis of LCC method, the supply costs (connected with fuel usage) are estimated. Moreover, it is examined if technical object dependability has the influence on these costs.

Keywords: Life Cycle Cost (LCC), operation costs, dependability.

1. INTRODUCTION

The most important indicator of exploitation effectiveness is object's exploitation economy, which results from the usage level of its exploitation potential. This potential is designed by technical system's construction engineers and is used during object's operation and maintenance phase performance.

Activities and events which occur during system's exploitation performance generate costs. These costs depend on technical objects' dependability characteristics. This dependability aspects of objects exploitation process can be considered in the context of Life Cycle Cost analysis performance.

Costs associated with the dependability, which are borne by a technical object's user in its entire life cycle, can be divided into three main groups of costs:

- the costs of failures, which contain loss due to failure occurrence, a repair cost of the object and loss of income due to unplanned downtime,
- preventive maintenance costs, which include the repair cost of technical object and, if necessary, loss of income due to a planned interruption in the work,
- the costs of current operation, which include for example: energy costs (fuel), staff salaries, etc.

The objective of this paper is to present and discuss a method for current operation cost evaluation to be used in the object durability period.

The paper consists of five sections. After Introduction, i.e. in the section 2, the essence of LCC concept is discussed and dependability influence on life cycle cost analysis performance is described. In the next section, methods available in the literature to model the current operation costs of technical object in the context of LCC analysis, are characterized. Later, in subsection 3.2, a new method, taking into account dependability aspect for estimating these costs is presented. Practical example on application of these approaches to predict the supply costs of technical object (connected with fuel usage) within its useful life is given in section 4. A brief summary and conclusions are included in the final section.

2. LIFE CYCLE COST VERSUS DEPENDABILITY OF A TECHNICAL OBJECT

In the literature, one can find different meanings of term “LCC” ([1], [4], [8], [10], [15], [16]). Generally this term refers to all of the costs that are incurred in the whole life cycle of atechnical object, in parts or combinations of different life cycle phases (*Figure 1*).

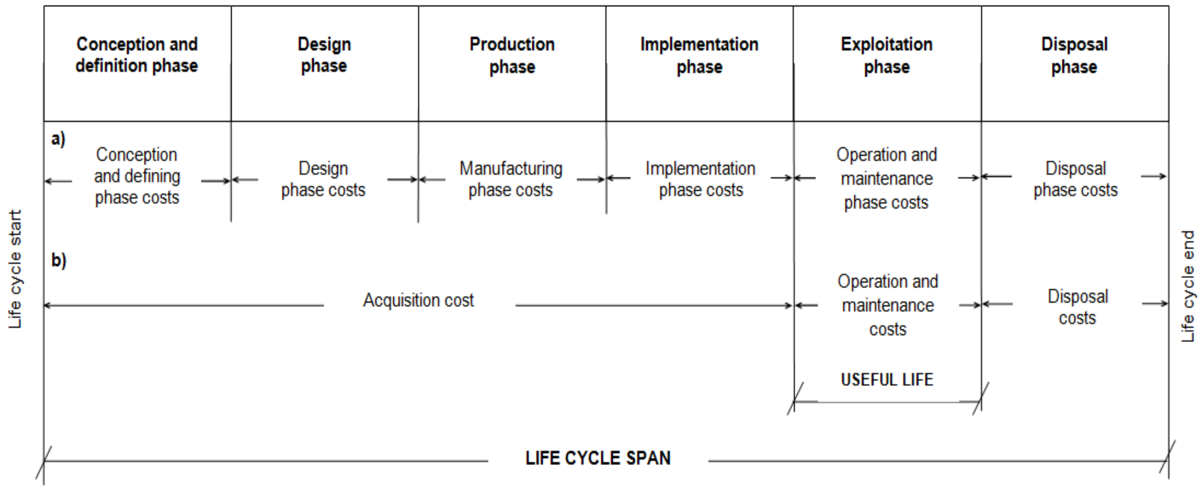


Figure 1. LCC breakdown into cost categories: a) according to the phase of object's life cycle, b) from the user's perspective of technical object

From the customer (buyer, user) point of view, the "living way" of object starts from the purchase moment. Accordingly, LCC is the sum of purchase price, costs being incurred in a usage period and, when applicable, the cost of wear-out process. Experience shows, that costs, which are incurred during the exploitation phase of technical object, i.e. operation and maintenance costs are much (even to 10 times) higher than its purchase cost [8], [13], and for this reason their analysis should be discussed and comparised with purchase price.

