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MAINTENANCE AUDIT AND BENCHMARKING - SEARCH FOR EVALUATION CRITERIA ON GLOBAL SCALE

Maintenance strategy and concept of management are very important for proper execution of maintenance of physical assets in different organizations. Authors present main objectives for maintenance and define maintenance strategy and concept. The key benefit of the paper is a methodology of strategy maintenance development. The methodology is based on input data definition and on proposed procedure of data processing. Proper developed maintenance strategy is a presumption of excellent maintenance effectiveness. The paper presents use of audit and benchmarking methods for development the maintenance strategies. Example of system of questions and their evaluation is presented. Some practical problems and experience from companies are discussed as well.

***Keywords**: maintenance audit, benchmarking, maintenance performance indicators.*

1. Introduction

Maintenance strategy and concept influence the performance of physical assets especially in medium and long time horizon. This is reflected particularly in the effectiveness, productivity and economic efficiency of maintenance and in fulfillment of fundamental requirements asked from maintenance, such as:

a) Maintaining physical assets in up-state,
b) Prevention of failure occurrence and consecutive faults,
c) Flexible fixing the failures occurred,
d) Diminishing environmental effects of production equipment,
e) Ensuring operational safety,
f) Spending optimum costs on maintenance.

Aim of this paper is to outline the structure and methods for proposal of evaluation criteria on global scale.

2. Audit

Audit can be characterised as a systematic, independent and documented process of obtaining evidences from audit and its objective evaluation with the aim to determinate extent of the audit criteria fulfilment.

Audit criteria of maintenance management quality are mostly qualitative and composed of requirements for proper organization structure and management of all maintenance processes [1, 2, 4, 6, 8]. Gradually it is possible to create also quantitative criteria expressed by concrete values of measurable quantities, such as man-hours and maintenance operations duration, preventive maintenance ratio, external service ratio, all financial indicators of maintenance, etc. The basic tool for gaining these quantity based criteria is benchmarking – see below.

It is appropriate to split out the audit criteria into several areas of maintenance management [7]. The proposed example consists of ten areas:

1. Characteristics of business activities and production facilities in the company.
2. Strategies and systems of maintenance in the company.
3. Organisation and management of human resources in maintenance.
4. Administration and documentation of maintenance management.
5. Preventive maintenance.
6. Planning, scheduling and work orders in maintenance.
7. Implementation of maintenance processes.
8. Purchase, stock and supplies of spare parts and material management.
9. Measurements of effectiveness and efficiency of maintenance, its improvement and evaluation of customers' satisfaction.
10. Computer based support of maintenance management.

Note:
Generally, in each audit there is certain subjectivity and this is true especially in maintenance audit as there is no standard like ISO 9001:2000, ISO 190011 etc. However, the maintenance audits can be carried out, and conclusions and recommendations for creation of maintenance management strategies can be done.

3. Benchmarking

Creation of maintenance strategy requires knowledge of number of indicators to be used during proposal, implementation and verification of results gained during maintenance strategy improvement process.

Benchmarking is focused on comparison of a process and product against processes and products recognised as the best ones with purpose of discovering opportunities for quality improvement. It enables determination of objectives of tasks and priorities in preparing plans that will lead to competitive advantage in the market.

These general benchmarking principles are valid for any maintenance processes and can be used also in a maintenance management.

3.1 Evaluation criteria on global scale

From the above given characteristics of audit and benchmarking it is clear that both the maintenance audit and benchmarking need well prepared, and if possible, standardised quantitative and qualitative indicators of maintenance performance (KPI).

There are numerous different indicators for maintenance performance, e.g. 13 key indicators defined by EFNMS, or indicators defined in EN 15 341 standard "Maintenance Key Performance Indicators" [3], etc.

It was EFNMS ambition to carry-out a European-wide study on maintenance based on 13 indicators defined by working group Maintenance Benchmarking. But although the indicators were sufficiently publicised among the EFNMS member countries, the results were not adequate to effort and so far there is no European-wide database on the 13 selected indicators, besides the Nordic survey in 2000 [10] and successful workshops in some member countries. Strong impulse for creation of a large database is expected from above mentioned European standard.

