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OPTYMALIZACJA PRZERW KONSERWACYJNYCH

OPTIMIZATION OF PREVENTIVE MAINTENANCE INTERVALS

W niniejszej pracy zaproponowano metodologię optymalizacji planowych prac konserwacyjnych opartą na wykorzystaniu danych pozyskanych z systemu informacji eksploatacyjnej - dopasowaniu struktury bazy danych, sposobu jej gromadzenia i przetwarzania. Algorytm przetwarzania danych opiera się na zastosowaniu teorii wymiany i jej modyfikacji dla danego problemu. Centralną zasadą algorytmu jest minimalizacja kosztów utrzymania i użytkowania sprzętu produkcyjnego. Algorytm ten może być używany jako oddzielne narzędzie lub może być integrowany z systemem komputerowego zarządzania eksploatacją i utrzymaniem ruchu jako moduł uzupełniający. Tym samym pozwala on na optymalizację przerw poświęconych różnego zakresu planowym pracom konserwacyjnym większości sprzętu produkcyjnego w przedsiębiorstwie. Przykład praktycznego zastosowania takiego algorytmu przedstawiono w końcowej części pracy.

Słowa kluczowe: *eksploatacja, optymalizacja, przerwa konserwacyjna.*

In the paper, the methodology of optimization of planned preventive maintenance is proposed, which is based on the utilization of data obtained from a maintenance information system – adjusting the database structure, collection and processing of data. The data processing algorithm is based on the application of theory of replacement and its modification for the given problem. The core principle of the algorithm is the minimization of costs of maintenance and operation of production equipment. The algorithm can be either used as a separate tool or integrated into the computer maintenance management system as a complementary module. Therefore it enables to optimize the intervals of various levels of planned preventive maintenance of most of the production equipment in a company. A practical example of application of such algorithm is presented in the end of the paper.

Keywords: *maintenance, optimisation, preventive maintenance interval.*

1. Introduction

In every firm a number of production equipment items can be found, for which a standard maintenance system based on a machines' operating time is applied. However, the used maintenance intervals (periods) are often determined just basing on a qualified estimate of the manufacturer or maintenance manager. This leads to an increase of machinery operating costs – too short maintenance period results in an increase of maintenance costs, too long maintenance intervals lead to increase of costs due to poor technical condition of the production equipment [1]. The efforts to apply sophisticated methods of preventive maintenance optimization are hindered by a number of problems. Some maintenance management information systems use for instance Markov processes, though these can be applied only for large populations of very similar machines. Known stochastic models are based on the knowledge of failure probability in various stages of the object's life – however, this implies the use of statistical methods and monitoring of a set of other metrics of machine's performance (reliability characteristics). The needed stochastic model of object renewal (replacement) then could be described and developed afterwards when the analysis of machine's operation history is done. Furthermore, the known models of optimization of preventive maintenance mostly consider only two-state elements. Some of these models could be successfully applied, but only in specific cases (electronic components, pipeline systems etc.). Generalizations or utilization of these methods for other applications, in this case for a population of heterogeneous machines of a manufacturing plant, would be very difficult or impossible [6].

One of the other ways of determination of optimal standard maintenance period is the application of renewal (replacement) theory in the field of maintenance using maintenance data recorded in a maintenance information system. The practical output of such application for a maintenance manager is the possibility of justified correction of preventive maintenance periods, basing on the results of algorithmic testing of data recorded in the maintenance information system [5].

2. Fundamentals of algorithm for optimization of preventive maintenance period

General criterial function of replacement seeks the minimum of average unit costs of replacement and operation – the minimum of the function marks the optimum time for replacement (see Equation 1) [2].

$$u(t) = \frac{N_O + N_P(t_S)}{t_S} \rightarrow min \tag{1}$$

Where: N_O - costs of renewal (CZK), $N_P(t_s)$ - cost of operation (CZK), t_s - mean time of operation (w), $u(t)$ - average unit costs of replacement and operation (CZK.w^{-1}).

For calculation of optimum period of standard maintenance, the function can be modified as follows:

$$u(t) = \frac{N_Ú + N_P(t)}{t} \rightarrow min \tag{2}$$

Where: $N_Ú$ - costs of preventive maintenance (CZK), $N_P(t)$ -

costs of operation (CZK), t - time of operation since the last standard preventive maintenance (w), $u(t)$ - average unit costs of preventive maintenance and operation ($CZK.w^{-1}$).

It is obvious, that the costs of maintenance itself act in the way of prolonging the standard preventive maintenance period. Conversely, the costs of operation, which rise due to worsening technical condition when extending the maintenance period, make the preventive maintenance period as short as possible. The sum curve $u(t)$ must have a local minimum, which needs to be found in order to determine the optimum period of preventive maintenance.

The costs of preventive maintenance $N_Ú$ for specific types of maintenance are known. The cost items usually include costs of materials, wages including overheads and costs of downtimes, if caused by maintenance. These costs are recorded for each maintenance action in the maintenance information system [7].

