

PHILOSOPHY OF OPERATIONAL VEHICLES MAINTENANCE PROGRAMME

МЕТОДИКА ДИНАМИЧЕСКОЙ ПРОГРАММЫ ПРОФИЛАКТИЧЕСКОГО ОБСЛУЖИВАНИЯ АВТОМАШИН

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Abstract:

The paper deals with one possible approach to the determination of the on-going vehicle maintenance programme. This approach is based on life cycle costs and a method called "Reliability centred maintenance". The objective of this method is to maintain system functions within required safety limits, maintain an inherent level of safety and reliability, optimise availability, and perform these objectives with minimal total life cycle costs. The design of the on-going vehicle maintenance programme was based on quantitative, qualitative and economic analyses.

KEYWORDS: OPERATIONAL (ON-GOING) MAINTENANCE PROGRAMME, VEHICLE LIFE CYCLE COSTS, RELIABILITY CENTRED MAINTENANCE, VEHICLE DURABILITY TIME.

1. Introduction

A maintenance programme generally consists of an initial programme and continuously developing operational (on-going) programme. As an example of a possible solution, this contribution includes a design of an operational maintenance programme.

The operational maintenance programme is elaborated using an initial maintenance programme. Thus it is necessary for the user to commence collecting operation data as soon as possible after a vehicle was put to operation.

To elaborate an effective on-going maintenance programme it is necessary to define:

- maintenance programme objectives,
- a method enabling the maintenance programme elaboration,
- content of the maintenance programme.

For the description of the on-going maintenance programme, the following progressive logic diagram was proposed (see Fig. 1). This progressive logic diagram is divided to three main parts – quantitative analysis, qualitative analysis based on RCM (Reliability Centred Maintenance), and economic analysis. These analyses are described further in this paper.

In the initial part of the on-going maintenance programme design, the following acts must be performed:

1. Collecting information
2. Data sorting

For vehicles, division to the following groups is proposed: engine, transmission mechanism, brakes, driving, wiring system, body and frame. This division is based on functionally significant items.

Concerning road traffic safety, it is important to divide brakes and driving to two separate groups and pay them increased attention.

It is appropriate to divide the data according to the classification of failure consequences:

- minor failure consequences,
- major failure consequences,
- critical failure consequences,
- catastrophic failure consequences.

Failures may be also classified according to other criteria:

- classification according to origination rate,
- classification according to extent,
- classification according to criteria combination,
- classification according to causality.

In the article, classification according to failure consequences is applied since each failure has a different effect to the safety, availability, and costs on corrective maintenance of the vehicle.

3. Performing individual analyses

After data are sorted, individual analyses are performed:

1. quantitative analysis,
2. RCM based qualitative analysis,
3. economic analysis.
4. Asking question "Is the system proposal optimal?"

If the answer is YES, integrated modifications in the on-going vehicle maintenance programme shall be accepted. If the answer is NO, the previous preventive maintenance system and vehicle durability shall be retained, or partial modifications, which are considered rational, shall be performed. Consequently, re verification in practice with evaluation of vehicle monitoring results shall be performed.

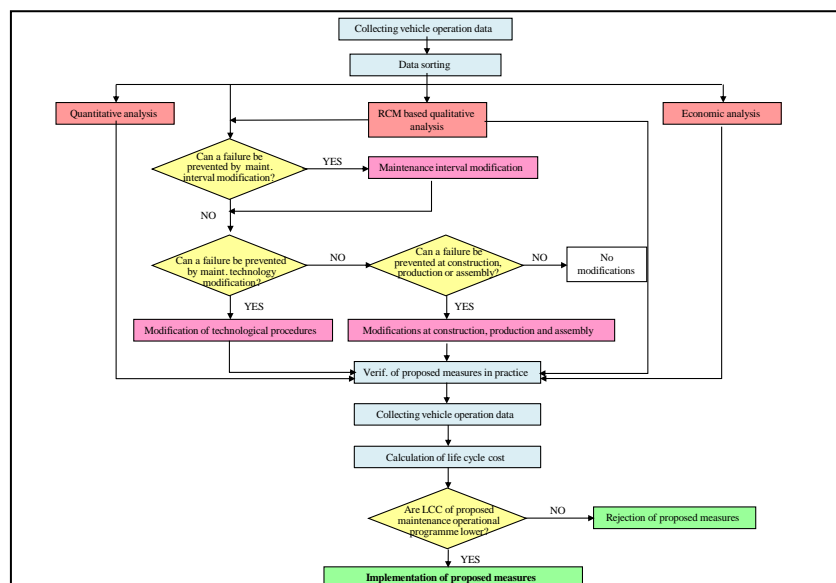


Fig 1: Proposed progressive logic diagram for determining an operational maintenance programme [8]