Another possibility for facilitating collection of benchmarking indicators is their automatic generation from CMMS. There is a system developed by Infor based on usage of VDM (Value Driven Maintenance) indicators. Another one, developed for D7i package by Inseko, a.s. corp. [5] that generates indicators according to EFNMS benchmarking methodology, thus giving instant overview on actual position of maintenance in a company. The new indicators by European standard, or any other required, can be added to the system.

EN 15341

A new European standard entitled "Maintenance – Key Performance Indicators" was approved in the beginning of the year 2007 and besides other it should solve the problem with definitions and give higher importance to maintenance benchmarking as the indicators are now included in the European standard. Problem of understanding the indicators will transfer to the problem of their correct and effective usage (although understanding problems will probably never disappear). The new standard comprises 71 of them, which is rather high number and in a sense it contradicts to the original intention of EFNMS to select the least number of the most representative indicators. The new standard let the users decide which indicators will be utilised, but this on the other hand brings a problem of mutual comparison when companies will not use the same indicators. So this brings a new action area for the EFNMS benchmarking working group, which in the meantime adopted a new name of "European Maintenance benchmarking Committee", to prepare and disseminate a unified approach to utilisation of the standard based on the experience of leading (world class) companies.

The system of indicators is structured into three groups:

1. Economic indicators (time / money; money / money)
2. Technical indicators (time / time; number / time; time / number)
3. Organisation indicators (e.g. persons / persons; etc.)

The objective of indicators is to help management to support management in achieving maintenance excellence and utilize technical assets in a competitive manner. Most of the indicators apply to all industrial and supporting facilities.

These indicators should be used to:

a) measure the status;
b) compare (internal and external benchmarks);
c) diagnose (analysis of strengths and weaknesses);
d) identify objectives and define targets to be reached;
e) plan improvement actions;
f) continuously measure changes over time.

These indicators can be evaluated as a ratio between selected factors (numerator and denominator) measuring activities, resources or events, according to a given formula. Whenever a factor is defined as "internal" or "external", the derived indicator, should also be used only for "internal" or "external" influences.

To select relevant indicators, the first step is to define the objectives to be reached at each level of the enterprise. At the company level, the requirement is to identify how maintenance can be managed in order to improve global performance (profits, market shares, competitiveness etc). At the systems level and production lines, the maintenance objectives can address some particular performance factors, which have been identified through previous analysis, such as improvement of availability, improvement on cost-effective maintenance, retaining health, safety and environment preservation, improvement in cost-effective management of the value of the maintenance inventory, control of contracted services, etc. At the equipment level, machines or types of machines, better control of reliability costs; maintainability and maintenance supportability, etc may be desirable.

Figure 1 illustrates external and internal factors as well as the groups and levels of indicators.

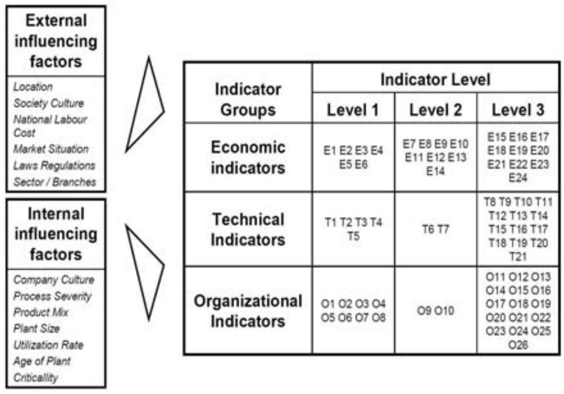

Fig. 1. Maintenance influencing factors and Maintenance Key Performance Indicators

When the objectives have been defined and the performance parameters to be measured have been identified, the next step is to find the indicators that allow measuring these parameters. The system can include capacity of maintaining the equipment, reliability of the equipment, efficiency of the maintenance activities, health, safety and the environment, etc. An indicator is relevant when its value or its evaluation is correlated with the evaluation of the performance parameter to be measured. A relevant indicator shall be one element of decision making.