The monitored items of costs need to include all the costs, caused by the deteriorated technical condition of the machine. In most cases these include the following cost items:

a) costs of repairs (after failure maintenance),
b) losses due to downtimes of production equipment,
c) costs of nonconforming products (scraps) produced due to bad technical condition,
d) costs of overconsumption of energies due to inefficiency caused by bad technical condition,
e) losses due to worse performance of a machine caused by its bad technical condition.

Though not every maintenance information system allows monitoring of all of the above described items of costs, those most important for the optimization of maintenance period (a, b, often also c) can be recorded in every maintenance information system and therefore can be utilized in the optimization algorithm [3].

3. Algorithm of optimization of preventive maintenance period

The recorded maintenance data of a selected object (production equipment) is processed by the algorithm in the following way:

1. The following information is entered: ID code of the selected maintained object, type of maintenance and the number of historical periods to be processed (statistically, basing on hundreds of processed types of maintenance, the sufficient number of periods is k=6 to 8).
2. For the chosen maintained object (production equipment) all the after-failure maintenance actions performed during the chosen history (ie. after-failure maintenance actions done between the standard preventive maintenance, for k periods).
3. In each period between preventive maintenance, the costs of operation and cumulative costs of operation are calculated. The costs of operation are calculated as follows:

$$N_P(t) = t_p.a_1 + t_{pú}.a_2 + N_{af}(+p_{nv}.a_3 + \Delta E) \qquad (3)$$

Where: $N_p(t)$ - costs of operation for gradually deteriorating technical condition of a machine (CZK), t_p - labour consumption of maintenance after failure (hrs), a_1 - hourly wage costs of maintenance personnel including overheads ($CZK.hr^{-1}$), $t_{pú}$ - duration of downtime due to after-failure maintenance (hrs), a_2 - hourly downtime costs of the machine (CZK), N_{af} - costs for after-failure maintenance (repair) (CZK), p_{nv} - number of nonconforming products (scrap) manufactured between maintenance actions (pcs), a_3 - loss (costs) of producing a nonconforming product, scrap costs (CZK), ΔE - costs of overconsumption of energy in the k-th period (CZK).

The last two terms of the equation are intentionally left in parentheses, because these are only rarely recorded in a suitable form and therefore it is not feasible to use them in most of manufacturing plants. Nevertheless, the dominant item of calculated costs is the costs of downtimes, which are typically by far higher than all the remaining items (for instance one hour of manufacturing line downtime in automotive industry equals to several millions CZK). Therefore the determination of optimal preventive maintenance period is not significantly affected by the two last terms in the equation and these can be ignored.

4. The average unit costs of maintenance and operations are calculated as the cumulative costs over the time of operation.
5. Finally, both the partial components of the total average unit costs are summed and the resulting values are fitted with a 2nd degree polynomial function. The coefficient of determination R^2 is calculated. The sum curve is then analysed to find the minimum and appropriate optimal time of operation between preventive maintenance actions (optimal preventive maintenance period). In case the R^2 values for more than a half of samples do not amount to at least 0.5, a warning message is shown indicating that the optimal period can not be determined with sufficient reliability and the algorithm is terminated.
6. The results of optimal periods of preventive maintenance for all the analysed historical periods between preventive maintenance actions are then processed as a weighted average of the obtained optimal maintenance periods and coefficients of determination, while only periods for which $R^2 \geq 0.5$ are considered:

$$I_{Úopt} = \frac{\sum_{i=1}^{k} t_{opti}.R^2_i}{\sum_{i=1}^{k} .R^2_i} \qquad (4)$$

The resulting optimal periods for selected types of preventive maintenance and production equipment are then visualized to the maintenance manager in a table. The table summarizes for each type of maintenance and production equipment the present maintenance period and the calculated optimal maintenance period. The three cases (Fig. 1) can then occur: the present main-

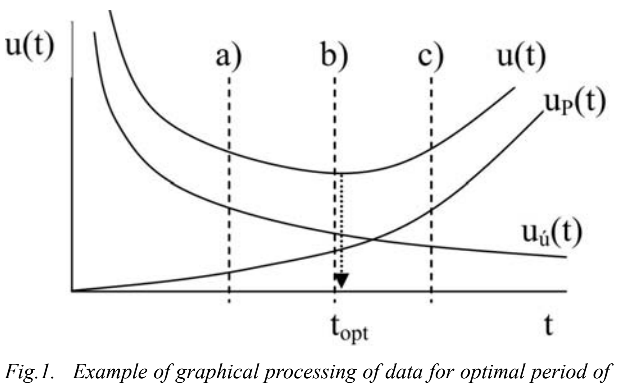

Fig.1. Example of graphical processing of data for optimal period of one type of preventive maintenance

tenance period is too short and it is possible to make it longer (case a); the present period is close to the calculated optimum and therefore confirmed as correct (case b); the present period is too long and needs to be shortened (case c). For each type of maintenance and machine the codes of three most frequent failures are shown – maintenance manager then can adjust both the duration of preventive maintenance periods and also the scope of preventive maintenance [4].

