Jan Furch

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A MODEL FOR PREDICTING MOTOR VEHICLE LIFE CYCLE COST AND ITS VERIFICATION

Summary

In the paper there is a draft of a general model to be used for calculating life cycle costs and determining an optimum period of durability of a motor vehicle. This model is created in the MATLAB software environment. The paper contains calculations and input data which are necessary for making a model that would predict motor vehicle life cycle costs and determine the optimum period of durability. The suggested model might be used for working out life cycle costs of a new vehicle type for which the costs have not been determined yet. This model can also be applied when comparing several types of motor land vehicles of the same category during purchase. It is advisable to use the model mainly during tenders, since life cycle costs are one of the major criterion when selecting a supplier. The model enables us to calculate not only life cycle costs, but also vehicle amortization which depends upon mileage and age of a vehicle. All cumulative values might be transformed into unit values related to the mileage.

Key words: *vehicle life cycle costs, prediction of vehicle life cycle costs, vehicle purchase costs, operating state costs, preventive maintenance costs, corrective maintenance costs, amortization costs.*

1. Introduction

At present, there is a need for reliable products. It is necessary for products to operate without doing harm to the environment. What is more, they should be easy to maintain throughout their technical life cycle [3]. In order to satisfy a customer, by optimizing acquisition costs, ownership costs, and decommissioning costs the producer is expected to design the products which are to be reliable and capable of competing in terms of costs. Ideally, this process of optimizing should start with the creation of a product and take all costs met throughout the product life into account. All decisions made about product design and production can affect requirements for the performance, safety, reliability, availability and maintenance support of a product [13]. These decisions determine the price of the product as well as ownership costs and decommissioning costs.

In an attempt to improve the design of products and reduce design changes, cost, and time to market, concurrent engineering or life cycle engineering has emerged as an effective approach to addressing these issues in today's competitive global market. As over 70% of the total life cycle cost of a product is committed to the early design stage, designers are in a position to substantially reduce the life cycle cost of the products they design by giving due consideration to life cycle cost implications of their design decisions. Increasing recognition of cost competition has spurred the development of methodologies such as design for manufacturability, design for assembly (DFA), design for producibility, design for maintainability and design for quality in the design for 'X' realm. Although these methodologies have for the most part proven successful in reducing cost, the design evaluation criterion in most of these methodologies is not cost. Therefore, methodologies and tools are needed to directly provide cost information to designers. Life cycle cost (LCC) analysis provides a framework for specifying the estimated total incremental cost of developing, producing, using, and retiring a particular item [1].

Prediction of the life cycle cost makes use of statistical and artificial neural network methods in conceptual product design. During the early design stages, over 70% of the total life cycle cost (LCC) of a product is committed and there may be competing concepts with dramatic differences. Additionally, both the lack of detailed information and the overhead in developing parametric LCC models for a range of concepts make the application of traditional LCC models impractical. An artificial neural network (ANN) model to predict the product LCC is developed and compared with a conventional statistical model, i.e. the regression model. The results show that the ANN model outperforms the traditional regression model used for predicting the product LCC [9].

Remote condition monitoring (RCM) can help to achieve increases in reliability, availability, maintainability and safety (RAMS). Nonetheless, the application of a LCC model to RCM has hitherto been overlooked [6].

A life cycle cost analysis is an economic analysis aimed at assessing overall costs of a product purchase, ownership and decommission. This analysis provides important input data in the decision-making process during design, development, usage and disposal phases [3, 4]. The producers can optimize their designs by evaluating alternatives and carrying out a study on cost and benefit optimisation. In order to optimize life cycle costs they can evaluate different strategies of operation, maintenance and decommission. The life cycle cost analysis might be used efficiently when evaluating the costs of specific activities, for example while evaluating different concepts and approaches to maintenance, solving problems of a specific part of a product, or dealing with problems connected with only a selected product life cycle phase or phases [5, 11, 13, 14].

The life cycle cost analysis is used for optimizing a design concept and is most effective in the early life cycle phases. However, the analysis can be also updated and used during subsequent life cycle phases in order to discover the areas of significant cost uncertainty and risk. Selected life cycle costs might be used for calculating life time or setting an optimum interval of product service maintenance [4].