It is necessary to precisely define:

- data to be collected to determine the values required for the indicator;
- measurement method (operating mode);
- tools required for the measurement (documents, counters, sensors, analyzers, computerized maintenance management system, etc.).

To make the possible evaluation and comparisons easier, it is necessary that the collected data are in conformity with the standardized definitions (e.g. EN 13306).

It is necessary to predetermine the frequency of the calculation and consider availability and time delay of the relevant data, changes over time and reactivity of the system to the actions undertaken.

Out of the scope of this standard remain definition of score, analysis and adopting required measures. The standard itself comprises a set of indicators, but their analysis will require additional projects.

SMRP (USA) metrics

Society for Maintenance and Reliability Professionals (SMRP) has defined and continually has been developing indicators (metrics as they call them) of the best practices to measure maintenance performance [11]. This process is ongoing and metrics can be found at www.smrp.org. The SMRP is active mostly in the USA and Canada, has over 1500 members of which 150 are executive company members.

Objective of the SMRP committee is to define best practices in maintenance and reliability and gradually create a set of the most frequently used metrics and definitions.

The SMRP best practices committee has selected 45 metrics (the number is not definite) that will be gradually defined in the following categories (see figure 2):

- Business and management.
- Manufacturing process reliability.
- Equipment reliability.
- People skills.
- Work management.

First comparisons

As the EFNMS indicators are now incorporated in the standard EN 15341 "Maintenance Key Performance Indicators" and SMRP is developing its system, these two activities lead during the Euromaintenance 2006 conference to meeting that initiated comparison activity aiming at a documentation of the similarities and the differences in the SMRP metrics and the EN 15341 standard.

The first indicators compared and identified as similar from EN 15341 and the SMRP metrics are:

SMRP Metrics		EN 15341 "Maintenance Key Performance Indicators"	
1.5 Annual Maintenance Cost per RAV	Annual Maintenance Cost Replacement Asset Value	E1	Total Maintenance Cost Assets Replacement Value
1.4 Stocked MRO	Stocked MRO Inventory Value Replacement Asset Value	E7	Average inventory value of maintenance materials Asset Replacement Value
5.13.1 Contractor Maintenance Cost	Contractor Maintenance Cost Total maintenance cost	E10	Total contractor cost Total maintenance cost
3.5.2 MTTR	Total Repair Time Number of Repair Events	T21	Total time to restore (MTTR) Number of failures
5.6.2 Proactive Work	PM & PdM Related Work Total Work	O18	Preventive maintenance man-hours Total maintenance man-hours
1.2 Stock Outs	Inventory Requests not Fulfilled Total Number of Inventory Requests (Inverted)	O26	Number of the spare parts supplied by the warehouse as requested Total number of spare parts required by maintenance (inverted)

To increase understanding and the application of the indicators, EFNMS and SMRP will organize workshop based on the indicators or metrics during Euromaintenance 2008 in Brussels.

With the increased globalisation and with companies acting globally, the need for a common understanding of the indicators to measure maintenance and availability performance is increasing, and there is no doubt that this activity in a short period of time will be a part in a global standard for maintenance indicators. This is highlighted by the fact that COPIMAN (Technical Committee on Maintenance of the Pan American Federation of Engineering Societies) is joining the comparison effort.

3.2. Discussion to existing indicators

From above given overview on current situation in the presented topic, one can see that there are various approaches to creation and classification of maintenance KPIs in the world. The first proposal of EFNMS (13 KPIs) has neither classification into groups nor hierarchy of indicators. The second system (EN 15 341 standard) extends the scope of KPIs up to 71 and defines three categories (economic, technical and organisation KPIs) and three hierarchy levels representing the breakdown structure of the assets in the company and enabling to measure performance indicators of the plant as the whole as well the production line and the piece of equipment. American (SMRP) approach is developing 45 (and more) metrics in 5 categories (business and management, manufacturing process reliability, equipment reliability, people skills, work management) and some kind of KPIs hierarchy can be recognised form the figure 2 (e.g. OEE is on higher level than downtime, etc.).