2. Quantitative analysis for the service maintenance programme elaboration

The following section presents a quantitative analysis progressive logic diagram, which is part of the design of an on-going vehicle maintenance programme.

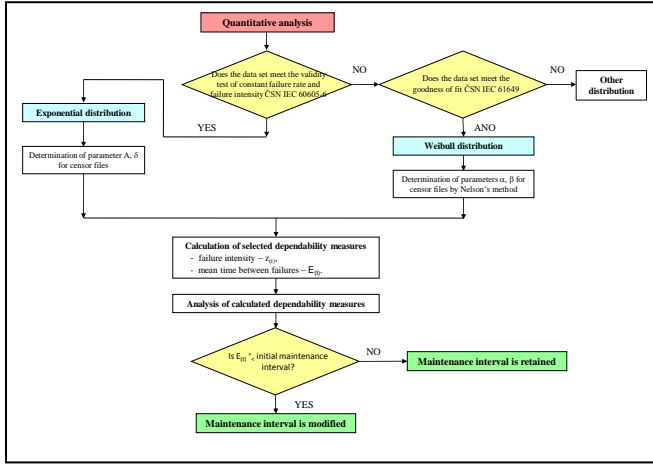


Fig. 2: Progressive logic diagram of quantitative analysis [8]

2.1 Determination of a continuous distribution type

For the determination of a continuous distribution type, the “constant rate validity test” [1], “failure intensity validity test” [1], and “test of goodness of fit for data with Weibull distribution” [2] methods were used. Results of the given calculations shall form the basis for the selection of a suitable type of continuous distribution, and consequently for the calculation of mean time between failures. In order to determine the values, it is necessary to lay down a continuous distribution type that will describe vehicle properties best. Verification of the failure rate behaviour for irreparable items or of the failure intensity for repairable items shall be performed [1].

2.2 Weibull distribution – determination of α , β parameters

This section contains formulas for calculating the point estimation of the most important measures according to Weibull distribution of a random variable valid for repairable as well as irreparable items. A number of machine parts and other equipment, to which exponential distribution does not apply, have durability time (operating time between failures) of Weibull distribution. Especially those machine parts showing mechanical wear and material fatigue. Also mechanical properties of materials, for example strength, have Weibull distribution.

The α and β parameters are presumed not to be negative. Parameter α is so called scale parameter, parameter β is so called shape parameter.

If the threshold value is zero ($c = 0$), W distribution (α , β) has only two parameters and the following expressions may be used [3], [4]. The basic theoretical characteristics of Weibull distribution have the following form [4]:

a) Mean value of $E(\tau)$ function

$$E(\tau) = \alpha \cdot K_{\beta} = \alpha \cdot \Gamma\left(1 + \frac{1}{\beta}\right) \quad (1)$$

Dispersion $D^2(X)$

$$D^2(X) = \alpha^2 \cdot g_{\beta}^2 = \alpha^2 \cdot \left[\Gamma\left(1 + \frac{2}{\beta}\right) - \Gamma^2\left(1 + \frac{1}{\beta}\right) \right] \quad (2)$$

Symbol Γ denotes gamma function the form of which is expressed as follows:

$$\Gamma(y) = \int_0^{\infty} x^{y-1} \cdot e^{-x} \cdot dx \quad (3)$$

These values are tabulated in [3].

Then it is necessary:

A) Determination of parameters α , β for Weibull distribution by Nelson’s method

This is one of methods suitable for processing generally censor files [6].