At present, there is a tendency to predict life cycle costs before a product is in operation. For this prediction single models [2, 4, 7, 10, 12, 13 and 15] might be used. In this paper, a possible procedure for predicting life cycle costs of motor vehicles with the use of the MATLAB software environment is introduced. A mathematical model which enables us to determine motor vehicle life using selected life cycle cost parameters is also included.

There are five phases of a motor vehicle life cycle [3, 4]:

1. period of concept and requirement determination,
2. design and development period, } - purchase costs,
3. manufacture period,
4. operating state and maintenance period, - proprietary costs,
5. disposal period. - disposal costs.

2. Calculation of predicted motor vehicle life cycle costs

Generally, the total costs borne during the given periods may be divided into purchase costs, possession costs, and disposal costs. For the draft model, a division of life cycle costs into the following five categories is recommended.

$$LCC = C_P + C_{OMC} + C_{OMP} + C_{OMO} + C_D \quad (1)$$

$$\mathrm{LCC_s} = \frac{LCC}{t} \quad (2)$$

where LCC - life cycle cost of motor vehicles, LCC_s - specific life cycle cost of motor vehicles, C_P - vehicle purchase cost, C_{OMC} - corrective maintenance cost, C_{OMP} - preventive maintenance cost, C_{OMO} - operating state of vehicle cost, C_D - vehicle disposal cost, t - time of vehicle operation [3, 4].

2.1 Costs of motor vehicle maintenance

The total vehicle maintenance costs consist of preventive maintenance costs and corrective maintenance costs.

$$C_{OM} = C_{OMC} + C_{OMP} \quad (3)$$

The maintenance costs comprise generally material costs, labour costs, and workshop equipment costs [3, 4].

$$C_{OM} = (C_{OMCM} + C_{OMCL} + C_{OMCF}) + (C_{OMPM} + C_{OMPL} + C_{OMPF}) \quad (4)$$

$$C_{OMs} = \frac{C_{OM}}{t} \quad (5)$$

where C_{OM} - cumulative maintenance costs, C_{OMs} - specific cumulative maintenance costs, C_{OMC} - corrective maintenance costs, C_{OMP} - preventive maintenance costs, costs of material used for corrective maintenance, C_{OMCL} - costs of labour force for corrective maintenance, C_{OMCF} - costs of workshop equipment used for corrective maintenance, C_{OMPM} - costs of material used for preventive maintenance, C_{OMPL} - costs of labour force for preventive maintenance, C_{OMPF} - costs of workshop equipment used for preventive maintenance, t - operating time in kilometres.

a) Corrective maintenance cost

The total costs which incur for ensuring repairs during the vehicle operating time depend on the number of failures which occur in the vehicle during its operation and on costs incurring for removing these failures. The calculation of the prediction cost of corrective maintenance is performed by at least one of the following ways, depending on the availability of information:

a) based on the failure intensity at interval z_t,

b) based on the mean time between failures Φ.

Cumulative and specific costs of corrective maintenance may be calculated using equations (6), (7) and (8):

$$C_{OMC(j)} = \sum_{n=1}^{n=j} z_{(t)} \cdot ic_R \quad (6)$$

$$C_{OMC} = \frac{c_R}{\phi} \cdot t \tag{7}$$

$$C_{OMCs} = \frac{C_{OMC}}{t} \tag{8}$$

$$z(t) = \lim_{\Delta t \to 0+} \frac{E[N(t+\Delta t) - N(t)]}{\Delta t} \tag{9}$$

where C_{OMC} - cumulative corrective maintenance costs during operating time t, C_{OMCs} - specific cumulative corrective maintenance costs during operating time t, t - operating time in kilometres, i - determined value of the interval in kilometres, j - number of determined intervals i, $z_{(t)}$ - failure intensity at interval t, Φ - mean time between failures, c_R - average cost of one failure repair consisting of material and labour costs [3].

Based on equations (6) and (7) the corrective maintenance cumulative costs are calculated for the monitored predicted interval. Calculations of corrective maintenance costs, which depend on the failure intensity $z_{(t)}$, include the process of aging and wear (degradation of the vehicle as a whole). This parameter is usually not available because it is necessary to perform the monitoring of the vehicle. On the other hand, the calculation based on the mean time between failures Φ, determined as an average distance between individual failures, does not include effects of degradation.

b) Vehicle preventive maintenance costs

These costs include the costs of preventive maintenance which is performed in compliance with a specified schedule for the maintenance of a given vehicle [10].

