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MAINTENANCE MANAGEMENT EFFICIENCY EVALUATION

The purposeful processing of long-term documented maintenance data can provide plenty of information not only about a machine's history, but also about its maintenance system. The main objective of data analysis is to continually improve the maintenance efficiency, which is closely related to improvements in dependability and overall productivity of the production equipment. This paper pinpoints the main problems of most widespread indicators of maintenance efficiency – OEE and other proposed alternative methods for maintenance efficiency assessment, with the aim of locating the weakest areas of the maintenance system.

Keywords: *maintenance system, data analysis, production equipment*

1. Introduction

The role of a firm's maintenance system in recent years has substantially changed to the benefit of the maintenance department, which was often comprehended as a burden, which drained funds from a firm's financial sources. Maintenance in going concerns today starts to be considered as one part of an integral process, where it is necessary to enforce similar quality management policies, in production and all other parts of the organizational management. One of the most important quality management policies is continual improvement, which has to be the permanent goal of each organization.

If something has to be improved, there should be a set of pre-determined objective criteria, which can be monitored to assess improvement. The determination of criteria in the case of maintenance systems is not as easy as, for example, the determination of the system labour index productivity: labourer, machinery, assembly line etc. In the case of maintenance it is very difficult to formulate productivity of labour, e.g. the number of failure eliminations per time unit, the number of fault isolations etc. It is wrong to use the common productivity labour index "amount of work per time unit", because service engineers may work at high intensity but impractically, uneconomically and ineffectively.

The Iceberg tip cost rule is used more in the case of maintenance than in production. Most maintenance costs are barely measurable or indeed immeasurable, that is why valuation of maintenance grade based only on the cost of maintenance is actually unapplicable. The benefits of any change to a maintenance system are noticeable only after a relatively long period of time. If a firm invests in preventive maintenance action, maintenance costs increase and positive influence will be noticeable only after several months. Conversely, if a firm significantly cuts down its maintenance funding, failure rates will only become apparent after several months.

2. The calculation of over all equipment effectiveness (OEE)

There are several criteria and processes used for the evaluation of maintenance effectiveness, none of them are suitable for every situation. The maintenance, according to its ČSN EN 13 306 definition (the combination of all technical, administrative and managerial activities during the life cost cycle of an entity, with the aim of maintaining its productivity or returning it to a productive state). Maintenance is very wide-ranging – that is why it is impractical to set only one index, which could involve levels of maintenance definitively and objectively quantified.

One of the most often used, as well as one of the most elaborate methods of calculating maintenance level is over-all equipment effectiveness OEE. This indicator evaluates the maintenance effectiveness primarily based on production downtimes, production quality and productive equipment performance. The benefit of this indicator is the synthesis of partial indicators of maintenance effectiveness and actual maintenance requirements (production volume). The method of calculating OEE is available in several publications, which is why the OEE formula is posted without any other explanation:

$$OEE = \frac{t_{PCS} - t_{ORG} - t_{OSOB}}{t_{PCS}} \cdot \frac{t_{PRC} - t_{PU} - t_{UP} - t_{PS} - t_{TP}}{t_{PRC}} \cdot \frac{W_{SK}}{W_{JM}} \cdot \frac{Q_H(t_{OPER}) - z_{CHYB} - z_{NAB}}{Q_H(t_{OPER})} \quad (1)$$

Tab. 1. Example of OEE calculation in month intervals

(notice: workshift = month)		January	February	March	April
t_{PCS}	Operating work shift time	720	672	720	712
t_{PRC}	Productive work shift time	720	672	720	712
t_{OPER}	Operative work shift time	591.9	551.4	594	590.3
t_{ORG}	Productive down-times	24	24	22	21.8
t_{OSOB}	Personal rest time	45	45	45	45
t_{PU+tUP}	Maintenance down-times (pl. or not pl.)	31.2	26.2	31.2	28.5
t_{PS}	Reshuffle down-times	18	16.2	18	17.5
t_{TP}	Down-time – technological failures	9.9	9.2	9.8	8.9
	SUM OF DOWN-TIMES	128.1	120.6	126	121.7
W_{sk}	Substantive performance of machinery	35.5	36	36.4	36.7
W_{jm}	Theoretical performance of machinery	41	41	41	41
$Q_{h(tOPER)}$	Gross production during shift time	21 012	19 850	21 622	21 664
$Q_{c(tOPER)}$	Net production during shift time	20 862	19 710	21 478	21 524
$Z_{\_CHYB}$	Number of non-conforming products from production	90	84	89	84
$Z_{\_NAB}$	Number of non-conforming products from start production	60	56	55	56
OEE	**over all equipment effectiveness**	**0.713485**	**0.722263**	**0.734286**	**0.743759**

Main problems of practical OEE use:

1. This index provides technical evaluation, but it does not subsume maintenance costs. If this method is used as the only indicator of maintenance effectiveness, then the apparent need for continual improvement could lead to excessive maintenance costs.
2. It does not involve other essential factors too, which have distinct influence on the level of maintenance, for example value stock of spare parts, value of material and immaterial asset of the company, age of production machineries etc.
3. The influence of OEE does not only extend to the quality maintenance system, there is also an influence on the quality of production processes (especially t_{ORG}, latently other items too), quality of spare parts logistics (part of downtimes because of maintenance), quality of the personnel operating of production machinery etc. Poor production control and planning wasted time due to absence of maintenance parts and ineffective use of machinery etc. This can also happen continual improvement of a maintenance system – will cause the OEE to fall.
4. Difficulty of OEE determination: Most maintenance managers do not have the appropriate software, with which to calculate OEE by automised algorithm. Calculations are achieved with MS Excel table (see above table 1), it is necessary to fill in by hand all the data in the table. Evaluation of maintenance effectiveness only has meaning for particular production machinery or assembly parts, which are numerous in a company in that case it is necessary to process the same amount of tables. Also the collection of data for OEE calculation generally is not automised which increases the difficulty of OEE determination.
5. The approach of upper management is sometimes problematic when the OEE calculation starts to stagnate. The maintenance division, by the implementation of effective actions and new maintenance methods, OEE was continually increased for a few years (for example from a starting value 0.6 to an actual value of 0.9). Thereby, it created highly effective maintenance system, but where other quality increase, will not be reflected in the OEE.
6. The problem with identification of all necessary data – as most important data is not recorded (or it is, but incorrectly) or data is not available to maintenance manager. These figures are not monitored by the information maintenance system.

It is necessary to consider OEE as an avowed principle and wide-spreaded index of maintenance level, which evaluates maintenance based on the main requirements of a quality maintenance system – maintenance is supposed to ensure high failure-free production machinery (OEE is characterized by down-times t_i), the highest performance (W_k) and quality of production (Z_{CHYB}, Z_{NAB}). However OEE has its minuses, it does not cover all maintenance aspects and for maintenance evaluation it should not be to be considered in isolation – it is an important index, but not the only one.

3. Other indicators of maintenance effectiveness

The evaluation of a maintenance system is primarily based on a comparison of the expected contribution, which we require from an effective system at the end state. The expectations of functional maintenance are: assurance quality, continual safe and ability to compete (low cost, ecological, etc.) production. From these factors are determined the basic partial requirements (expectation) expected of an effective maintenance system:

- increase in dependability of productive machinery (primarily stand-by, safety and operating life),
- noticeable change in the rate of maintenance after failure, compared to planned maintenance to the benefit of planned maintenance,
- a reduction in production down-time, resulting in increased productivity,
- a reduction in spare parts consumption, which are needed after failure,
- a marked reduction in failures and maintenance after failures,
- reduction of overtime costs of maintenance workers,
- reduction of total maintenance cost in the long term,
- distinctive reduction of frequent failures based on recorded data about machine failures and their analysis,
- reduction of non-quality costs,
- within the scope of an integrated quality management system, as there is an increase in the maintenance efficiency, company should expect to see a reduction in the environmental impact of company activities and an improvement in its safety record.

At the present time it is common that maintenance management systems are supported by information systems (IS). It is impossible without IS to evaluate maintenance effectiveness (untrustworthy data) and there is no chance to control maintenance (for example: make decisions based on facts which are missing) and you can plan only on a short-term basis. Assuming that maintenance is supported by IS, it is possible to obtain several indicators which can quantify most of the maintenance requirements. For regular operative evaluation it is necessary to set up algorithms of all partial and over-all indicators involved in maintenance IS. It is also important to ensure availability of data with the minimum of work difficulty to the IS user, i.e. maintenance manager. If it is difficult for the maintenance manager to obtain data from IS, then his final work is usually poor. It is problematic to process data obtained from maintenance IS in the case of software which does not have in-built analytical tools, for example: creating macro in wide-spread MS Office – Excel, after data import.

3.1. Partial indicators of maintenance level obtained from maintenance IS

The following data is entered in to the IS after every maintenance action: when the maintenance was done, type of maintenance, on what machinery, the amount of labour input, the amount spent on material and spare parts, the costs of maintenance (partial costs included), down-time caused by the maintenance and in the case of maintenance after failure – the cause of failure. This kind of data is available for periodical maintenance level efficiency, providing partial and overall indexes which provide actual information of achieved level of the requirements stated in chapter 3.

