

MATHEMATICAL MODEL FOR VEHICLES LIFE CYCLE COSTS DETERMINATION

МАТЕМАТИЧЕСКИЙ МОДЕЛЬ ДЛЯ ОПРЕДЕЛЕНИЯ РАСХОДОВ ЖИЗНЕННОГО ЦИКЛА ТРАНСПОРТНЫХ СРЕДСТВ

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Abstract:

The paper deals with the determination of optimal vehicle durability time depending on life cycle costs and failure intensity. This method adopts two separate approaches. The first approach is based on the life cycle costs calculation, and the second on the determination of failure intensity relation. As an example of vehicle durability time assessment, the monitoring and calculation of the fixed indicators of the Land Rover Defender is used. In the course of twelve years 55 Land Rover vehicles were monitored. These vehicles drove almost eight million kilometers.

KEYWORDS: VEHICLE DURABILITY TIME, VEHICLE LIFE CYCLE COSTS, FAILURE INTENSITY.

1. Introduction

Currently it is requested that required vehicle reliability is guaranteed and that the life cycle cost is minimal. At the same time it is important for the vehicles to carry out their function safely without any wrong impact on the environment and on the road traffic. The decision on the vehicle purchase is not only influenced by the initial costs (purchase costs), but also by the expected operating costs and maintenance costs for the total life cycle (proprietary costs) and liquidation costs (disposal). Vehicle providers could use this model to optimize and evaluate various operating, maintenance and liquidation strategies.

2. Calculation of the life cycle cost

Generally the total costs spent during the listed periods may be divided to purchase costs, proprietary costs and liquidation costs [1], [2].

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

where: LCC - life cycle cost,

C_P - cost on purchase,

C_{OMC} - cost on corrective maintenance,

C_{OMP} - cost on preventive maintenance,

C_{OMO} - cost on operating state,

C_D - cost on liquidation.

2.1 Purchase costs

Purchase costs can be expressed as the relation:

$$C_P = C_{CD} + C_{DD} + C_M + C_S + C_{RG} \quad (2)$$

where: C_{CD} - costs on concept and demand determination period,

C_{DD} - costs on vehicle proposal and development period,

C_M - costs on manufacture period,

C_S - costs on vehicle sale period,

C_{RG} - costs on repair support during guarantee period.

2.2 Maintenance costs

Total vehicle maintenance costs consist of preventive maintenance and corrective maintenance costs.

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

Maintenance costs consist of material costs, work costs and workshop equipment costs. [3].

$$C_{OM} = (C_{OMCM} + C_{OMCL} + C_{OMCF}) + (C_{OMPM} + C_{OMPL} + C_{OMPF}) \quad (3)$$

where: C_{OM} - cost on maintenance,

C_{OMC} - cost on corrective maintenance,

C_{OMP} - cost on preventive maintenance,

C_{OMCM} - cost on used material at corrective maintenance,

C_{OMCL} - cost on labour at corrective maintenance,

C_{OMCF} - costs on fittings used at corrective maintenance,

C_{OMPM} - costs on used material at preventive maintenance,

C_{OMPL} - costs on labour at preventive maintenance,

C_{OMPF} - costs on fittings used at preventive maintenance.

a) Vehicle corrective maintenance costs:

The total amount of costs, which are necessary to ensure repairs during the vehicle usage, depends on the number of its failure occurrences during its operating state, and on the height of costs which are necessary to eliminate these failures. Let us state: the measure of vehicle reliability is expressed as failure intensity $z_{(t)}$, operating time between failures $E_{(t)}$, or mean operating time between failures Φ , then repair support costs are:

$$C_{OMC} = z_{(t)} \cdot t \cdot \hat{c}_R \quad (4)$$

$$C_{OMC} = E_{(t)} \cdot t \cdot \hat{c}_R \quad (5)$$

$$C_{OMC} = \Phi \cdot t \cdot \hat{c}_R \quad (6)$$

where: C_{OMC} - costs on corrective maintenance during operating time t,

$z_{(t)}$ - failure rate,

t - operating time,

\hat{c}_R - average costs on one failure repair,

$E_{(t)}$ - time between failures,

Φ - mean time between failures.

b) Vehicle preventive maintenance costs:

These include scheduled preventive maintenance costs for the maintenance, which is carried out in harmony with the predetermined time-schedule for the given vehicle maintenance.

Total costs spent on ensuring the preventive maintenance during the vehicle usage, depends on the number of preventive maintenance actions (maintenance interval), carried out during the vehicle usage. Further on it depends on the price relation of the preventive maintenance actions, and these, include the price of material costs and work costs. Then preventive maintenance support costs may be expressed as:

$$C_{OMP} = t \cdot \hat{c}_M \quad (7)$$

where: C_{OMP} - costs on preventive maintenance support during operating time t,

t - operating time,

\hat{c}_M - average costs on preventive maintenance support applied to operating time unit.