The total amount of costs which incur for ensuring the preventive maintenance during the vehicle operation depends on the number of preventive maintenance actions (maintenance interval) performed on the vehicle during its operation. The amount of these costs further depends on price relations of preventive maintenance actions comprising material price and labour costs. Thus, for the costs of ensuring preventive maintenance it may be written [5, 14, 15]

$$C_{OMP} = t \cdot \hat{c}_M \tag{10}$$

$$C_{OMPs} = \frac{C_{OMP}}{t} \tag{11}$$

where C_{OMP} - cumulative costs incurred for ensuring preventive maintenance during operating time t, C_{OMPs} - specific cumulative costs incurred for ensuring preventive maintenance during operating time t, t - operating time in kilometres, $\hat{c}_M$ - average cost incurred for ensuring preventive maintenance, consisting of material and labour costs related to an operation time unit.

For predicting the preventive maintenance costs the following values are selected:

a) service maintenance interval (km),
b) frequency of service maintenance during the service maintenance period,
c) types of service maintenance during the service maintenance period.

Considering the values above, the following indicators are calculated [5]:

a) guarantee inspection costs (price),
b) costs of individual types of service maintenance, comprising material price and labour costs (price),
c) costs of the service maintenance period (price),
d) average costs of service maintenance relating to a kilometre of operation (price/km),

e) cumulative costs of service maintenance during the operation time (price),
f) specific cumulative costs of service maintenance during the operating time (price/km).

2.2 Operation costs

The period of operation includes fuel costs C_F, costs of service fluids, oils and lubricants C_{OL} which are refilled during the operation (not within service maintenance), tyre costs C_T, battery costs C_{AB}, costs of the vehicle insurance and a road tax, and other possible costs resulting from the legislation C_{IRT}, motorway sticker costs C_{MT}, costs of technical condition control C_{TC}, exhaust-emission measurement costs C_E [4]. The individual cost is calculated by using the following equations:

$$C_{OMO} = C_F + C_{OL} + C_T + C_{AB} + C_{IRT} + C_{MT} + C_{TC} + C_E \quad (12)$$

$$C_F = \frac{c_{aF}}{100} \cdot p_F \cdot t_o \quad (13)$$

$$C_{OL} = \frac{c_{aOL}}{100} \cdot p_{OL} \cdot t_o \quad (14)$$

$$C_T = \frac{t_o}{d_{aT}} \cdot n_T \cdot p_t \quad (15)$$

$$d_{aAB} = t_1 \cdot d_{AB} \quad (16)$$

$$C_{AB} = \frac{t_o}{d_{aAB}} \cdot n_{AB} \cdot p_{AB} \quad (17)$$

$$C_{IRT} = C_I + C_{RT} \quad (18)$$

where C_{OMO} - operation costs, c_{aF} - average fuel consumption (l/100 km), p_F - price per litre of fuel (price/l), t_o - operation time (km), t_1 – annual operation time (km), c_{aOL} - average consumption of oil and lubricant (l/100 km), p_{OL} - oil and lubricant price (price/l), d_{aT} - average tyre durability (km), n_T - number of tyres per vehicle (pcs), p_T - tyre price (price), d_{AB} - average battery durability (years), d_{aAB} - average battery durability (km), n_{AB} - number of batteries in the vehicle (pcs), p_{AB} - battery price (price), C_I - vehicle insurance price (price), C_{RT} - road tax price (price) [4].

When predicting operational costs the following data should be available:

a) price per litre of fuel (price),
b) average consumption of the vehicle in litres (l/100 km),
c) battery price (price),
d) battery durability in kilometres (years),
e) tyre price (price),
f) tyre durability (km),
g) price of annual liability insurance (price),
h) price of annual accident insurance (price),
i) price of annual motorway sticker (price),
j) costs of technical inspection and exhaust-emission measurement per year (price).

Based on the specified data and by using equations (12 – 18), the total cumulative operation costs are calculated.

2.3 Disposal costs

This category includes costs of putting vehicles out of operation and of vehicle disposal after the vehicles reach the end of their lifetime. [11].

$$C_D = C_{DD} + C_{DR} \tag{19}$$

where C_{DD} - costs of dismounting and removing engineering parts, C_{DR} - costs of recycling or safe disposal.

