PERIODIC CONTROL OPTIMIZATION ACCORDING TO AVAILABILITY FOR VEHICLES

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Abstract : *Periodic technical control is the monitoring of the vehicle's condition and the prognosis for its future status. Predictive maintenance decisions are based on the results of forecast. The paper proposes to perform a mathematical modeling of predictive maintenance for vehicles. It is assumed that the vehicle is technically checked periodically, observing the procedure of a complete verification, using the specified equipment, calibrated metrologically. The efficiency of predictive maintenance is evaluated by the average availability and the cost of stopping per unit of time. The mathematical models are proposed for the calculation of maintenance indicators for an arbitrary distribution of time until failure. The objective is to determine the optimal number of periodic technical controls in order to reduce operational defects. The advantage of predictive maintenance is highlighted by comparison with corrective maintenance.*
Keywords: *predictive maintenance (PM); periodic technical control (PTC); maintenance focused on reliability (RCM); average running time (MTBF); average repair time (MTR).*

1. INTRODUCTION

The vehicle is designed into account to ensure its availability in safe conditions, both for the occupants and for the other participants in the traffic. Any manufacturer of motor vehicles shall provide in the user manual intervals of time or kilometers traveled for maintenance operations. At the same time, periodic technical checks are recommended for early detection of premises of subsequent defects.
The law provides for Periodic Technical Inspections for the same purpose.
A maintenance strategy for vehicles is predictive maintenance (PM), which can be applied to any system if there is a physical parameter in deterioration, such as wear, vibration, deformation, pressure, voltage or current, which can be measured. Predictive maintenance allows recognition of problems that may occur in the near future. predicting wear or accelerating aging and preventing failure by repairing or replacing the affected component. Predictive maintenance is based on the study of the reliability and the service life of the components, which means that the remaining useful life of the equipment can be foreseen. However, due to the uncertainty of the statistically determined reliability indicators, there may be incorrect decisions regarding the remaining time or kilometer to failure.
The large number of publications related to various mathematical models and implementation techniques for different maintenance strategies denotes the major interest for the PM, both in order to maintain availability and to keep costs under control.
The paper [1] defines the concept of RCM - maintenance focused on reliability and the fundamental concepts of RCM and the seven key elements. The process is used to determine the maintenance requirements of any physical asset in its operating context and discusses how the operation predicted by the user is ensured in the operating context of the user. In [2], a systematic method is proposed to determine the optimal combination of control methods to minimize the amount of verification costs and losses caused by equipment failure. The detection capability of both, the personnel and the verification and control equipment was taken into account. The concept of sustainability, to support the three pillars, social, economic and environmental, is based on the association between ecology and industry. Thus, the paper [3] aims to investigate the role of maintenance in order to contribute to the development promoted by industrial ecology and the paradigms of the circular economy. The maintenance activity is presented on a global level, allowing, in a second stage, the placement of the maintenance processes in an ecotechnological field. In [4], it is emphasized the need to use inspection or monitoring devices to allow the early detection of future failures to initiate PM. A systematic method is proposed to determine the optimal combination of inspection and verification methods to minimize the amount of control costs and losses caused by system failure. Article [5] proposes a method of maintenance planning that takes into account the interrelationship between maintenance and operations. In the proposed system, operational losses include production losses due to both scrap and maintenance. Maintenance losses include inspection costs, repair

costs and other losses, such as those incurred in failing to comply with safety and health at work instructions. A prototype system has been developed that evaluates these losses using Monte Carlo simulation.
The proposed methodology applies flexible decision procedures, depending on the conclusions expressed at the PTC - periodic technical control for maintenance management. The models considered by the PM do not take into account the probabilities of the correct and incorrect decisions taken by the results of the periodic controls (PTC). The purpose of this paper is to develop a model for determining the optimal periodicity of the PTC, under the conditions of a PM strategy.
The decision rule is based on the evaluation of the time remaining until failure in the codifications of the results of the periodic checks. In compliance with the above rule, the probabilities of correct and incorrect decision taken based on the PTC results are calculated. The effectiveness of PM is evaluated by indicators such as average availability and cost of downtime.