B) Determination of confidence interval for parameters α with known parameters β and γ

Two-sided confidence interval $\langle a_D, a_H \rangle$ for parameter α with known parameters β , γ with confidence coefficient $1 - \alpha$ shall be determined from relation [3].

2.3 Calculation of selected dependability measures

1) Failure intensity

Failure intensity $z(t)$ is the limit of a ratio – if it exists – of the mean failure number of a repaired item within $(t, t + \Delta t)$ time interval to the length of this interval Δt , if the length of the time interval is approaching zero [8].

$$z(t) = \lim_{\Delta t \rightarrow 0^+} \frac{E[N(t + \Delta t) - N(t)]}{\Delta t} \quad (4)$$

where: $N(t)$ - number of failures within $(0, t)$ time interval,
 E - expected value,
 $t + \Delta t$ - time interval.

Using the given expression, it is possible to calculate failure intensity for the whole vehicle or for individual groups of the vehicle.

2) Mean time between failures calculated with Weibull distribution

The calculation of mean time between failures for a vehicle (or groups) may be performed in longer intervals (e.g. 50000 km). After determining values in these intervals, curve regression with function expression may be carried out. In this way values of mean time between failures in the interval from production to disposal may be calculated.

The calculation shall be done in each interval using the following procedure:

- Failures according to consequences are selected, divided to intervals; calculation includes also unclosed file values when a failure did not occur.
- Using Nelson’s method, cumulative rate $H(x)$ values are calculated.
- Using Weibull diagram, cumulative values $H(x)$ are plotted depending on the mileage.
- Values α and β are read from Weibull diagram.
- Mean time between failures is calculated using Weibull distribution and calculated values α and β .
- Resulting values are plotted to the diagram and regression curve with function expression is calculated. Upon theoretical as well as practical knowledge it is recommended to employ regression analysis. In this analysis, special non-linearizable models shall be used with exponential trend. The most appropriate particular regression curve has the following general form:

$$y = b_1 \cdot e^{-\beta_1 \cdot x} + b_2 \cdot e^{-\beta_2 \cdot x} \quad (5)$$

where: y - mean time between failures in kilometres,
 x - operating time in kilometres,
 b_1, b_2 - estimation of parameters,
 β_1, β_2 - estimation of parameters.

- Mean time between failures in defined maximum durability time of a vehicle is calculated from the given equation.
- Confidence interval for parameter α with known parameter β is determined.

2.4 Analysis of calculated dependability measures

A) Analysis of failure intensity

The calculation of failure intensity is recommended to be employed for the determination of the vehicle durability time. This is a possible criterion used for the durability time determination.

B) Analysis of mean time between failures calculated with Weibull distribution

The calculation of mean time between failures is recommended to be employed for the determination of interval between preventive maintenances, i.e. so called service interval. As generally assumed, a vehicle is a piece of equipment for which the interval between failures shortens with increasing mileage.

2.5 Decision on the optimal interval for service maintenance

Upon the analysis of mean time between failures calculated with Weibull distribution, a decision on the determined interval optimality shall be made. There are two possibilities: to refuse the interval modification, because the calculated interval is the same as the interval recommended by the manufacturer, or to accept the interval modification, because it seems to be optimal. It means that if preventive maintenance costs decrease within the vehicle durability time, at the same time corrective maintenance costs should not increase. Another possibility is, that the service maintenance interval will shorten and at the same time preventive maintenance costs will increase, with expected decrease of corrective maintenance costs. For the verification of stated hypotheses it is necessary to continue monitoring failure occurrence for the newly proposed interval in order to draw a final conclusion.

3. Qualitative analysis based on reliability centred maintenance

This qualitative analysis is based on principles of reliability centred maintenance (RCM). The following section contains an example of determining failure effects and optimal acts which are necessary to be performed within the vehicle preventive maintenance.

In the first part of the decision logic tree, categorisation of failure effects is performed. Questions such as "Is functional failure occurrence during a usual check obvious to the operator?" are asked here. Answers are "yes" or "no", with assigning categories of failure effects such as apparent failure, latent failure etc.