Although much has been done in the field of KPIs, we feel some weaknesses in the area of structuring and hierarchical composition of these KPIs. The structure by categories could be created e.g. in accordance with 10 audit areas of maintenance management. A set of KPIs would be defined in the area 9 (measurements of effectiveness and efficiency of maintenance, its improvement and evaluation of customers' satisfaction), while the individual KPIs would cover the remaining 9 areas of maintenance management audit. We can expect that for the area 4 (administration and documentation of maintenance management) and for the area 10 (computer based support of maintenance management) it would be very difficult to define measurable KPIs. On the other hand a proper structure of KPIs in accordance the areas of audit would increase its objectiveness and improve its usability. Unfortunately the presented 10 areas of maintenance management quality audit are not standardised and anyone may say why maintenance management quality audit could not have more or less areas with content than is presented in this paper.

Another possible structure of maintenance KPIs could be based on application of standardised quality management according to the ISO 9001:2000 that can be decomposed according to process model into four main areas: (1) maintenance management responsibility and performance, (2) maintenance resource management and performance, (3) maintenance realization and performance and (4) maintenance measurement, analysis and improvement. A set of maintenance KPIs would be defined in the fourth area and KPIs would be classified into the remaining three large categories.

Furthermore, from the brief analysis of maintenance performance indicators it can be recognised that complex (overall) indicators are missing, which could present maintenance performance possibly by one number. Currently indicator of overall equipment effectiveness (OEE) belongs to such indicators. The weak point of this indicator is that id does not comprise any data of economic character.

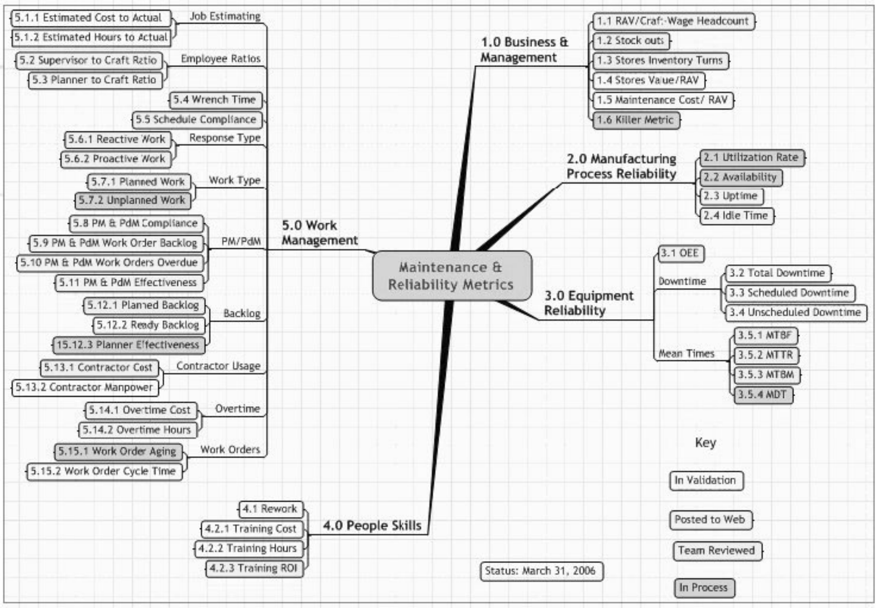

Fig. 2. Overview of SMRP maintenance best practices metrics

3.3. Proposal of overall indicators

Right in the beginning of these considerations it is necessary to say that definition of "absolute" overall indicator of total maintenance management quality and performance is very difficult and in fact almost impossible. However we will try to propose indicators that could at least partly fulfil requirements asked from overall indicator, which could characterise by one figure a maintenance management level that is its performance, effectiveness and efficiency.