Basic partial indicators of the maintenance level efficiency which can be obtained directly from maintenance IS for required time periods (months, quarters, etc.), are:

1. Amount of maintenance after failure.
2. Total number of down-time hours at the period, eventually their partial elements.
3. Amount of down-times or cost representations of down-time losses.
4. Costs of spare parts and materials spent by maintenance.
5. Amount of failures, eventually their quantity in main categories.
6. Total maintenance costs, eventually their partial elements (wages, materials, overtime down-times).
7. Preventative maintenance costs.
8. Maintenance after failure costs.
9. Total maintenance labour input.
10. Labour input of maintenance personnel after failure.

From these, it is possible to obtain derived partial indexes of maintenance efficiency, for example:

11. Ratio of the amount of maintenance after failure compared to the total number of all maintenance actions.
12. Ratio of the amount of preventative maintenance costs compared to the total maintenance costs.
13. Ratio of the amount of preventative maintenance labour compared to the total maintenance labour input.
14. Average labour input of single maintenance.

15. Average labour input of single maintenance after failure.
16. Mean time to failure.
17. Mean time between failures.
18. Mean active corrective maintenance time.

Combining IS data and other easily recordable data (time fund of maintenance workers, reduction value of maintained assets, service time of particular objects, business turnover, number of non-conforming products, etc.) makes it possible to calculate other derived partial indexes:

19. Total maintenance costs as a percentage of reduction value of maintained assets.
20. Value of material and spare parts spent for maintenance as a percentage of the reduction value of maintained assets.
21. Labour input of maintenance after failure as a percentage of the total time fund of maintenance workers.
22. Labour input of preventative maintenance as a percentage of the total time fund of maintenance workers.
23. Total maintenance costs as a percentage of the business turnover.
24. Down-times owing to maintenance as a percentage of the operational time of productive machinery.

The evaluation of maintenance efficiency by means of partial indexes is not as easy. When are evaluated only some of them, then the influence of others is not considered. On the other hand, too many indicators lead to a difficulty in monitoring final trends (they differ in tens or hundreds of a percent and ordinarily vary only in particular time periods). In comparison with a previous period, total maintenance costs increase, but on the other hand costs of maintenance after failure decrease and all at once the number of maintenance after failure and material costs spent by the maintenance department decrease. Therefore the determination of the overall maintenance efficiency can be problematic.

3.2. The evaluation of maintenance level by means of overall indexes

The above-mentioned basic and derived partial indexes of maintenance levels are suitable for integration into one overall index for easy evaluation. This index describes the overall output value. There is again a principal that all (or most) initial data has to be available from the IS and that it is calculated by preprogrammed algorithms in the maintenance system. Thus obtaining of an overall maintenance efficiency index is easy and not time consuming (usually carried out for ten objects). One of the overall indexes can be a modified version of OEE, where contrary to formula (1), only downtimes cause by maintenance are involved; data which is easy to obtain from IS.

Appropriately constructed radar plots from the partial indexes may be another suitable Overall Index (OI) method, whose surface (its changes in time) is a change indicator of maintenance efficiency. A brief explanation of how to construct OI and calculate its surface are is given below:

1. The selection of partial indexes, which will be evaluated. All of these are supposed to have the same tendency, for example when the maintenance efficiency is increasing all of them are supposed to be declining.
2. Because of digit place diversity in the initial data (for example maintenance costs in millions, downtimes in tens etc.), it is necessary to enter them into the logarithm and categorize them with the same units. Furthermore, algorithmized data entered into the algorithm may be modified with the unit coefficients.
3. Radar plot surface calculation of each time period which is being evaluated (it is not necessary to construct the radar plot). This allows the maintenance manager to monitor performance in comparable time periods.

The following example describes the application of OI determination created in MS Excel, which after macro proceeding automatically accumulates partial indexes from the maintenance IS in the appropriate month and calculates an OI from them. The following figures were used to calculate OI: total down-times caused by maintenance, maintenance costs, labour input and amount of maintenance after failure (declining tendency is required).

Other partial indexes are also suitable for OI calculation, for example indexes in chapter 3.1. In the case of partial indexes converted into percentages (s. indexes 19 – 24) it is not necessary to do logarithmic calculations.

If the choice of partial indexes in the determination of OI is correct, then OI is a suitable indicator of maintenance level and each negative change in its trend signals the need for a more accurate analysis of maintenance systems and the implementation of corrective procedures. Despite the obvious advantages of OI calculation, it has one essential fault – OI is determined in periodical time intervals for multiple maintained objects. OI calculations (as well as the calculation of OEE) for all the organizations or departments usually does not have an accurate predicative ability, in the sense of the detection of maintenance weak points. The calculated OI evaluation is time consuming for the maintenance manager. The second step should therefore be an algorithmic processing of all