These disposal costs may be present as a plus or minus value, depending on the disposal method. The plus value may be achieved if the vehicle is exploited and individual raw materials are handed over to a refuse collection. The minus values will be achieved if the vehicle is ecologically disposed of by another company.

A law including a vehicle disposal method as a duty of the manufacturer is being considered. This price would be included in the vehicle price, as it is for example in electrical appliances.

For these reasons disposal costs are not included in the calculations of the vehicle life cycle costs.

3. Prediction of a motor vehicle life based on selected life cycle costs

The prediction of motor vehicle life is based on vehicle amortisation and maintenance costs. Vehicle amortisation costs consist of vehicle purchase costs and the amortisation itself based on the expert standard used for motor vehicle valuation [8].

1) Costs of motor vehicle purchase and amortisation

The costs of motor vehicle purchase is calculated according to (20). Then, the real value of a motor vehicle during its operation is calculated from the purchase costs which are reduced by the vehicle amortisation costs. These costs are determined from the vehicle operating time (age) and mileage.

a) Costs of motor vehicle purchase

Motor vehicle purchase costs may be expressed as [3, 7, 11]:

$$C_P = C_{CD} + C_{DD} + C_M + C_S + C_G, \tag{19}$$

where C_{CD} - costs of the period of concept and requirement determination, C_{DD} - costs of the design and development period, C_M - costs of the period of manufacture, C_S - costs of the vehicle sales period, C_G - costs of ensuring repairs during a guarantee period.

b) Calculation of motor vehicle residual value (amortisation)

The value of an amortised motor vehicle is determined based on the vehicle operating time (age) and mileage. For a certain vehicle type, the price is calculated from the amortisation scales (Table 1 - 4), in which a basic percentage deduction for the operating time and a basic percentage deduction for mileage are determined. The vehicle value is then calculated as an arithmetic average of the following values [8]:

$$C_{PA} = \left(C_{AT} + C_{AO}\right)/2, \tag{20}$$

$$C_{PAs} = \frac{C_{PA}}{t} \tag{21}$$

where C_{PA} - costs of motor vehicle purchase and amortisation, C_{PAs} - specific costs of motor vehicle purchase and amortisation, C_{AT} - amortisation value of the vehicle depending on the operating time, C_{AO} - amortisation value of the vehicle depending on its mileage.

When calculating the prediction of motor vehicle life, the values listed below are selected:

- costs of motor vehicle purchase (price),
- period of durability of a motor vehicle (km),
- period of durability of a motor vehicle (years).

Table 1 Basic percentages deductions in time (C_{AT}) for different types of vehicles [8]

Operating time [year]	Passenger car and motor vehicles to a total weight of 3500 kg		Lorries and special lorries. Buses and minibuses.
	% deduction in the year of operation starting from 951 cm^3 to 2000 cm^3 displacement	% deduction in the year of operation starting from 2001 cm^3 displacement	
1	25	33	20
2	33	40	30
3	40	45	40
4	45	50	50
5	50	55	60
6	55	60	70
7	60	65	75
8	65	70	80
9	70	74	85
10	74	78	90
11	78	82	90
12	82	86	90
13	86	90	90
14	90	90	90
15 and others	90	90	90

Table 2 Basic percentages deductions per mileage (C_{AO}) for passenger cars [8]

Passenger vehicles with displacement [cm^3]	Range in kilometres	% deduction per each 1000 km
951 - 2000	to first 20000	1.00
	other	0.50
2001 - 3000	to first 30000	0.67
	other	0.33
over 3000	to first 40000	0.50
	other	0.25

Table 3 Basic percentages deductions per mileage (C_{AO}) for a motor truck [8]

Lorries of the total weight	Most frequent way of use	% deduction per each 1000 km
to 5 000 kg	road and city traffic	0.30
	difficult operation conditions	0.50
	construction work (in the field)	0.75

Lorries of the total weight	Most frequent way of use	% deduction per each 1000 km
5 001 - 16 000 kg	road and city traffic	0.20
	difficult operation conditions	0.30
	construction work (in the field)	0.50
over 16 001 kg	road and city traffic	0.12
	difficult operation conditions	0.30
	construction work (in the field)	0.50

Table 4 Basic percentages deductions per mileage (C_{AO}) for buses and minibuses [8]

Vehicles	% deduction per each 1000 km
Minibuses	0.30
City buses	0.25
Public service buses and special vehicles based on buses	0.20
Long distance coaches	0.08

2) Costs of motor vehicle maintenance

When calculating the costs of motor vehicle maintenance data from chapter 2.1 are used.