In the second part, maintenance tasks selection is proposed resulting from the RCM based decision logic tree, which is the result of the decision logic tree. Questions such as "Is functional failure occurrence during a usual check obvious to the operator?" are asked here. Answers are "yes" or "no", with assigning categories of failure effects such as apparent failure, latent failure etc. Further, maintenance tasks selection is proposed resulting from the RCM based decision logic tree, which is the result of the decision logic tree.

4. Economic analysis based on life cycle costs

The life cycle costs analysis is an economic analysis process for assessing the total costs on purchase, possessing, and disposal of an item. The analysis may be used within the whole life cycle of the item, or in some parts, or in combinations of various periods of the life cycle [5].

There are five periods of the vehicle life cycle:

1. Period of concept and requirements determination
2. Design and development period
3. Manufacture period
4. Operation and maintenance period
5. Disposal period

4.1 Calculation of selected life cycle costs

$$LCC_S = C_{PA} + C_{OMC} + C_{OMP} \quad (6)$$

where: LCC_S - selected life cycle costs,
 C_P - costs on vehicle purchase and amortisation,
 C_{OMC} - corrective maintenance costs,
 C_{OMP} - preventive maintenance costs.

1. Costs on vehicle purchase and amortisation

The actual value of a vehicle during its operation shall be calculated from costs on vehicle purchase reduced by its amortisation. Costs on amortisation include the vehicle age and mileage.

a) Costs on vehicle purchase

Vehicle purchase costs may be expressed as:

$$C_P = C_{CD} + C_{DD} + C_M + C_P + C_G \quad (7)$$

where: C_{CD} - costs on the period of concept and requirements determination,

C_{DD} - costs on the design and development period,

C_M - costs on the manufacture period,

C_S - costs on the vehicle sale period,

C_G - costs on ensuring repairs during a guarantee period.

b) Calculation of vehicle residual value (amortisation)

The value of amortised vehicle shall be determined upon the vehicle operating time (age) and mileage. For a certain vehicle type, the price shall be calculated from amortisation scales [7], in which a basic percentage deduction from the operating time and a basic percentage deduction for mileage are determined. The vehicle value shall then be calculated as an arithmetic average of the following values:

$$C_{PA} = (C_{AT} + C_{AO})/2 \quad (8)$$

where: C_{PA} - costs on 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.

2. Costs on vehicle maintenance

a) Corrective maintenance costs

The total costs which are required 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 necessary for removing these failures. Corrective maintenance costs may be calculated as follows:

$$C_{OMC(j)} = \sum_{n=1}^{n=j} z_{(n)} \cdot i \cdot C_R \quad (9)$$

$$f_{C_{OMC}} = c_R \cdot \int_{t_0}^t \frac{t}{E_t} \cdot dt \quad (10)$$

$$C_{OMC} = \frac{c_R}{\Phi} \cdot t \quad (11)$$

where: C_{OMC} - 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,

$z_{(n)}$ - failure intensity in interval n,

$E_{(t)}$ - mean time between failures depending on mileage t, calculated with Weibull distribution,

Φ - mean time between failures,

C_R - average cost on one failure repair, consisting of costs on material and costs on work.

b) Preventive maintenance costs

These include costs on scheduled preventive maintenance performed in compliance with a specified maintenance schedule for a given vehicle.

For costs on ensuring preventive maintenance, the following generally applies:

$$C_{OMP} = t \cdot \hat{c}_M \quad (12)$$

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

t - operating time in kilometres,

\hat{c}_M - average cost on ensuring preventive maintenance, consisting of costs on material and costs on work relating to an operation time unit.

c) Total costs on vehicle maintenance

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

$$C_{OM} = C_{OMC} + C_{OMP} \quad (13)$$

4.2 Determination of optimal vehicle durability time

Optimal durability time of an vehicle is recommended to be determined upon selected components of vehicle life cycle costs (costs on vehicle purchase and amortisation, maintenance cost), and upon the failure intensity analysis.

1) Determination of vehicle durability time upon selected life cycle costs

This is one of possible methods employed for the determination of the vehicle life cycle. The determination of vehicle durability time based on LCC may be performed in two ways:

- By deducing optimal life cycle costs directly from the graph.
- By determining optimal life cycle costs using points of the elaborated graph through which a suitable regression curve shall be laid. This curve is expressed by an equation of function $f(x)$. For expressing the function equation, Matlab software may be used, or any other that meets required conditions. Calculation procedure:

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

$$f'(x_0) = 0 \quad (14)$$

The result is a local extreme within interval $[0, T_D]$.