The authors propose two overall indicators to further discussion:

a) the increment of profit caused by maintenance
b) indicator of maintenance management quality and performance

A. In practice it is necessary to leave the philosophical and strategic ideas and come up with practical solution. How can the efficiency of financial resources expended in maintenance be ensured in practice? The simplest solution is based on monitoring the shifts of the maintenance contribution to profits of the organisation caused by changes of total efficiency of the production equipment and changes of maintenance costs. The maintenance contributions are evaluated separately while all other factors remain constant. The increment of profit caused by maintenance can be formulated as follows:

$$\Delta PROFITm(\Delta T) = \Delta REVENUESm(\Delta T) - \Delta COSTSm(\Delta T) = REVENUESnom(\Delta T) * [TEE(T_2) - TEE(T_1)] - [COSTSm(T_2) - COSTSm(T_1)] \quad (1)$$

where: $\Delta PROFITm(\Delta T)$ – increment of maintenance contribution to the organisation's profits in time period of ΔT, $\Delta REVENUESm(\Delta T)$ – increment of maintenance contribution to organisation's revenues in period of ΔT, $\Delta COSTSm(\Delta T)$ – maintenance costs increment in period of ΔT, $REVENUESnom(\Delta T)$ – nominal revenues (revenues in case of 100% efficiency of production equipment) for period of ΔT, $TEE(T_2)$ – average level of total equipment efficiency in current period of ΔT, $TEE(T_1)$ – average level of total equipment efficiency in previous period of ΔT, $COSTSm(T_2)$ – costs of equipment maintenance in current period of ΔT, $COSTSm(T_1)$ – costs of equipment maintenance in previous period of ΔT, ΔT – examined calendar period (a month, quarter etc.)

By analysing the calculation (1) we can find out, that as the TEE in consecutive periods grows, so does the maintenance contribution to the organisation's profit in the period ΔT (positive increment of the maintenance contribution) and as the TEE in consecutive periods decreases, the maintenance contribution to the profit for the period ΔT decreases as well (the maintenance contribution increment is negative, i.e. drop in revenues). In the case of an increase of the maintenance costs (for period ΔT) in consecutive periods, the increment of maintenance costs $\Delta COSTSm(\Delta T)$ for period ΔT is positive. In the case of decreasing maintenance costs (for period ΔT) in consecutive periods, the increment of maintenance costs $\Delta COSTSm(\Delta T)$ for period ΔT is negative (this increases the maintenance contribution to profit).

It can be summarized, that the maintenance contribution to profit of an organisation will grow most rapidly, when the maintenance costs will decrease and the level of maintenance management will rise (the TEE will rise) – Table 1, variant 1. The increment of the maintenance contribution to the organisation's profit can be positive also in the case of an increasing level of the total efficiency of equipment and the maintenance costs remain unchanged or will grow more slowly than the maintenance contribution to the profit – Table 1, variants 2 and 3. Entirely bad economical situation (loss) occurs, when the total equipment efficiency stays constant (at a lower level) or decreases, while the maintenance costs grow – Table 1, variants 4 and 5.

The indicator of maintenance contribution to an organisation's profits makes it possible to monitor the dynamics of the financial impact of maintenance management and maintenance financing to entire organisation's profit. The positive increment of this indicator for certain period of time definitely represents the positive, desirable trend in maintenance management and its negative increment indicates negative, undesirable trend in

Tab. 1. Illustration of typical variants of maintenance contribution to organisation's profit – calculated according to (1)

Variant	1	2	3	4	5
REVENUESnom(ΔT)	1 000 000,-	1 000 000,-	1 000 000,-	1 000 000,-	1 000 000,-
$TEE(T_2)$	0,8	0,7	0,9	0,45	0,90
$TEE(T_1)$	0,5	0,6	0,9	0,45	0,95
$COSTSm(T_2)$	60 000,-	50 000,-	40 000,-	60 000,-	55 000,-
$COSTSm(T_1)$	100 000,-	50 000,-	60 000,-	50 000,-	50 000,-
ΔPROFITm(ΔT)	340 000,-	100 000,-	20 000	- 10 000	- 55 000,-

maintenance management. However, some temporary negative fluctuations of this indicator should not be seen by definition as unfavourable because the calculation of the revenues increments does not include effects out of the growth of production equipment efficiency (for example, it does not include the factors Safety, environmental profile, reducing the stock, customer acquisition and lock-in etc.). The negative increments can be, of course, also expected in case where there are variations in the factors considered constants (e.g. substantial expansion of production, reduction of production, changes in production programme etc.). In this case it is necessary to consider those factors. When high levels of maintenance management have been reached (other factors stay constant), the increments of maintenance contribution should be kept at zero, because the total efficiency of production equipment and the level of maintenance management reached its peak and remains there, and the maintenance costs remain unchanged at this optimal level (inflation is not considered). From above stated, it is obvious that the most substantial increments of this indicator can be expected during maintenance management improvements (positive increments) and during the drop in quality of the maintenance management (negative values). Verification of this indicator in practice will show its possible application.