3) Determination of the period of durability of a motor vehicle based on the selected life cycle costs

This is one of possible methods for determining a vehicle life cycle [12]. The determination of the period of durability of a vehile based on the LCC may be performed in two ways:

a) by deducing optimal life cycle costs directly from the graph.
b) by determining optimal life cycle costs using points of the elaborated graph through which a suitable regression curve is laid out. This curve is expressed by an equation of function $f(x)$.

Calculation procedure:

- Finding a local extreme of the function within the [0, T_D] domain, where T_D is the vehicle's period of durability. The calculation is performed with the first derivation of function $f'(x)$, where the following applies:

$$f'(x_0) = 0. \tag{22}$$

  The result is a local extreme within interval [0, T_D].
- Finding a strong local minimum of the function within the [0, T_D] domain:

$$f''(x_0) = 0\,. \tag{23}$$

After the function minimum within the searched interval [0, T_D] is set, it is necessary to determine the value of the vehicle's period of durability. It is recommended to determine an optimal interval in kilometres which is 5 to 10 % higher than the calculated value of the minimal costs (Fig. 3).

4. Results of the draft model in MATLAB

Based on the previous relations and the required input data a mathematical model has been created in the MATLAB software environment. This software seems to be an appropriate tool for achieving accurate results during a relatively short period of time. Another advantage of the software is that graphs in different forms can be created (Fig. 1, Fig. 3). When changing input parameters it is possible to perform the optimisation of a vehicle life based on the selected vehicle life cycle costs (Fig. 3). The draft of the prediction of life cycle costs has been verified by observing 56 Land Rover Defender vehicles. The difference between the predicted and the established life cycle cost was up to 10 per cent which is by any means a very good result.