User obtains accurate estimates of above mentioned costs via LCC analysis. Thus, at the purchase stage, buyer can choose the most cost-effective technical object, i.e. the cheapest in long term perspective, out of several competitive types offered by industry.

Exploitation phase covers activities and events, which contributed to the appearance of costs (*Figure 2*). These costs can be divided into three groups of costs, that are characterized in the section 1.

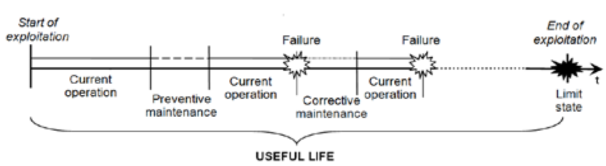


Figure 2. Activities and events causing costs during technical object's useful life

The costs which are incurred by object's user in its useful life, are derivative of purchase cost (i.e. technical object's purchase price). The amount of these two cost components are depended on dependability, which represents integral view of object availability. The relation between dependability and LCC is presented in *Figure 3* and *Figure 4*.

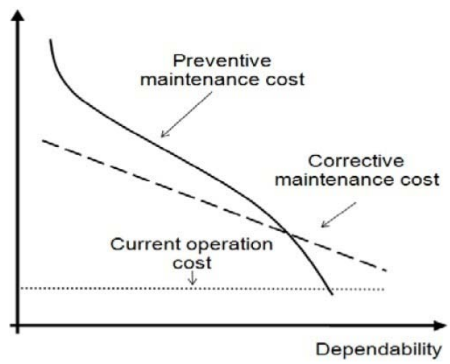


Figure 3. Distribution of individual components of exploitation costs, depending on the dependability of a technical object

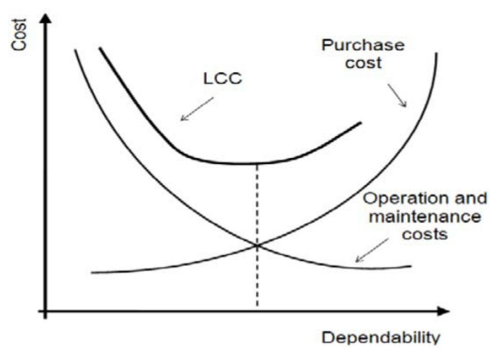


Figure 4. The relationship between dependability and object's LCC

As opposed to purchase cost, the exploitation costs of technical object are unknown at its purchase moment. These costs are difficult to predict, because of their variability over useful life. The best way to determine the costs of operation and maintenance is to use the available historical exploitation data. The results of dependability exploitation studies of the same group of technical objects provide many valuable information, for example about failure rate, mean time between failure, mean repair time, mean repair rate, reliability and unreliability function, availability ratio etc. Only knowledge of the information allows to assess appropriate operation and maintenance costs.

From literature, it is apparent that maintenance costs depend on the level of technical object's dependability and current operation costs do not depend on it – there are constant over time (*Figure 3*). Only these costs, in particular energy costs (fuel), are further considered in the paper. The author focuses on examining the influence of dependability on the amount of supply costs (connected with fuel usage) and their estimating.

3. CURRENT OPERATION COST IN LCC EVALUATION

The existing literature deals with assessing current operation cost over object's useful life is not very rich. This issues is discussed only in a few papers, i.e. [1], [2], [3], [9], [11], [12]. One can noticed, that the type of object determines the measurement method of energy consumption cost. For example, standards [11] and [12] give the formula for the calculation of these costs for an equipment package where the power requirement is constant throughout the lifetime and not dependent of the production, whereas papers [1] and [3] show how to estimate the cost of the fuel consumption of the aircraft and motor, respectively. The universal method for calculating these costs, which can be used for every technical object is described in publications [2] and [9].