B. Basic inputs for the second propose overall indicator of maintenance management quality and performance could be composed of the following items:

a) total internal and external maintenance costs *Cm* of all physical and intangible assets in organisation per certain period of time, e.g. month, quarter, year etc. (wages, salaries and overtimes for managerial, supervision, support staff and direct staff; payroll added costs for the above mentioned persons (taxes, insurance, legislative contributions); spares and material consumables charged to maintenance (including freight costs); tools and equipment (not capitalized or rented); contractors, rented facilities; consultancy services; administration costs for maintenance; education and training; costs for maintenance activities carried out by production people; costs for transportation, hotels, etc.; documentation; CMMS (computerized maintenance management software) and planning systems; energy and utilities; depreciation of maintenance capitalized equipments and workshops, warehouse for spare-parts. Not included: costs for product changeover or transaction time (e.g. exchange of dies); depreciation of strategic spare parts; downtime costs.

b) overall equipment effectiveness *(OEE)* related to certain period of time, e.g. month, quarter, year etc.; this coefficient is composed of indicator of availability *A* covering required operation time, corrective maintenance), indicator of performance efficiency *P* covering lowered performance caused by worsened technical state due to maintenance and indicator of quality *Q* expressing ratio of nonconforming products due to maintenance. OEE is calculated by the following formula:

$$OEE = A * P * Q \qquad OEE, A, P, Q \in \langle 0;1 \rangle \tag{1}$$

More detailed methodology for OEE calculation can be found e.g. in [9].

c) ideal revenues of organisation *Rid* for coefficient of overall equipment effectiveness OEE = 1 (ideal state when production would run without any loses caused by maintenance and total ideal production for paying customers) related to certain period of time, e.g. month, quarter, year etc.

d) real revenues of organisation *Rreal* corresponding to real overall equipment effectiveness related to certain period of time, e.g. month, quarter, year etc.

e) costs for environmental damage and injuries *Cedi* affected by maintenance and related to certain period of time, e.g. month, quarter, year etc.

Based on these input data it is possible to create formula that expresses overall indicator of maintenance management quality and performance *Iqp:*

$$Iqp = 1 - \frac{Cm + Cedi + (1 - OEE)Rid}{Rreal} \tag{2}$$

The presented quality and performance of maintenance management (2) can reach theoretically ideal value 1, and that is in case when total maintenance costs Cm and costs for environmental damage and injuries Ced will be zero and OEE will equal 1. In reality value of this indicator will always be less than 1; however, it is clear that nearing to value one (or 100%) is positive and desired trend.

Advantage of this indicator is in its property to attain and represent more effects and factors of maintenance management (e.g. influence of ratio of internal and external maintenance, preventive and corrective maintenance, influence of worsening of technical state on equipment performance, effects of nonconforming products, influence of maintenance on environmental damage and injuries, influence of training level of maintenance personnel, maintenance tools, etc.)

Disadvantage lays in difficulty to obtain of some data, in inflation financial processes, effects of currency rates, in market and other constraints of maximum utilisation of production capacities; in short term interval it can be, in speculative or another way, influenced by temporary reduction of expenditures on maintenance, etc.

4. Conclusion

Authors of the paper have characterised the existing state in the area of maintenance performance indicators used in maintenance benchmarking and emphasised also possible links with audits of maintenance management and various possibilities for creation of structure of these indicators.

Based on the analysis two overall indicators were proposed for further discussion. These indicators link maintenance performance measurement with its economy - that is basically relation of production equipment availability with costs on its maintenance.

But what is even more important, the significance of indicators lays in their progress during period of time which enables to recognise changes after a new strategy was adopted in maintenance management.

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