2.3 Costs on operating state

This phase includes fuel costs C_F , working fluids costs, motor oils and lubricants C_{OL} ; these are replenished during the operating state (not during the service maintenance), tyre costs C_T , storage batteries costs C_{AB} , motor vehicle insurance costs and road tax, if need be further costs sequent to laws C_{IRT} , motorway toll sticker cost C_T , technical conditions check cost C_{VI} , emissions testing cost C_E and continuous training costs C_T [4].

$$C_{OMO} = C_F + C_{OL} + C_T + C_{AB} + C_{IRT} + C_{TC} + C_E \quad (8)$$

$$C_F = \frac{c_{aF}}{100} \cdot p_F \cdot t_o \quad (9)$$

$$C_{OL} = \frac{c_{aOL}}{100} \cdot p_{OL} \cdot t_o \quad (10)$$

$$C_T = \frac{t_c}{d_{aT}} \cdot n_T \cdot p_T \quad (11)$$

$$C_{AB} = \frac{t_c}{d_{aAB}} \cdot n_{AB} \cdot p_{AB} \quad (12)$$

$$C_{IRT} = C_I + C_{RT} \quad (13)$$

where: C_{OMO} - costs on operating state,
 c_{aF} - average fuel consumption (l/100 km),
 p_F - price for fuel / litre (CZK/l),
 t_o - operating time (km),
 c_{aOL} - average oil and lubricant consumption (l/100 km),
 p_{OL} - price of oil and lubricant (CZK/l),
 d_{aT} - average tyre durability (km),
 n_T - number of tyres on vehicle (pcs.),
 p_T - price of tyre (CZK),
 d_{aAB} - average accumulator battery durability (km),
 n_{AB} - number of accumulator batteries on vehicle (pcs.),
 p_{AB} - price of accumulator battery (CZK),
 C_I - price of motor vehicle insurance (CZK),
 C_{RT} - price of road-traffic tax (CZK),
 C_{TC} - price of inspection at technical control station,
 C_E - price of inspection at emissions testing station.

2.4 Liquidation costs

Liquidation costs of vehicles with completed life cycle fall into this category.

$$C_D = C_{DD} + C_{DR} \quad (14)$$

where: C_{DD} - costs on vehicle disassembly and disposal,
 C_{DR} - costs on recycling or safety disposal.

These liquidation costs may appear as plus or minus values depending on the way of liquidation. We get plus values when the vehicle is exploited and separate materials are salvaged. Contrary to that we get minus values, if we exploit the services of some ecological company.

Currently there are ideas about creating a law which would include such way of liquidation of a vehicle, which would be part of the duties of the producers. That type of costs would be included in the vehicle price, as it is true for electrotechnics.

That is why I have not included the liquidation costs in the calculation of the life cycle cost of the vehicle.

3. Possible approach to the creation of the model for the determination of the life cycle cost of vehicles

3.1 Calculation of the depreciated price of the vehicle

Following values are selected for the calculation:

- Purchase costs of the vehicle – given in Czech crowns,
- Durability period of the vehicle – given in kilometers,
- Durability period of the vehicle – given in years.

For these values a chart of calculations is designed. This stems from [5]. To calculate the depreciated price 4 points in the course of the vehicle durability are selected as a minimum. The starting point is given when the vehicle is delivered and starts its operation and the final point is the one when the vehicle is taken out of service because of durability. The remaining minimally two points are chosen somewhere between the two end points. Based on the calculation and setting out the points we draw the regressive curve with the expression of the optimal function. Based on the calculated

function the remaining points in the meantime of durability of the vehicle are calculated (supposed meantime is 10 000 km).

3.2 Calculation of the preventive maintenance costs

To calculate it the following values are selected:

- Service maintenance meantime in kilometers,
- Number of service maintenance,
- Determination of types of service maintenance during the period of service maintenance,
- Determination of the guarantee inspection costs in Czech crowns,
- Determination of the costs on individual types of service maintenance which consist of material costs and work costs.

From these values the following measures will be calculated (worked out):

- The period of service maintenance costs in Czech crowns,
- Average costs per kilometer,
- Determination of regressive curve with the explication of the best-fit function.

3.3 Calculation of corrective maintenance costs

The calculation can be done in the following ways:

- From the calculation of failure intensity,
- From the calculation of operating time between failures,
- From the calculation of the mean operating time between failures that does not include the degradation process.

The number of failures during the durability of vehicles and the mileage during the monitoring are the items that are proceeded from.