4. Example of application of the algorithm for optimization of preventive maintenance period

The described algorithm was tested for real data from a maintenance information system in a manufacturer of small machinery. In the phase of testing, MS Excel spreadsheet was used for processing of the data. The data were imported from the database of performed maintenance actions and then processed according to the previously described procedure. As an example, the optimization of quarterly period of standard preventive maintenance of Suhner drilling machine was selected. The original period of maintenance was 90 days. The costs of this preventive maintenance amounted to 15 450 CZK, wage costs of maintenance technician including overheads were 330 CZK /hour, one hour of downtime was appreciated to 4 500 CZK. The maintenance data for the selected machine have been recorded since 2002, data from the 8 previous consecutive 90-day periods of preventive maintenance for the calculation of optimal maintenance period. For each analysed period the minimum of total costs was found and the optimal period of preventive maintenance with the coefficient of determination of the obtained sum function *u(t)* were determined. The example of graphical processing of one of the analysed periods is presented in Fig. 2.

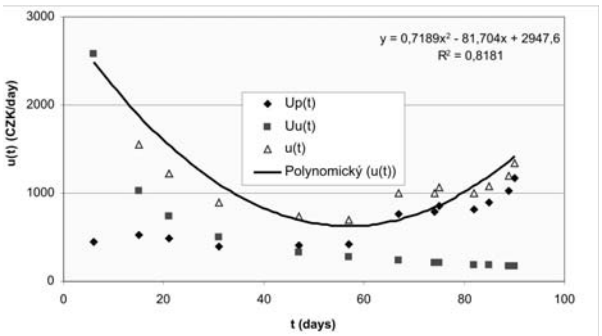

Fig. 2 Example of graphical processing of data from one of the analysed maintenance periods

After the data from all eight analysed maintenance periods have been processed, the optimal period of the given type of preventive standard maintenance was calculated as weighted average of all the t_{opt}, for which the value of $R^2 \geq 0.5$ (see Tab. 1).

This means that the original period of preventive standard maintenance 90 days was too long and should be shortened to just 53 days. The maintenance manager can also look at the table of failure codes for the selected maintained object, either complete, or only the three most frequent (see Tab. 2), and for the possible correction of the scope of preventive maintenance also at the notes of maintenance technicians regarding the performed repairs (example of these notes is shown at Fig. 3).

Tab.1. Final processing of the partial values

Period	t_{opt}	R^2	$t_{opt}.R^2$
1	57	0,82	46,74
2	53	0,89	47,17
3	62	0,85	52,7
4	46	0,5	23
5	45	0,83	37,35
6	54	0,68	36,72
7	46	0,77	35,42
8	56	0,71	39,76
	Sum:	6,05	
Optimal maintenance period:			52,70 days

Tab. 2. List of most frequent failures for the selected maintained object

code of failure	number of failures
E00	47
E50	64
M00	56
M30	32

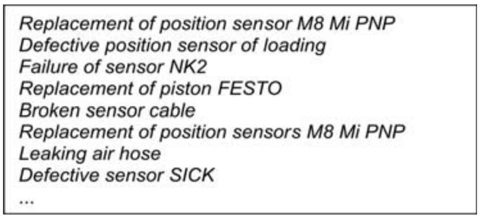
Replacement of position sensor M8 Mi PNP
Defective position sensor of loading
Failure of sensor NK2
Replacement of piston FESTO
Broken sensor cable
Replacement of position sensors M8 Mi PNP
Leaking air hose
Defective sensor SICK
...

Fig. 3. Example of notes of maintenance technicians (translated)

For this real-data example, the following corrections were accepted:

- the period of preventive maintenance was shortened from 90 days down to 53 days,
- the maintenance scope was extended with other operations according to the occurrence of most frequent failures and information from the notes of maintenance technicians (regular checks of sensor cables and preventive replacements of inexpensive sensors of position).

In the manufacturing plant this algorithm was applied for 98 types of preventive maintenance for various machines. For 34 of them the original maintenance period was significantly out of the calculated optimum and was therefore corrected. The monitoring (though still only short-term) of changes of costs for machines with corrected maintenance periods (and mostly also scope of preventive maintenance) shown that 6 months after the corrections were imposed the costs of operation (influenced especially by the reduction of downtimes) of these machines dropped in average by 16 %. A more profound analysis and evaluation will be carried out one year after the corrections of standard preventive maintenance.

5. Conclusion

In the paper the methodology for optimization of planned preventive maintenance is proposed. The methodology is based on the data from the maintenance information system – adjustment of the databases structure, data collection, selection/filtering of the data, testing and final processing. The algorithm of data processing is based on renewal (replacement) theory and its modification for the solution of the given problem. The core of the algorithm is the minimization of costs of maintenance and operation of production equipment. The algorithm can be used as a supporting tool for a maintenance information system or developed and integrated into the maintenance information system as a supporting module. Therefore the algorithm enables easy optimization of planned preventive maintenance periods for most of the production equipment in a production plant. The first results of its application for real data from a manufacturing plant show that the proposed method is suitable and improves efficiency of maintenance system.

6. References

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