3.1. THE UNIVERSAL METHODS OF ASSESSMENT OF TECHNICAL OBJECT OPERATION COSTS IN LCC ANALYSIS

In the traditional costs account, operation costs (C_O) are the sum of fuel consumption costs by technical object (c_{ze}) and staff salaries (c_s). In the mathematical way, it is written as following formula:

$$C_O = c_{ze} + c_s \tag{1}$$

where:

$$c_{ze} = z_e \times c_e \tag{2}$$

where:

z_e - energy (fuel) consumption,

c_e - energy (fuel) cost, i.e. fuel price.

According to D. Kumar *et al.*[9]and B.S. Dhillon [2], in LCC account, the energy consumed by the object should be dependent on the availability (A). Generally, availability is defined as the probability that the technical system or object is operating properly when it is requested for use. In other words, availability is the probability that a system or object is not failed or undergoing repair when it needs to be used. In the simplest form, A, is expressed as a ratio of the expected value of the uptime of a system to the aggregate of the expected values of up and down time:

$$A = \frac{Uptime}{Uptime + Downtime} \tag{3}$$

B.S. Dhillon [2] claims that, the total value of the object operation cost in its useful life $TC_O(T)$ should be calculated using the following equation:

$$TC_O(T) = A \times c_P \tag{4}$$

where:

c_P - the purchase cost (price) of technical object,

T - the expected total useful life of object, which can be expressed e.g. by hours, days, years, kilometers, etc., for $t = 1,2,...,T$.

According to D. Kumar *et al.* [9], $TC_O(T)$ is expressed as follows:

$$TC_O(T) = A \times T \times c_o \tag{5}$$

where:

c_o - operation cost, i.e. energy cost and manpower cost per unit time.

As opposed to B.S. Dhillon [2], D. Kumar *et al.*[9]emphasize the importance of discounting in LCC evaluation. The rationale for discounting costs in this analysis derives from the idea that money available now is worth more than the same amount of money available in the future.

The process of discounting involves selecting a discount rate (r), that reflects the time value of money. The general discounting formula to calculate present value of future sum of money (FV) at the end of n time periods (years) is:

$$PV = FV \cdot \frac{1}{(1+r)^n} \tag{6}$$

where:

PV - the sum of all cash flows discounted for the years in which they occur and is a money value,

n - the number of periods (years) being discounted, where $j = 1,2,3,...,n$,

$\frac{1}{(1+r)^n}$ - the discount factor for n^{th} year.

To sum up, the present value of costs is obtained if costs which are incurred in the future (in the n^{th} year) are multiplied by the discount factor. On the one hand the amount of future costs depends on value and spreading over time of costs flow, on the other hand on assumed discount rate. The discounting technique used in LCC method is considered extensively in literature, for instance in [1], [5], [14].

The issue of discounting in relation to costs appraisal of long-term perspective is also considered in [3]. When the operation cost varies greatly during the object's useful life, the equation (7) is recommended for estimating the present worth of total operation cost of object (specifically for motor), if not, equation (8) is used for these calculations.

$$TC_O PV(T) = C_{O1} \cdot \left(\frac{1}{1+r}\right) + C_{O2} \cdot \left(\frac{1}{1+r}\right)^2 + C_{O3} \cdot \left(\frac{1}{1+r}\right)^3 + ... + C_{On} \cdot \left(\frac{1}{1+r}\right)^n \tag{7}$$

$$TC_O PV(T) = C_O \cdot \left[\left(\frac{1+i}{1+r}\right) + \left(\frac{1+i}{1+r}\right)^2 + \left(\frac{1+i}{1+r}\right)^3 + ... + \left(\frac{1+i}{1+r}\right)^n\right] \tag{8}$$

where:

$TC_O PV(T)$- the present value of the total operation cost in object's useful life T; the T must be expressed in years, because n is expressed that way, hence $T = n$,

C_{On} - the object operation cost in year n; for $j = 1,2,3,...,n$,

i - the escalation (inflation) rate.