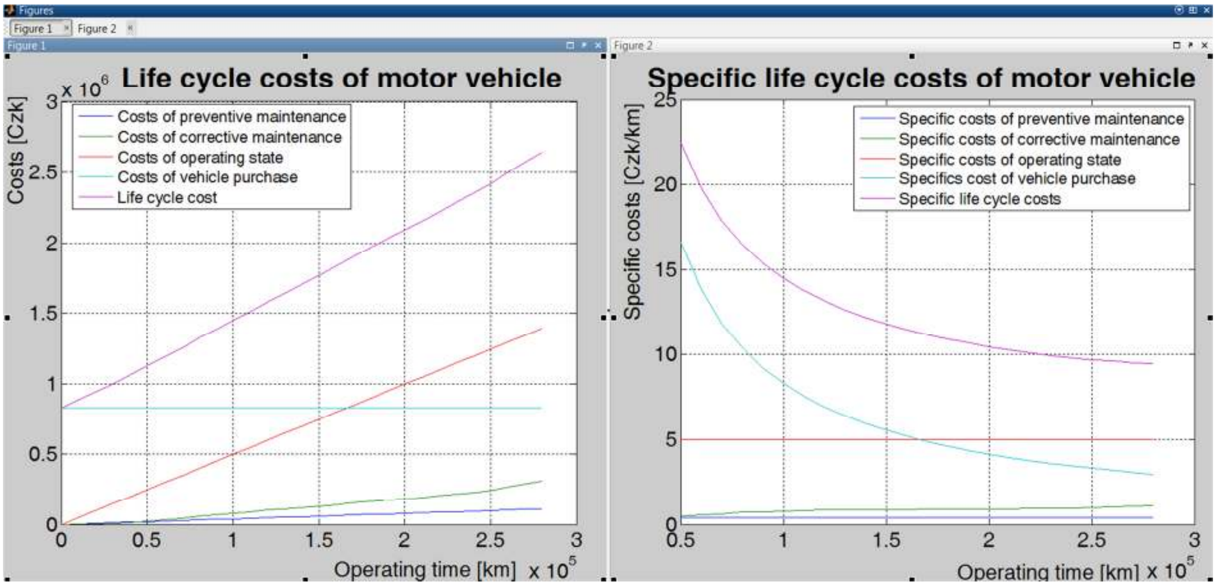

Fig. 1 Cumulative and specific life cycle costs of Land Rover Defender in MATLAB

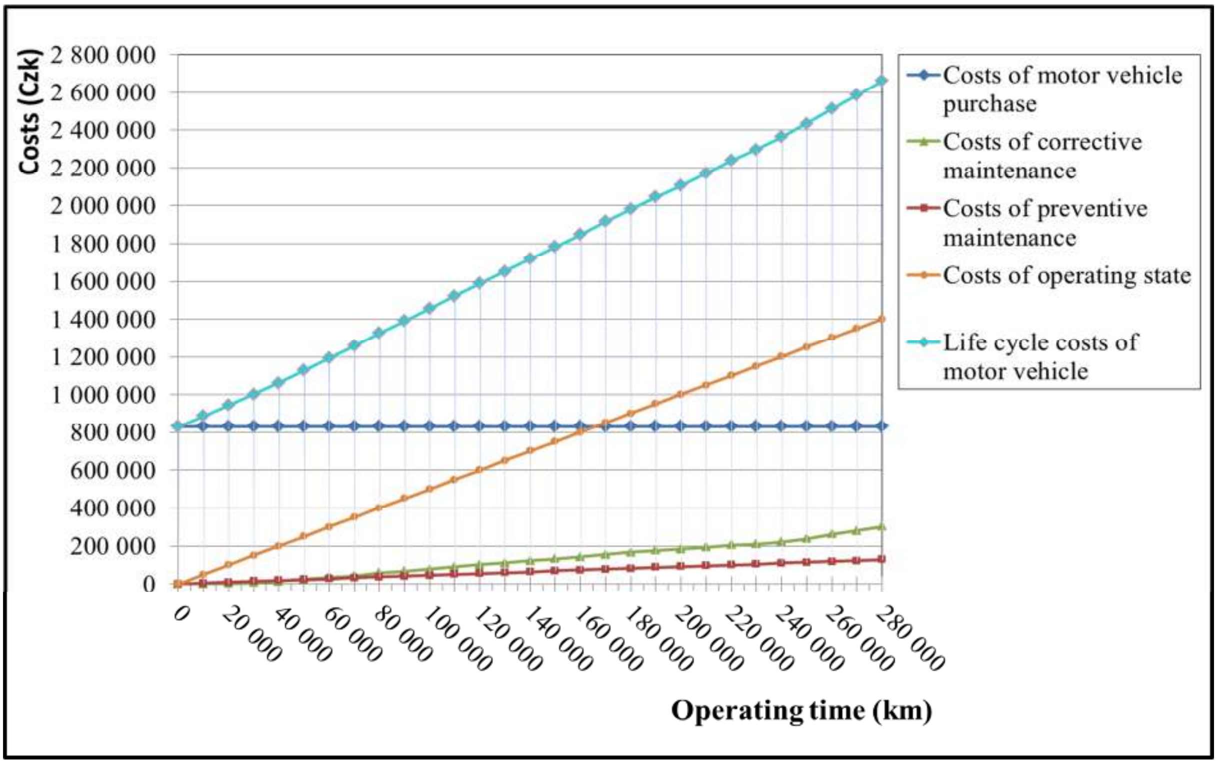