2. WORKING HYPOTHESES

It is considered that the condition of the vehicle is completely determined by the availability value. The vehicle must be operated up to the normal operating time, T and will be subjected to periodic control (PTC) at regular time intervals, respectively $t = k\Delta t, (k = (1, N))$. It is also considered the existence of a threshold, B, under which the vehicle is in a malfunctioning state, in need of corrective maintenance. Availability is considered [6], as:

$$A = \frac{MTBF}{MTBF+MTR} \qquad (1)$$

where *MTBF* is a synthetic indicator that appreciates the overall level of device reliability and *MTR* is the average repair time.
In the field of , the Weibull distribution function is used [7]. Maintenance decisions - true decisions (TD) or false decisions (FD) are taken from the professional experience of the decision maker, depending on the state of the vehicle, which can be found in the following situations:
S1: $A\ (k\Delta t)\ -B = x_k \leq 0$, the correct decision-the vehicle enters into maintenance operations (TD)
S2: $A\ (k\Delta t)\ -B = x_k \geq 0$ and $A\ ((k + 1)\ \Delta t)\ -B = x_{k+1} \leq 0$, the decision under uncertain conditions, the vehicle enters into maintenance operations (TD)
S3: $A\ (k\Delta t)\ -B = x_k \geq 0$ and $A\ ((k + 1)\ \Delta t)\ -B = x_{k+1} \leq 0$, decision in uncertain conditions, the vehicle awaits the next PTC (FD)
S4: $A\ (k\Delta t)\ -B = x_k \geq 0$ and $A\ ((k + 1)\ \Delta t)\ -B = x_{k+1} \geq 0$, the decision under uncertain conditions, the vehicle enters into maintenance operations (FD)
S5: $A\ (k\Delta t)\ -B = x_k \geq 0$ and $A\ ((k + 1)\ \Delta t)\ -B = x_{k+1} \geq 0$, decision in uncertain conditions, the vehicle awaits the next PTC (TD)

3. PROBABILITIES OF DECISIONS

Event X, associated with PCT, is considered to be a discrete random variable (linear with availability, as defined above), that can take a finite number of x_k values.
If $x_k \leq 0$, the probability of a correct decision (TD) is $p_1 = 1$. Let us define the conditional probabilities of the correct and incorrect decisions taken when performing the PTC on the vehicle, assuming that its failure occurs at the time τ, $\tau \in (k\Delta t,\ (k + 1)\ \Delta t)$. If $x_k \geq 0$ and $x_{k+1} \leq 0$, the probability of a TD is p_2 and the probability of a wrong decision (FD) is $q_2 = 1-p_2$; if $x_k \geq 0$ and $x_{k+1} \geq 0$ the probability of a TD is p_3 and also the probability of FD is $q_3 = 1-p_3$. The probability of a correct decision becomes:

$$P_{TD} = \frac{n_1 \cdot p_1 + n_2 \cdot p_2 + n_3 \cdot (1-p_3)}{n_1 + n_2 + n_3} \qquad (2)$$

The probability of a wrong decision becomes:

$$P_{FD} = \frac{n_2 \cdot (1-p_2) + n_3 \cdot p_3}{n_1 + n_2 + n_3} \qquad (3)$$

where: $n_1 + n_2 + n_3 = N$; $p_2 + p_3 = 1$ and $PTD + PFD = 1$
The probability of right or wrong decisions depends to a large extent on the diagnostic capabilities of the control devices and the competence of the PCT workers.To try modeling predictive maintenance for periodically controlled vehicles, the decisions that lead to the introduction of vehicles for repairs are useful.
The probability of decisions to introduce vehicles for repairs becomes:

$$P_R = \frac{n_1 + n_2 \cdot p_2 + n_3 \cdot (1-p_3)}{n_1 + n_2 + n_3} = \frac{n_1 + (n_2 + n_3) \cdot p_2}{N} \qquad (4)$$

In this case, the likelihood of the vehicle still being used becomes:

$$P_D = \frac{n_2 \cdot (1-p_2) + n_3 \cdot p_3}{n_1 + n_2 + n_3} \qquad (5)$$

4. ESTIMATE OPTIMAL NUMBER OF PREDICTIVE CHECKS

The problem of determining the optimal number of PTC, denoted by *N*, depends on selected optimization criteria. To highlight the PTC, in connection with the unavailability time, it consists of
- the time when the vehicle was immobilized as a defect, T_d
- the average time the vehicle was repaired, t_{rc}
- average time of planned revisions, t_{pm}
- the time when the vehicle was checked periodically, tptc

When the observation is made at time intervals, given by the periodicity of the PTC, (1) it takes the form:

$$A = \frac{T - \{T_d + [n_1 + (n_2+n_3) \cdot p_2] \cdot t_{rc} + r \cdot t_{pm} + N \cdot t_{ptc}\ \})}{T} \qquad (6)$$

PTC optimization is reduced to function minimization:

$$I(N) = T_d + [n_1 + (n_2 + n_3) \cdot p_2] \cdot t_{rc} + r \cdot t_{pm} + N \cdot t_{ptc} \qquad (7)$$