For the final calculation of the corrective maintenance costs it is necessary to know the average value of failure costs.

3.4 Calculation of operating costs

For the calculation the following values are chosen:

- The price of a litre of fuelling in Czech crowns,
- Average consumption of vehicles in litres per 100 kilometer,
- The price of the accumulator in Czech crowns,
- Durability of the accumulator in kilometres (years),
- The tyre price in Czech crowns,
- The tyre durability in kilometers,
- The price of the annual mandatory insurance in Czech crowns,
- The price of the annual all-risk insurance in Czech crowns,
- The price of the annual motorway tax disc in Czech crowns,
- STK costs and emission costs in Czech crowns.

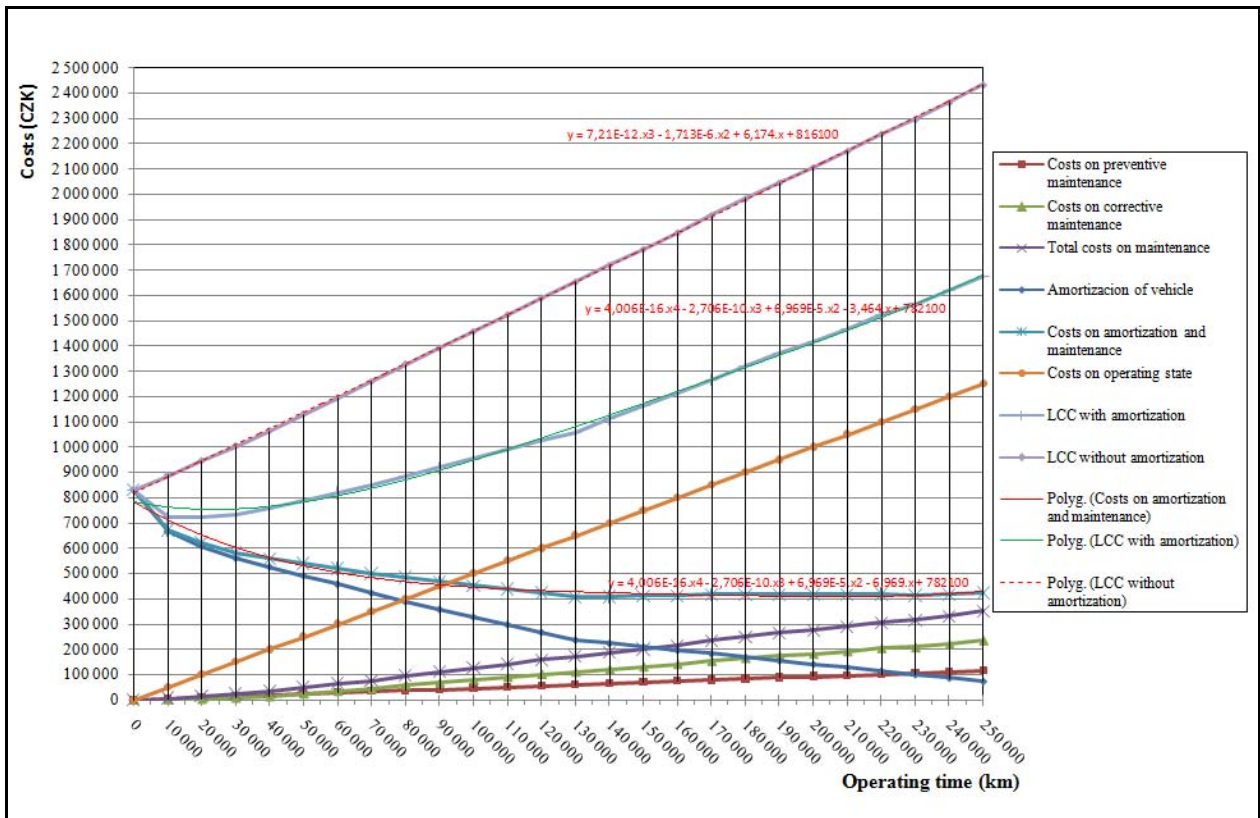
These values are used to carry out the calculation of the total operating costs - see chapter 2.3.

3.5 Calculation of liquidation costs

These costs are not included in the suggested model, because I assume that comparing two vehicles of the same type, they are more or less the same. In case of need the price for liquidation at the end of vehicle durability would be counted.