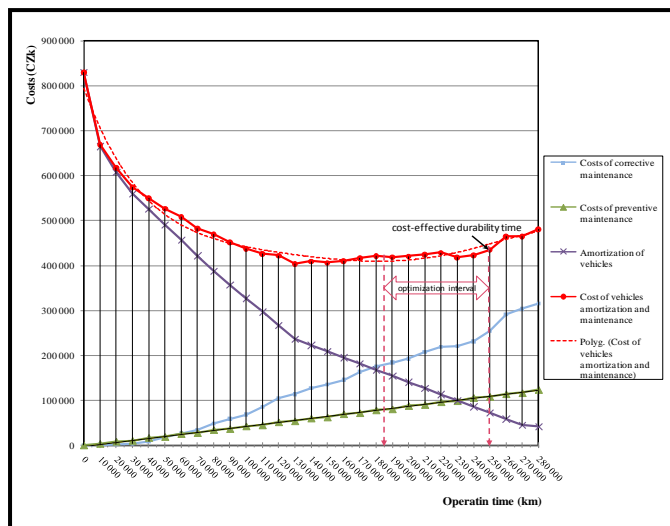
- Finding a strong local minimum of the function within $[0, T_D]$ domain:

$$f''(x_0) > 0 \quad (15)$$

where for the local minimum the following applies:

$$f''(x_0) > 0 \quad (16)$$

After the function minimum within the searched interval $[0, T_D]$ is determined, it is necessary to determine the value of vehicle durability time. It is recommended to determine optimal mileage interval which is 5-10 % higher than the calculated value of the minimal costs, see Graph 1.



Graph 1: Example determinativ of optimal durability time depending on costs fo vehicle Land Rover Defender [8]

2) Determination of vehicle durability time upon failure intensity

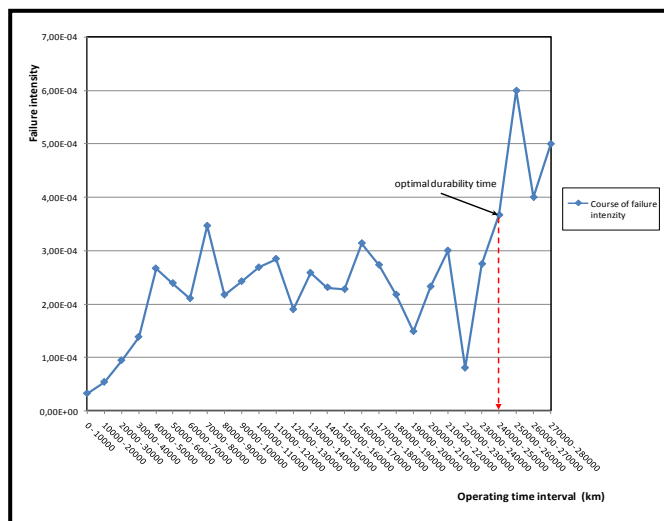
The second method of determining optimal vehicle durability time is based on the calculation of failure intensity. The following expression is used for he calculation:

$$z(t) = \lim_{\Delta t \rightarrow 0^+} \frac{E[N(t + \Delta t) - N(t)]}{\Delta t} \quad (17)$$

where: $N(t)$ - number of failures within the time interval,
 E - expected value,

$t + \Delta t$ - time interval.

Using the given expression, it is possible to calculate failure intensity for the whole vehicle or for individual groups of the vehicle.



Graph 2: Example expression of failure intensity-mileage dependency for vehicle Land Rover Defender [8]

5. Conclusion

Upon the analysis of life cycle costs and failure intensity, the optimal durability time of the vehicle shall be determined. Both optimisation intervals are used as the basis. If the optimisation intervals interlap the value shall be determined from the optimisation interval rounded to tens of thousands of kilometres. If the optimisation intervals do not interlap it shall be necessary to perform a detailed analysis of both criteria and then determine so called optimal durability time of the vehicle.

6. References

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