Welding automat KL-145V

	January	February	March	April
Down-times	36	32	34	30
Maintenance costs	93 562	89 523	92 785	51 204
Labour input	47	44	42	43
Anount of maintenance after failure	8	6	5	4
Conversion				
Down-times	1,56	1,51	1,53	1,48
Maintenance costs	2,49	2,48	2,48	2,35
Labour input	1,67	1,64	1,62	1,63
Anount of maintenance after failure	1,81	1,56	1,40	1,20
Overall maintenance efficiency index				
OI	**6,93**	**6,35**	**6,12**	**5,53**
OI		0,58	0,23	0,59

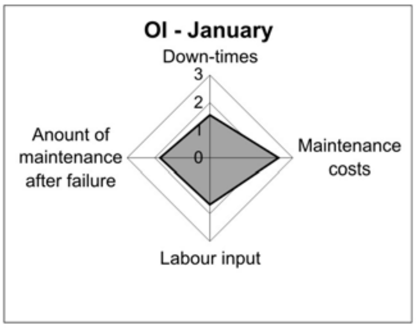

Fig.1. Example of OI calculation

OI figures in order to notify the maintenance manager of any distinctive changes in current OI trends of the evaluated objects. The main purpose of calculating OI trends is to monitor each change in order to pinpoint maintenance weak points, which should be noticeable from the processed outcome in a very brief and well-arranged form. The advantage of this kind of data processing is that the maintenance manager does not need to browse numerous entries relating to objects – algorithms only show objects with negative trends of OI. Example of an algorithm which was constructed using MS Excel for the above-mentioned purpose of evaluating OI trends is shown in the figure 2.

An advantage of this method is not only that the maintenance manager looks after for only particular equipment but also has access to an immediate visual display of more detailed data about particular machinery – for example, if he selects "Press PD4…", which has the worst trend, other trends from previous periods will be shown too (last four quarters). Other specific data about equipment is available (bottom of figure 2). The maintenance manager can view information about the technical specification of equipment and the statement of maintenance during certain time periods, including the possibility of distinguishing between maintenance due to failure or for other reasons. Statements of maintenance workers' notice of particular maintenance or lists of materials and spare parts used for maintenance, which should lead to the detection of the cause of OI negative trends. Equipment with the best OI trend values are shown on the right side, such a trend describes the feasibility of implemented changes in the maintenance system.

Statement from:	9.2.2005	Period:	9.11.2004 → 9.2.2005

Negative trends:		**Positive trends:**	
Level settings:	2	Level settings:	4
Press PD4-HH-630+400.1ES	8	Welding Vertical Lathe FANUC	9
Power Press 800t	6	Spot Welder Regaut AB 02.1	8
Press PE4-HH-500.1ES-second	6	Press PE4-HH-500.1ES fourth	7
Drilling Machine HBE 320 - 2	4	Welding Station 1 - SAAB	6
Welding Station R.2 Audi W10	3	Press PE4-HH-500.1ES third	4
TSV (BMW E9x)-Mag2-Welding Robot	2	Welding Station 2 - SAAB	4
Unloading Workstation TS Golf	2		
Press Hydrap Tsh HPDb 1000	2		
Laser Lasercell 1005	2		

Trend statement (last quarter)	**Now**	**-1**	**-2**	**-3**
Press PD4-HH-630+400.1ES	8	2	0	1

Basic equipment data	Maintenance statement	Notice statement	Spare parts and material statement

Fig.2. Outcome of quarterly processed indicators of maintenance efficiency of chosen objects

The factors which go into calculating to the OI are not static but can be changed according to the data collected (however, each piece of data must be in a proportional unit). The data used to calculate fig. 2 has been collected for more than one year during which time OI of maintenance efficiency is expressed as a cumulative trend of down-times of selected machinery. These figures can then tell the maintenance manager what is required of the maintenance efficiency system. Changes of cumulative down-time trends can be simply quantified by costs. Since January 2006 similar algorithm has been tested, which not only evaluate cumulative down-time trends in one OI but also cumulative maintenance costs, maintenance after failure labour input, mean time to failure, mean time between failures and the amount of failures.

The next step will be to develop algorithm which will involve fault maintenance section searching. Lists of equipment with weak maintenance level will be analysed. The maintenance manager will have a statement of productive equipment with weak maintenance levels and also information about particular sections which require particular attention in order to carry out corrective procedures.

4. Conclusion

The basic requirement involved in the quality system and the maintenance quality system, is the continual improvement of maintenance efficiency based on the data analysis of the actual behavior of the system particularly weak point localization and pursue corrections. There are many indicators of maintenance level, but the most preferable is to take advantage of the overall indexes, which synthesize many partial indexes. If the analytical tools are appropriately designed, then they are able to execute the analysis of maintenance efficiency with the inclusion of detailed characterization and localization of the weak points. Overall Index may help not only for continual improvement of the maintenance quality management system but also for the comparison of the same or different production machinery. Further more, it can also be used for evaluation of external maintenance contactor when they provide total maintenance of major production plants etc.

5. References

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