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DESIGN OF CONDITION-BASED DECISION SUPPORT SYSTEM FOR PREVENTIVE MAINTENANCE

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Presented paper deals with the topic of preventive maintenance. A decision support system was designed, incorporating historical as well as forecast information to calculate the time remaining to preventive maintenance. The designed system optimizes maintenance costs without any further investment and running costs. An algorithm of the designed system is introduced and a case study of its implementation is described in the paper.

Keywords: preventive maintenance; bill of material; equipment list; working instructions; material forecast

According to Ahmad and Kamaruddin (2012), maintenance strategies can be broadly classified into Corrective Maintenance (CM) and Preventive Maintenance (PM) strategies. Authors further report that the PM concept involves the performance of maintenance activities prior to the failure of equipment. One of the main objectives of PM is to reduce the failure rate or failure frequency of the equipment. This strategy contributes to minimizing failure costs and machine downtime (production loss), and increasing of product quality. The PM strategies can be based on Original Equipment Manufacturer (OEM) recommendation, which is however, not applicable in practical conditions. Other strategies are based on operational research and comprise strategies such as Time-based (TBM) and Condition-based Maintenance (CBM). Time-based maintenance, also known as periodic-based maintenance, is a traditional maintenance technique. In TBM, maintenance decisions (e.g. preventive repair times/intervals) are determined in accordance with the failure time analyses. In other words, the ageing (expected lifetime), T, of some equipment is estimated according to failure time data or user-based data. TBM assumes that the failure behaviour (characteristic) of the equipment is predictable.

Condition-based maintenance, also known as predictive maintenance is the most modern and popular maintenance technique. CBM was introduced in 1975 in order to maximise the efficiency of PM decision making. CBM is a maintenance programme that recommends maintenance actions (decisions) based on the information collected via condition monitoring process. CBM is well discussed topic (Yam et al., 2001; Grall et al., 2002; Marseguerra et al., 2002).

It is a proactive process requiring the development of a predictive model that can trigger the alarm for corresponding maintenance (Peng et al., 2010). In CBM, the lifetime (age) of the equipment is monitored via its operating condition, which can be measured according to various monitoring parameters, such as vibration, temperature, lubricating oil, contaminants, and noise levels. The motivation for CBM use is that 99% of equipment failure occurrences are preceded by certain signs, conditions, or indications. Therefore, CBM is needed for better equipment health management, lower life cycle costs, catastrophic failure avoidance, etc. (Ahmad and Kamaruddin, 2012). However, the introduction of CBM without managerial support at all levels, appropriate data and analysis, disciplined and knowledgeable maintenance staff is unlikely to achieve desired results (Ellis, 2008).

According to the ISO TS standard, the producer has to use the preventive maintenance based on time intervals, as well as 'prediction' maintenance to ensure the continuous improvement.

The downside of this method is the fact that data must be imported manually into the available software.

Input data sources for maintenance software used by current systems are as follows:

1. cycle counters with relatively precise data records, however, their pricey purchasing costs as well as the fact that it would be necessary to buy a counter for each tool and family tool are great disadvantages. This brings forth the problem with compatibility of software by various tool producers and the main company software;
2. the most common system is cycle records dependent on operator's responsibility. Here, the human influence is evident and due to large amount of data, these records are not available on time.

The process of continuous quality improvement in organizations requires the active use of management tools by organization managers in order to improve the quality of production (Prístavka et al., 2016).

Therefore, to overcome the above-mentioned problems, the aim of this paper was to design a decision support system (DSS) suitable for small and medium sized companies and to evaluate it in a case study of the company Hessel Slovakia

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s.r.o. The system should enable the usage of automatic software-based information and should transfer the data into maintenance software just in time (JIT).

Methods

The aim of the paper was to design a system which would determine the time when the next PM steps must be taken. Resulting from literature review and practical applications, the design of the DSS for PM was based on the following assumptions:

- PM frequency pre-described by OEM is used;
- both historical and forecast data are used;
- the system has to be independent of operator – with no need to use manually recorded data (due to the fact that no system based on manual data records is efficient to such an extent that maintenances would be performed sufficiently frequently and the equipment would be in its initial level of order);
- the relationship among existing company parameters and process parameters generally available in most cases should be used – so that no additional agenda is created.

Designed system should be created in available interface such as MS Excel and MS Access.

Proposed system will be tested in the company Hessel Slovakia, s.r.o. specialized in cable harnesses production. A family of tools was selected, to which the concept of time-based maintenance was applied. The condition-based maintenance will be simulated and results will be used for comparison. The efficiency of these two types of strategies was compared in the following features:

– time necessary for conducting the maintenance;
– other features.