Fig. 2 Estimation of cumulative life cycle costs of Land Rover Defender

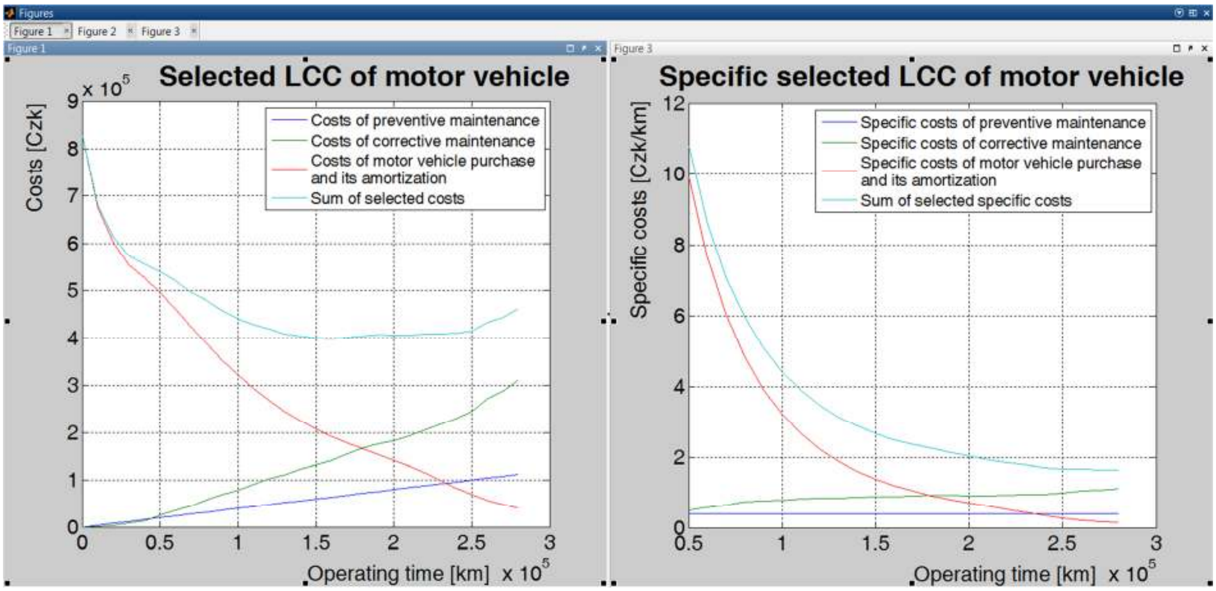

Fig. 3 Predicted selected cumulative and specific life cycle costs of Land Rover Defender in MATLAB