4. Calculation results of the determination of the life cycle of vehicle Land Rover Defender

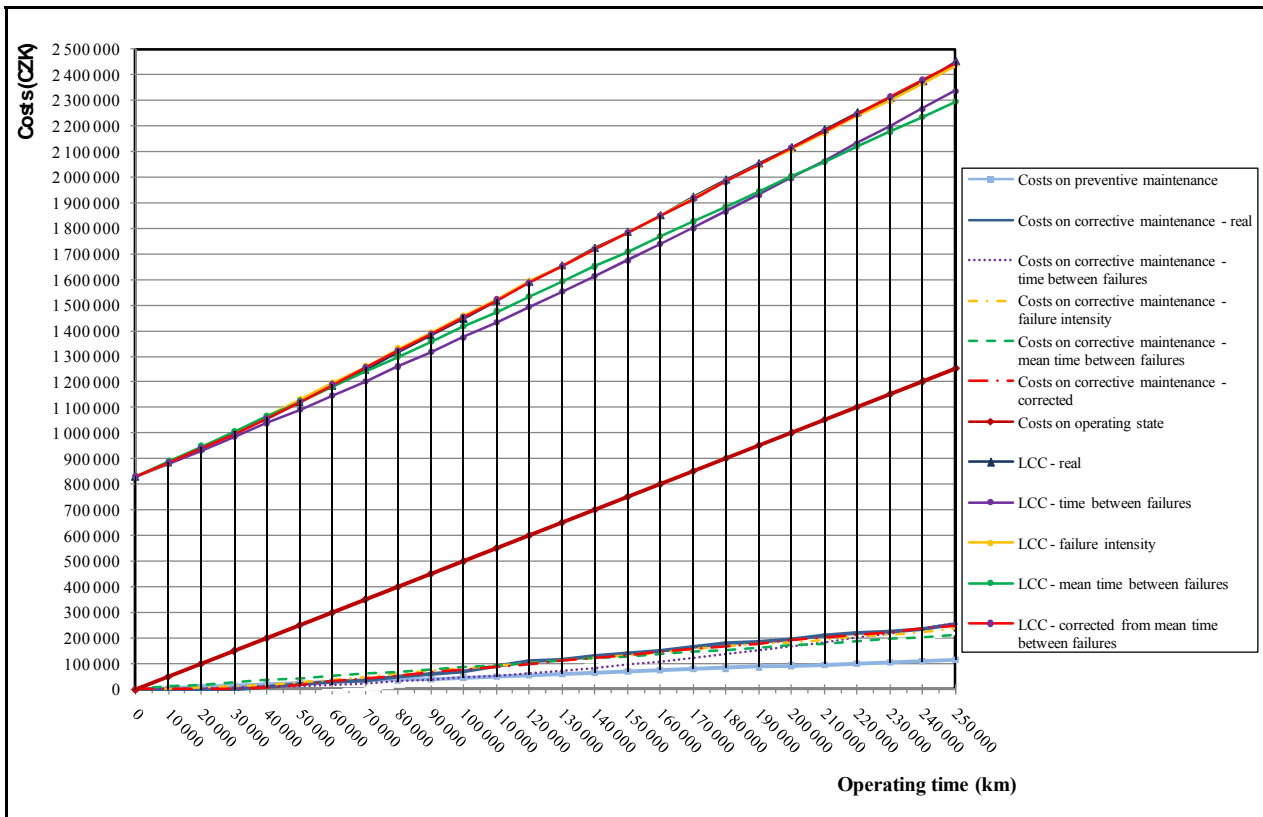
On the basis of the assembled programme and the given entry information it is possible to count the preventive maintenance costs and the corrective maintenance costs, the purchase costs and the amortization costs within time and not least the life cycle of vehicles costs. In this case it is possible to model (simulate) up to unlimited mileage. The calculation is carried out there up to 250 000 km, because this point was chosen as an optimal point for putting vehicles out of service.



Graph 1: Explication of the life cycle costs of the vehicle Land Rover Defender based on operating time between failures

In graph 2, there are figured the corrective maintenance costs that proceeded from the operating time between failures, the mean operating time between failures, the failure intensity and from the

actual established (determined) values. These values were determined (found out) during the 12-year operating state of 55 vehicles.



Graph 2: Comparison of the life cycle costs of Land Rover Defender vehicle

5. Conclusion

In this contribution a model for the calculation of the life cycle costs of vehicles is described. This model can be used on the basis

of data that we get from the manufacturer or from the actual operating state. Through the use of this model we are able to calculate the life cycle costs without monitoring x vehicles during a

few years. In graph 2, we can see that the difference LCC between the model and the actual monitoring is negligible. The closest on to actual LCC monitoring is the curve when the corrective maintenance costs were calculated from the failure intensity, or perhaps by the analysis correction of the corrective maintenance costs acquired from the mean operating time between failures.

This work was elaborated within a project of the Faculty of Military Technology. The title of this project was “The influence of technology development on improvement of tactical and operating mobility of army technology” fig. MO0FVT0000401.

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