Results and discussion

Design of decision support system

The decision support system was designed using the following company information and parameters. The historical data came from existing company reports/documents. All information sources were standard process documents. Firstly, the bill of material of finished goods (BOM). According to final inspection records at production line, BOM has always declared what number of raw materials was used – processed. On top of this parameter, additional information coming from scrap records was used because it can significantly influence this number. Working instructions (WI) were used as a second input. In general, this list describes the number of production steps and detailed manual of it for operator. Standard time of operation, which is additional information in WI, was applied to our calculations. This number may appear as a cycle, showing mostly the frequency necessary for achieving a standard time per operation. This parameter is reflected by number of pieces produced per minute, hour, shift. The second option is to describe the operation standard time by time itself. In this case, equipment with versatile use pending on different setups for different products is usually defined by total time in run. The so called equipment list (EL) is used as a last source of historical data. I might be, but is not necessarily part of WI. The EL comprises information on how each operation should be performed at its assigned working place, using assigned working equipment, the order of use of each individual piece of equipment, processing of defined number of materials (based on BOM).

Proposed system uses the relationships among all the above-mentioned parameters/information. As it was described above, predefinition of production by EL and WI ensures the process flow. When assessing the equipment and other tools for PM, selected production steps and related information are subtracted from these documents. Each operation takes different time, and different number of cycles are needed to kick off the final product at the end of the line. It is necessary to emphasize that even though the parallel production steps are used in order to increase the final efficiency of the line, the real usage time of the single tool does not decrease. According to this philosophy, the share of preventive cycle time (given by OEM) consumed per one finished product or finished good can be exactly calculated. All produced part records, coming from final outgoing inspection, were taken into consideration in obtaining a result, comprising the number of processed raw materials quantified through BOM. Moreover, to get the real numbers, the amount of raw material is extended by scrap reports. Preventive frequency should not be based merely on history. Depending on various factors, production rates can vary at any time. Therefore, the future is as important as history in this case. The novelty of our system is based on the fact that not only historical data of all consumed materials are used but also forecast information is processed as well. Here, a material request planning (MRP) calculator is used. MRP forecasts the future as long as customer planning covers its demands. Material usage (consumption) applied as a cumulative parameter and MRP applied as a variable forecast parameter allow us to determine the material frequency at the production line very precisely.

When confronting materials and their usage with the EL, time, respectively cycles consumed per each tool or equipment are calculated. Equation (1) describes the above-mentioned system.

$$TTPM = \frac{n\big(F - \big(ICC - (PM_R \times PM_F)\big)\big)}{\sum_{i=0}^{n} MRP_i} \quad \text{PM} \tag{1}$$

$$ICC = \sum_{1}^{n} M_c \times EL_t \tag{2}$$

where:

TTPM – time to preventive maintenance
ICC – informative cycle counter
M_c – cumulative material consumption per week
EL_t – equipment list defined time, or cycle
MRP – material request planning – average material forecast per week
PM_R – records of preventive maintenance done per each operation of PM needed

PM_f – preventive maintenance frequency – frequency of either time, or cycles prescribed by equipment producer and/or an additional organizational setups

Case study

To test the designed system, one particular operation step using one tool family was selected. Moreover, selected project itself is specific with versatile project portfolio with high running products, daily JIT deliveries, as well as products used as aftermarket service parts with very low demands. This represents different loads for the tools, a fact we will confront on time-based and condition-based preventive maintenance programmes. Tool family comprises 85 tools that are used for processing of 85 different raw materials at the same stage of production process. For understanding of usage reference equation, this tool family is characteristic by cycle counting – this means that one cycle refers to one material unit.

As it was mentioned above, we started with assigning of all 85 tools to raw material which are processed by means of them. To do this, the equipment list or other available company documents such as a control plan were used. Table 1 shows an example of EL:

We expected that we will obtain the information about the number of processed materials from final inspection records of finished goods at the end of line tests. To be able to transfer and evaluate such data, the BOM of each product is needed to be able to multiply the structure of particular materials at the final product with the time or cycles used (Table 2).

Other input data such as material consumption, MRP forecasted material volumes came from company databases. The information on service interval or several intervals given by tool producer is the last input necessary for defining the final parameter – time – for preventive maintenance (TTPM).