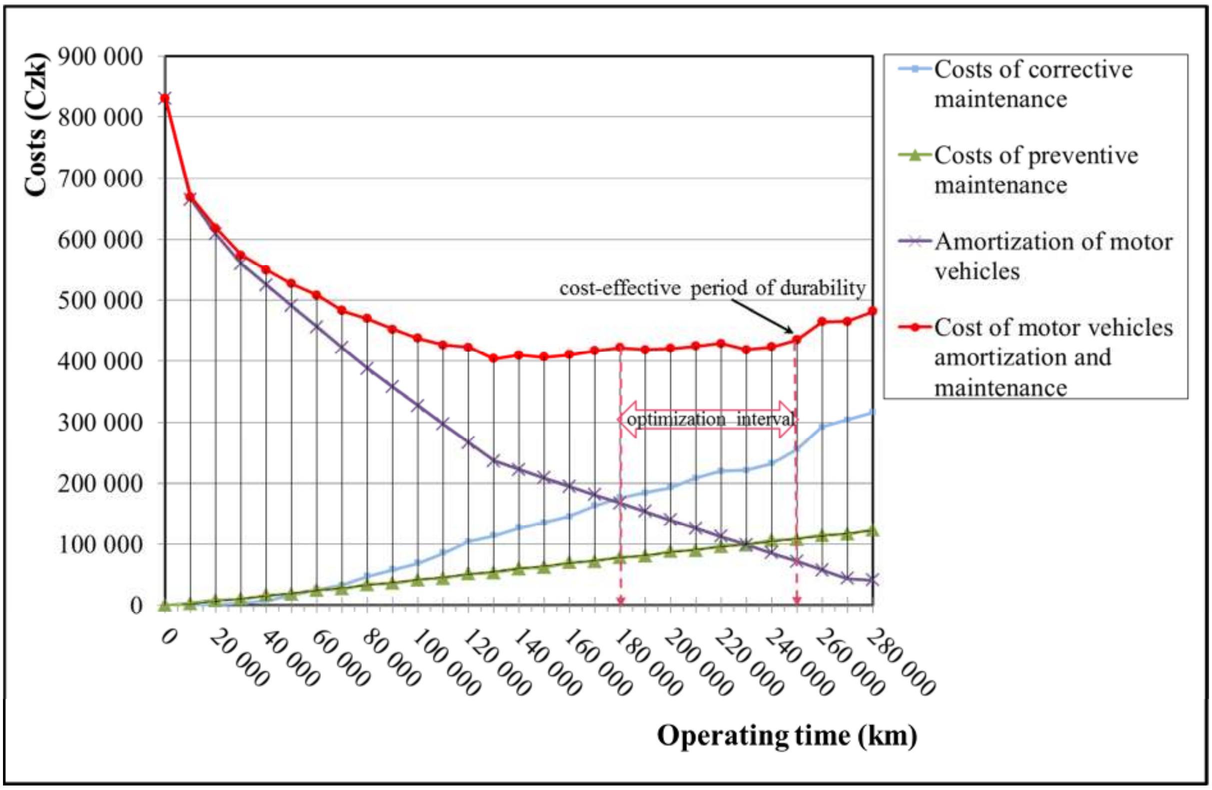

Fig. 4 Estimation of selected cumulative life cycle costs of Land Rover Defender

Life cycle costs of the vehicle UAZ – 469 were calculated and are shown in Figure 5. This calculation is based on the proposed model for life cycle cost prediction. The UAZ – 469 vehicle is similar to the Land Rover vehicle. According to the graph the vehicle durability is about 80 000 km which corresponds to the manufacturer's recommendations.

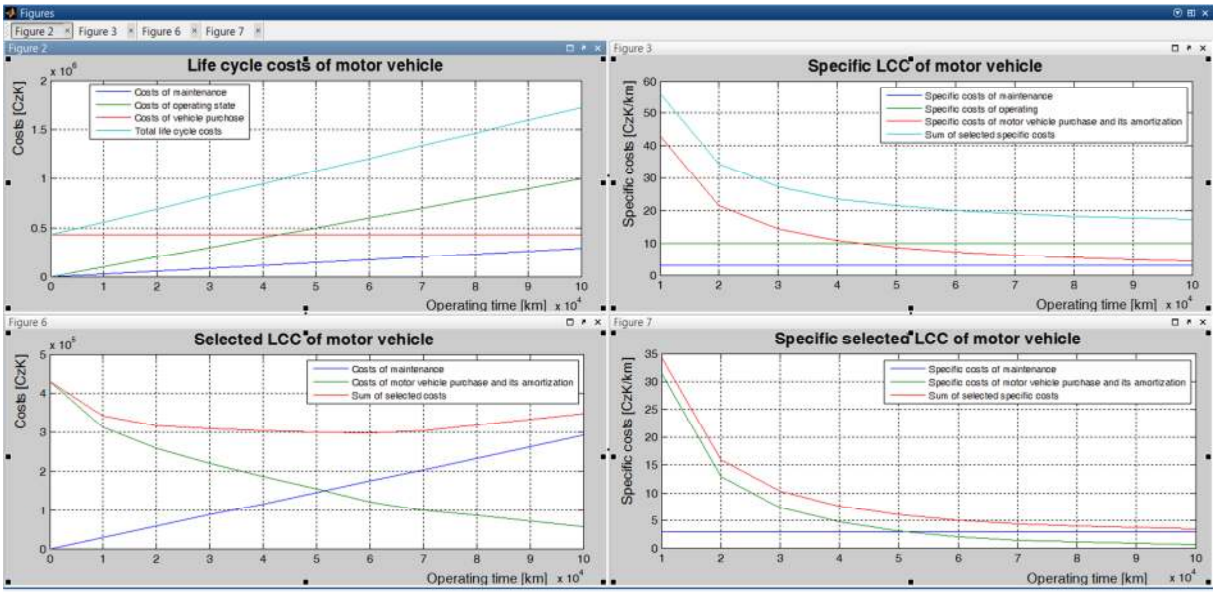

Fig. 5 Predicted selected cumulative and specific life cycle costs of UAZ - 469 in MATLAB

5. Conclusion

The paper contains a description of a model applied when predicting life cycle cost and made in the MATLAB software environment. It contains formulae, procedures, and necessary data for the calculation of individual costs of the vehicle life cycle. The method described above may be used for a preliminary determination of life cycle costs of a new vehicle and a comparison of several vehicles of the same category. This comparison may be applied as a criterion in tenders for the supply of new technical equipment.

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prof. Eng. Jan Furch, Ph.D.
University of Defence Brno
Faculty of Military Technology
Kounicova Str. 65
662 10 Brno, Czech Republic