B.S. Dhillon [3] also presents method for calculating only costs of energy consumption. For constant annual z_e and the fuel escalation rate (i), during the useful life of the object, the present value of total fuel consumption cost $Tc_{ze}PV$ is defined by formula (9), in different case by equation (10):

$$Tc_{ze}PV = z_e \cdot c_e \cdot \sum_{j=1}^{n} \left[\frac{(1+i)}{(1+r)}\right]^j \tag{9}$$

$$Tc_{ze}PV = \sum_{j=1}^{n} z_{e_j} \cdot \left[\frac{c_{e_{n=1}} \left(1+i\right)^n}{(1+r)^n}\right] \tag{10}$$

To sum up, in presented methods, the variability of operation costs over time are reflected either by object's availability ratio [2], [9] or/and costs discounting [3]. Traditional approach (i.e. energy consumption which is multiplied by its price) to calculate fuel consumption costs and converting their future values to present ones is not quite a good solution. In the process of exploitation, the technical object loses its functional properties. Therefore, when estimating operation costs, the object's dependability should be considered. In equation (4) and equation (5) the object's dependability is expressed by its availability - it is a very good solution, because it is the measure accounting for the reliability, maintainability as well as supportability properties of a object. However, these all characterized methods do not provide accurate mechanism to estimate the future value of operation costs. Determination of accurate and precise information about these costs it is possible, when operation costs per unit time for every t^{th} period in object's useful life are given.

3.2. THE NEW METHOD FOR ESTIMATING TECHNICAL OBJECT'S OPERATION COSTS IN LCC EVALUATION

The proposed method of objects operation cost evaluation in its useful life is very simple to use but requires detailed economical-technical information and data about the real objects exploitation process. Firstly, one should have knowledge of technical objects availability, and secondly the operation cost of object per unit time for every t^{th} period during its useful life T must be know. Mathematically, the total future value of operation cost in T is given by following formula:

$$TC_O(T) = \sum_{t=1}^{T} A \cdot t \cdot c_{ot} \qquad (11)$$

As opposed to equation (5), where the object operation cost is constant in each year of T, i.e. $c_O = c_{O1} = c_{O2} = ... = c_{Ot}$, the equation (11) reflects the variability of c_o during T, i.e. $c_{O1} \neq c_{O2} \neq ... = c_{Ot}$. Based on the described method, only the total costs of fuel consumption in determined T is estimated. The results of this analysis are presented in section 4.

4. CASE STUDY

Analysis regards to the city transportation system operating in Lower Silesia province, Poland. The municipal transport services are provided by a common carrier, which operates on railroads mostly non-electrified. The analyzed rail carrier has begun transport activities on the 14th December 2008, and now operates 13 railway lines.

The carrier train encompasses 21 railbuses that have been bought by the Lower Silesia Marshall Office. The research analysis contains 10 single mode railbuses of type X (manufactured by the same producer). The analysis time period is illustrated in *Figure 5*.

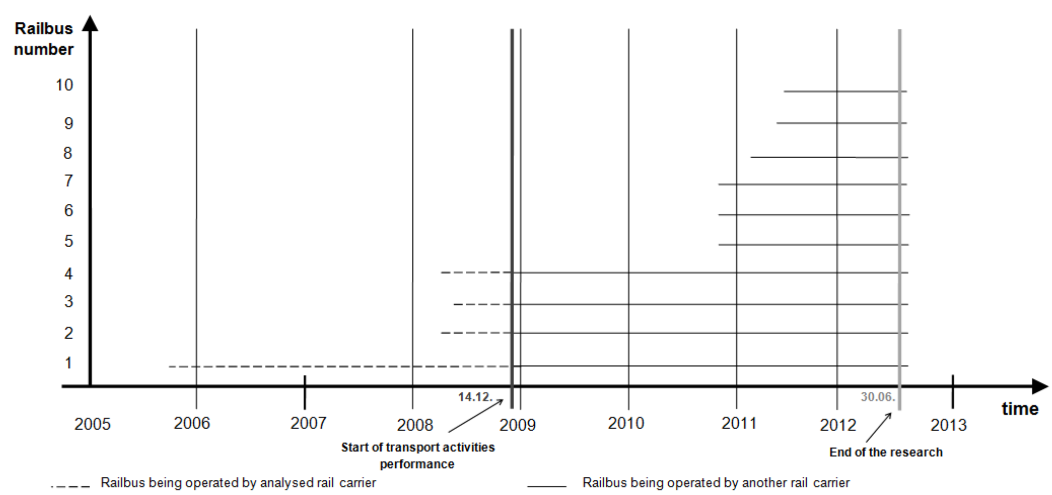


Figure 5. Time schedule of performed research analysis

The costs of fuel consumption were calculated using the following assumptions:

- the annual exploitation time of a rail-bus (t) is expressed in kilometers - it is 120,000 kilometres (km),
- the period of analysis (T) is next 5 years, which correspond to 600,000 km performed by the railbus),
- the price of one liter of petrol (c_e) is estimated at 4.6 PLN (this value reflects mean fuel price during the analyzed time period),
- the (mean) fuel consumption by a rail-bus (z_e) is constant - it is equal to 62 liters per 100 km (the value reflects mean fuel consumption during the analyzed time period),
- the availability ratios of railbuses, calculated as it is shown in equation (1), is presented at the *Figure 6*. As it can be seen, the average availability ratio of a rail-bus equals 0.86,
- the nominal, annual interest rate of a consumer credit is used as discount rate; it is a constant value for all years in the future and is equal to 13,9% [6],
- the annual percentage change in the price of goods and services (i.e. the inflation rate) is a constant value for all years in the future and is equal to 4% [7].

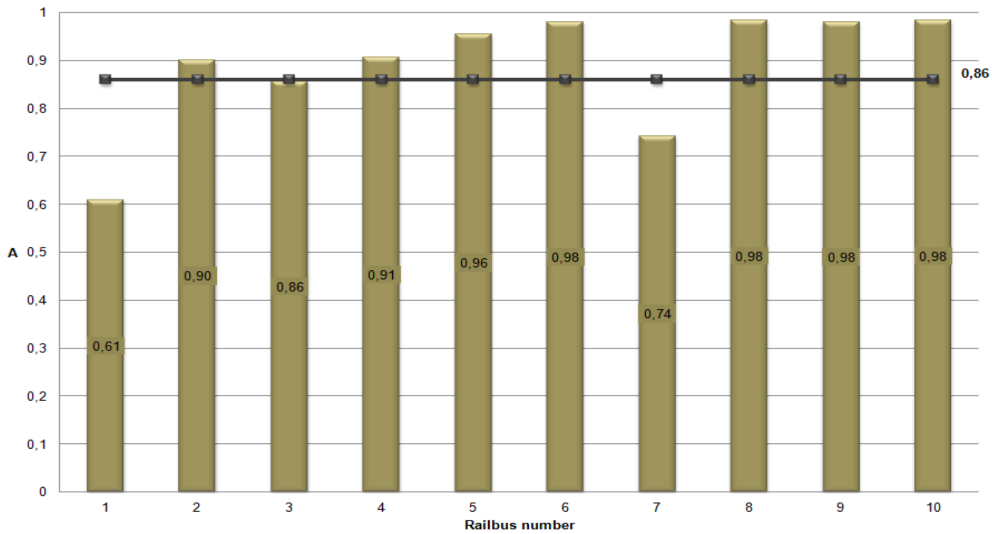


Figure 6. Availability ratio for analyzed railbuses

Case study results

The aim of this study is to determine the future costs of fuel consumption, which will be incurred during the specific period of time (5 years), in the purchase moment t_0. The predictable, future costs associated with the fuel consumption of a railbus during 5 years are presented in *Figure 7*. Moreover the results of numerical test performed with the use of the methods 1, 2, 3 and 4 described in section 3, one shown in *Table 1*. Methods 1, 2, 3 and 4 are described by the following equations respectively:

- equation (2), where:

  $c_{ze}(T) = \sum_{t=1}^{T} z_e \cdot c_e$ (12),
- equation (5), where:

  $c_o = c_{ze}$ (13),
- equation (9),
- equation (11).