Designed algorithm was applied to case study data. Tool family used in the example comprises three service intervals

Table 1 Example of equipment list

Project	Tool family	Tool number	Assigned raw material overworked	Cycle time in min	Cycle count in pc
Automotive	Press	335-1597	41221597	0.00	1
Automotive	Press	333-1597	41221597	0.00	1
Automotive	Press	334-1597	41221597	0.00	1
Automotive	Press	130-0497	41220497	0.00	1
Automotive	Press	336-0497	41220497	0.00	1
Automotive	Press	274-1600	41221600	0.00	1
Automotive	Press	341-1648	41221648	0.00	1
Automotive	Press	342-1648	41221648	0.00	1
Automotive	Press	337-9088	41219088	0.00	1

Table 2 Example of the bill of materials

Project	PN	Material number	Structure
Automotive	16-B-185-1692	xxxx	1
Automotive	16-B-185-1692	41221597	6
Automotive	16-B-185-1692	xxxx	1
Automotive	16-B-185-1692	xxxx	1
Automotive	16-B-185-1692	41220497	12
Automotive	16-B-185-1692	xxxx	1
Automotive	16-B-185-1692	xxxx	1
Automotive	16-B-185-1692	xxxx	1
Automotive	16-B-185-1692	41219088	21

Table 3 Examples of DSS output – calculation of time to preventive maintenance (TTPM)

Tool number	Tool family	Cycles/Timed control			Cumulative	Dispo	Cycles control			TTPM			
		A	B	C	cycles/time in hrs	cycles/time in hrs	A	B	C		A	B	C
335-1597	press	150,000	500,000	1,000,000	4,370,520	187,000	30	9	4	weeks	1.5	3.4	3.4
335-1597	press	150,000	500,000	1,000,000	5,827,360	236,000	39	12	6	days	-2.3	2.9	5.0
341-1648	press	150,000	500,000	1,000,000	1,456,840	109,000	10	3	1	weeks	1.8	5.0	5.0

Table 4 Comparison of time-based controls and condition-based controls using the number of checks

Toll number	Annual number of cycles	Cycle control 'A'	Number of condition based controls	Number of time based controls if weekly
341-1648	5,232,000	150,000	35	48
326-1577	1,032,539	150,000	7	48
50-0664	504,851	150,000	3	48
8-0888	210,152	150,000	1	48
334-1597	8,778,667	125,000	70	48
342-1648	3,545,600	125,000	28	48
			145	**288**

with different tasks; these intervals are called intervals 'A, B, C' by the software. Thanks to this simple navigation, it is easy to find a ToDo list in the maintenance plan for each tool. The case study of possible implementation is shown in Table 3.

Let us focus our attention on the example marked with yellow colour. Selected tool with number 341-1648 belongs to examined press tool family. As it was mentioned above, there should be carried out a different set of preventive maintenance of the presses at all three levels of use. Task 'A' is performed after 150,000 cycles, task 'B' after 500,000 cycles and task 'C' after 1×10^6 cycles. Using the information from Table 1, we already know that raw material assigned to this particular tool number is 41221648. In order to calculate the number of cycles and fill the data in column Cycles/Time, hrs (Table 3), the number of materials used in production up to present time is uploaded. This is valid for materials which were pressed and assembled to final products. In our example, almost $1 \times 5 \times 10^6$ presses were carried out. MRP provides additional information. It describes the expected use of press for the next period. In our case, production forecasts, together with the consistency of foreseen production numbers result to ca additional 100,000 cycles to be done each week. Once the records of preventive maintenance checks are stored (columns 'A, B and C' in our case), the conversion of all data leads to new time condition-based planning for each operation/check. The plan of preventive maintenance including its priorities is produced as often as data are downloaded and input data are updated.

In order to determine the advantages of the new supporting system, we decided to compare the time planned maintaining schedule with the condition-based maintenance system for all 85 selected tools. Results are shown in Table 4. It is evident that the application of designed system in our case study decreases the number of needed maintenance controls by 75%. The quantification of this difference might be done through the number of maintenance hours spent in the production process, or extra costs for over-maintenance. Moreover, this system provides the possibility to follow tasks per time priorities, which is not possible when using time-based management, as in spite of its literal meaning it does not allow any impartial priority sorting. Overall, the system provides simple tool for efficient system of maintenance, which is tailored for needs of small and medium sized companies.

Summary and conclusions

The aim of the paper was to design a decision support system for preventive maintenance suitable for small and medium sized companies and to apply it in a case study. Designed system is based on historical as well as forecast data. It uses existing documents/reports of the company and does not lay any additional load on staff. It is a simple tool which does not introduce investment costs and optimizes the costs of maintenance. When applying the system to the case study, the need of maintenance controls was decreased by 75% compared to time-based maintenance system.

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