For this, we will analyze each term separately.
The time when the vehicle was immobilized as a defect, T_d, may be due to the lack of spare parts (insufficient budget or inadequate planning) or the lack of repair personnel. This is not influenced by the periodicity of the PTC.
The number of planned revisions, *r*, and the time allocated to them, t_{pm} , is stipulated by the manufacturer in the technical manual of the vehicle. The period of the periodic checks, t_{ptc} , is a time that cannot be modified because it is in accordance with the verification procedure, being normed on the type and amplitude of verification operations. In expression (7), t_{rc} , represents the average repair time, whose usual acronym is MTR. Taking into account the above, (7) can be reduced to:

$$I(N) = K + [n_1 + (n_2 + n_3) \cdot p_2] \cdot t_{rc} + N \cdot t_{ptc} \qquad (8)$$

Deriving by *N*, we obtain:

$$\frac{\partial I}{\partial N} = \frac{\partial [n_1 + (n_2+n_3) \cdot p_2]}{\partial N}\, t_{rc} + t_{ptc} \qquad (9)$$

If the vehicle failure occurs at time τ, $\tau \in (k\Delta t,\ (k+1)\ \Delta t]$, then p_2 , according to the Weibull distribution function, the probability p_2 becomes the failure rate (intensity):

$$p_2 = Z(\tau) = \beta \cdot \lambda \cdot \tau^{\beta-1} \qquad (10)$$

and

$$n_1 = \frac{N}{k} \cdot Z(\tau) \qquad (11)$$

where τ is a time parameter, β represents a shape parameter which, by its values, changes the allure of the variation curves of the reliability indicators, being able to model the behavior of the vehicles in different periods of the life of the devices (constant on intervals) and λ scale parameter which shows the extent of time distribution of Weibull function (constant).
Equating (10) with *0*, we obtain:

$$\frac{\beta \cdot \lambda \cdot \tau^{\beta-1}}{k} + \left(1 - \frac{\beta \cdot \lambda \cdot \tau^{\beta-1}}{k}\right) \cdot\ \beta \cdot \lambda \cdot \tau^{\beta-1} \cdot t_{rc} + t_{ptc} = 0 \qquad (12)$$

leading to:

$$\beta \cdot \lambda \cdot \tau^{\beta-1} = \frac{-\left(\frac{1}{k} + t_{rc}\right) + \sqrt{\left(\frac{1}{k} + t_{rc}\right)^2 + 4 \cdot \frac{t_{rc}}{k} \cdot t_{ptc}}}{2 \cdot \frac{t_{rc}}{k}} \qquad (13)$$

or

$$k = \frac{t_{rc} \cdot (\beta \cdot \lambda \cdot \tau^{\beta-1} \cdot t_{rc} - t_{ptc})}{\beta \cdot \lambda \cdot \tau^{\beta-1} \cdot t_{rc} \cdot (\beta \cdot \lambda \cdot \tau^{\beta-1} \cdot t_{rc} + 1)} \qquad (14)$$

where *k* is the optimal number of PTC, at operating time τ. Therefore, establishing a regular PTC interval for the entire life of the vehicle, a strategy currently used, is inefficient in terms of its availability.

5. STATISTICAL APPROACH IN MODEL CALIBRATION

Statistical data were obtained on a group of 50 cars of the same manufacturer, the same models, with the years of manufacturing and commissioning 2005 (25 cars) and the rest in 2007. On cars manufactured in 2005, 3 were put out of circulation. after 13 years, 10 after 14 years and those manufactured in 2007 were withdrawn 2 after 12 years. The purchase was considered to have a standard operating life of 5 years, but their average monthly run is 2000 km. The average lifespan is currently estimated at 13 years and an average turnover of 312000 km.
The statistical records took into account the life stages of the vehicles. The following data were obtained:
- periodicity RT1, considered Monthly Technical Control, with the acronym PTC, monthly
- RT2 periodicity, considered Annual Technical Review, annually or at 10,000 km traveled for the 2005 lot and 15000 km for the 2007 lot. RT2 was considered to coincide with RT1
- the average time of RT1 is 2 hours, $t_{ptc} = 2$ *hours*
- the average time of RT2 is 6 hours, $t_{pm} = 6$ *hours*
- the average monthly operating time - 160 hours
- the average time during which the vehicle was immobilized, without being in repair, $T_d = 3$ *days / year*
- the average time the vehicle repaired, $t_{rc} = 3$ *days*.