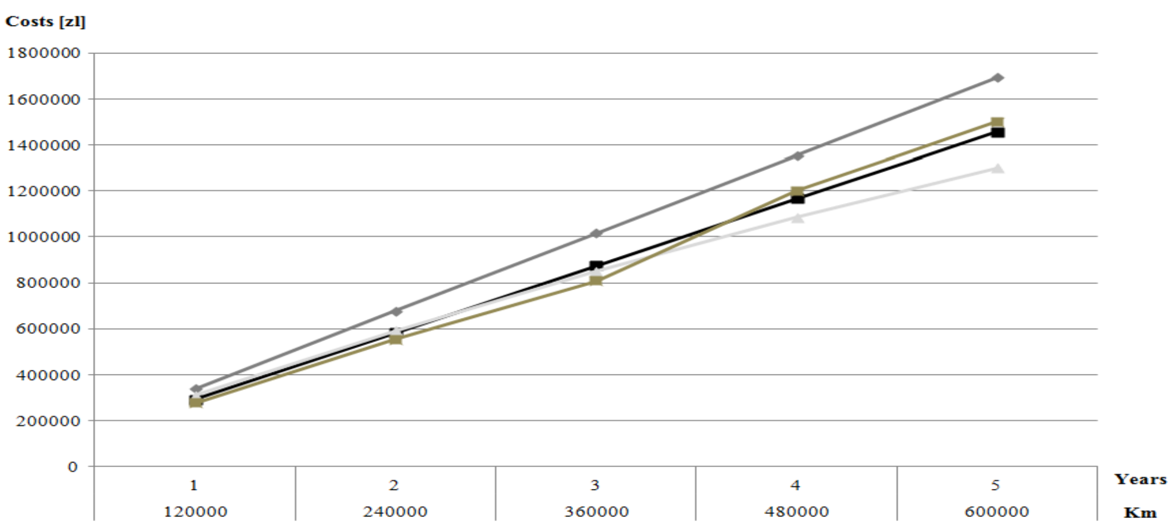
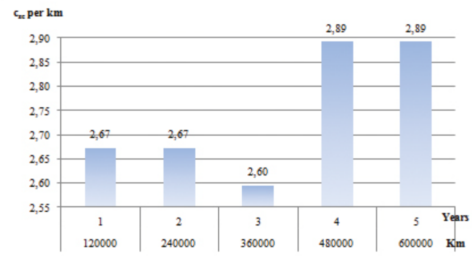


Figure 7. The future value of fuel consumption costs in object's useful life calculated on the basis of 4 methods

Table 1. Summary of case study results

The calculation methods of fuel consumption costs	Concept of availability is used (√) or not (-)	The fuel consumption behavior during the T	Fuel consumption costs per kilometre [zl/km]	Total value of fuel consumption costs in T [PLN]	Present value of fuel consumption costs in T [PLN]
Method 1	-	Constant	2,82	1 692 800,20	-
Method 2	√			1 457 249,81	-
Method 3	-			-	1 299 328,59
Method 4	√	Changeable		1 500 248,89	-

The study findings show that the forecast, future costs of fuel consumption estimated on the basis of method 3 are much lower than the costs calculated with the use of the other three approaches. On the other hand, future costs evaluated using method 1 are the highest out of all methods. However, the future value costs of technical object estimated using these two above mentioned methods are less precise than the value, which has been obtained from the approaches that take into consideration the availability of technical object. It is unlikely, that during entire useful life, the percentage of time that a object is fully operational will be the same and equal to 100%. Therefore, it is much better to use the methods based on object's availability, which take into account its reliability, maintainability and maintenance support. These factors define how often the object will sustain failures, and how much time and effort it would require to return it to its full productive operational capacity.

It should be noted that method 3 describes the constant energy consumption. The constant cost of fuel consumption occurrence during the T of object is not very probable. For those reasons, calculation of the future supply costs (connected with fuel usage) with the use of method 1, method 2 and method 3 is not entirely correct. Hence, these costs estimation based on 4 approach is the closest to those, which probably will appear in 5 years time. The outcomes of this research shows, that in 5 years, the owner of railbus, will pay 1,500,248.9 PLN for fuel supply. As opposed to method 1, 2 and 3, method 4 allows to calculate future costs only in the period of time when the fuel consumption cost per kilometre is known, i.e. the cost, which will appear in year 6, 7, 8 etc. is not known, because no analysedrailbus has performed 720,000 km, 840,000 km, 960,000 km etc.

5. CONCLUSION

In this paper, methods which allow to estimate the future operation costs of technical object are described. In presented methods, the variability of operation costs over time is reflected either by object's availability ratio or/and costs discounting. Moreover, as it is revealed, the chosen way of calculation of these costs has a significant impact on their future value. The methods, which take into account dependability aspect are the ideal solution for future costs calculation, because then, one can see the variability of costs over time.

ACKNOWLEDGEMENTS

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