In the stage of early failures, T1, the following average values were recorded:
$N = 6; n_1 = 2; p_1 = 1; n_2 = 3; p_2 = 0.7; n_3 = 3; p_3 = 0.3$
In the next 4.5 years, respectively at the end of the first normalized life, T2:
$N = 54; n_1 = 2; p_1 = 1; n_2 = 32; p_2 = 0.8; n_3 = 20; p_3 = 0.2$
For the second normal lifespan, T3, the averages were obtained:
$N = 60; n_1 = 4; p_1 = 1; n_2 = 28; p_2 = 0.75; n_3 = 28; p_3 = 0.25$
In the aging phase, T4, the following average values were recorded:
$N = 36; n_1 = 15; p_1 = 1; n_2 = 18; p_2 = 0.66; n_3 = 3; p_3 = 0.34$
In this case the values of β and λ obtained are:
$\beta_1 = 0.75; \beta_2 = 0.98; \beta_3 = 1.04; \beta_4 = 1.79$
$\lambda_1 = 0.13; \lambda_2 = 0.143; \lambda_3 = 0.142; \lambda_4 = 0.072$
To be mentioned for $\beta < 1$, we are in period of early failures; for $\beta = 1$, we are in the life stage; and for $\beta > 1$, we are in the stage of aging.

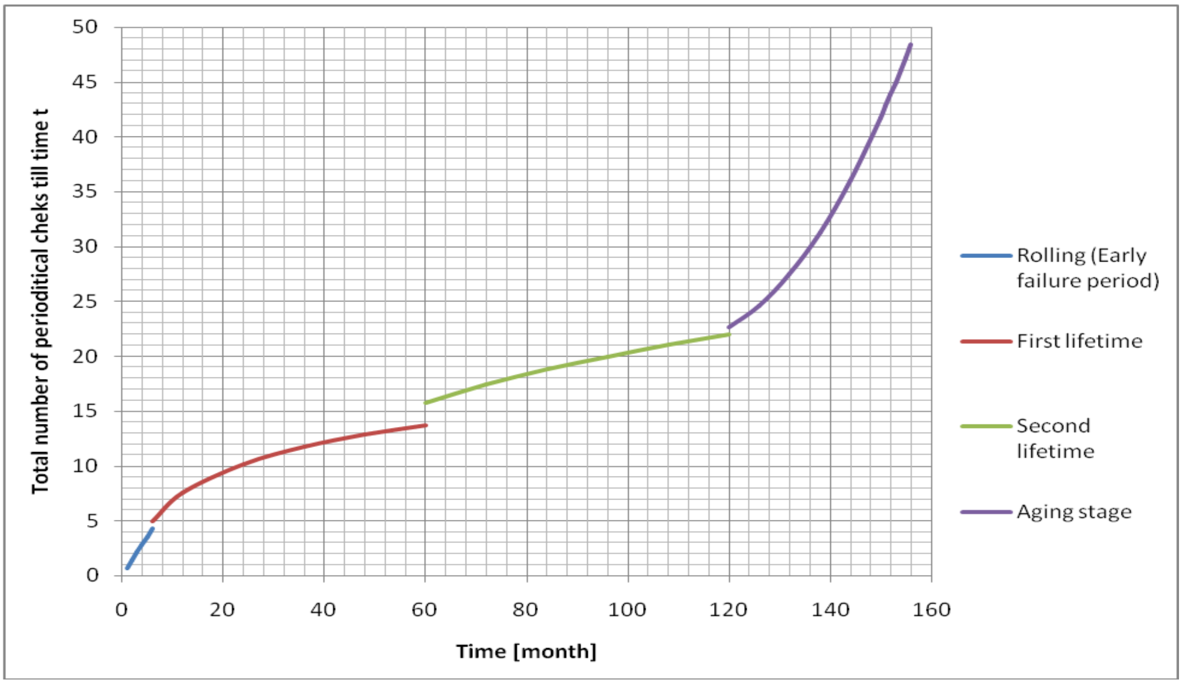

Figure 1: Variation of the optimal total number of PTC at time t

The variation of the optimal total number of PTC at time t is illustrated in fig. 1. From the data collected and from the graph above, it is possible to mediate the periodicity of the PTC, respectively of their number depending on life period when is located. During rolling, a periodicity of less than 1.5 months is covered. Under normal operation, a seasonal check , at 6 month, would be sufficient, but in aging stage, a monthly technical check is recommended.

6. CONCLUSION

In this paper, we have proposed a new approach for determining the optimal periodicity of the PTC depending on the availability of the vehicle. A credible average of its periodicity is obtained when each stage of the proper vehicle operation is analyzed separately. The mathematical expressions were derived to optimize the average time spent by the vehicle in different states of its operation and maintenance. Expressing time in equivalent kilometers traveled is more useful in the case of intensive motor vehicle operation. This will take into account the regime of urban, extra-urban or mixed exploitation.

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