

A Comprehensive Approach for Maintenance Performance Measurement

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Abstract Performance Indicators are needed in order to be able to control maintenance processes. Although diverse researches have been done attempting to develop maintenance performance measurement, most of the existing resources suggest Overall Equipment Effectiveness (OEE) for measuring maintenance performance. However, it does not provide the means for a complete performance analysis in maintenance, individually. This paper demonstrates different approaches for determining Maintenance Performance Indicators (MPI) and provides a comprehensive approach for evaluating performance in terms of economic and technical ratios, as well as OEE. Some examples are also presented for a better understanding of the demonstrated ratios.

Introduction

The costs of maintenance are estimated to be between 15% and 40% of production costs (Dunn, 1987; Lofsten, 2000), and the trend toward automation has forced managers to pay more attention to maintenance. Managers have figured out, that maintenance, with its high cost and low efficiency, is one of the last cost saving frontiers in management (Sheu and Krajewski, 1994). Effective maintenance is critical to many operations. It extends equipment life, improves equipment availability and retains equipment in proper condition. Conversely, poorly maintained equipment may lead to more frequent equipment failures, poor utilization of equipment and delayed production schedules. Misaligned or malfunctioning equipment may result in scrap or products of questionable quality. Finally, poor maintenance may mean more frequent equipment replacement because of shorter life (Swanson, 2001).

Performance indicators are numeric values for an aspect of a (sub) process that isn't influenced by related processes and is representative as a measure for the effectiveness and/or efficiency of that aspect of the (sub) processes. Management requires performance information to be able to control the maintenance process. In practical situations, performance indicators are needed by the maintenance manager, supervisors, foremen and engineers, as well as planners. The absolute value of such indicators compared to a norm (to be chosen beforehand) or a trend in this value can be used to glean performance levels (Arts *et al.*, 1998).

Performance measurement has received much attention lately (see, for example, Neely *et al.*, 1995 for a review). In the past, maintenance performance reporting in many companies has been limited to a minimum budget reporting (Pintelon, 1990). This is only partly due to the fact that both academics and practitioners have, for a long time, failed to recognize maintenance management as a full-grown business function. Another reason is that maintenance performance reporting is difficult. The main issue is of course, "how to measure maintenance performance?" or "what performance indicators do

we need in order to gain sufficient insight in the maintenance operations?” It is clear that due to the complexity of the maintenance function and its dependence on the specificity of the situation on-hand these questions are not easy to answer. Various researchers provide the following synthesis that most organizations and their managers are aware that they need to measure productivity for (i) comparing their own performance with that of their competitors, (ii) knowing the relative performance of their individual departments, (iii) comparing relative benefits of various inputs, and (iv) collective bargaining purposes while dealing with trade unions (Aggarwal, 1980).

Whatever form they take, productivity and efficiency calculations are made for two purposes; to decide upon the allocation of resources, and to evaluate the performance of a business after resources have been committed (planning and control). A partial maintenance productivity goal for instance is that the firm should seek to maximize its maintenance productivity in economic terms, and should aim at producing any level of output which is decided upon at minimum maintenance cost with respect to the machine's state (i.e. availability). Therefore, the aim of a maintenance quality assessment is to get an idea about the performance of maintenance through the assessment of the existing problems, both from the organizational and operational point of view, so as to be able to suggest measures of improvement, determine the priorities for the recommended measures and set up a plan of action (Groote, 1995).

Observations of practice led researchers to develop the following prescriptions for practice that had been independently developed in several of the firms (Schroeder *et al.*, 1986): (i) measurements should be understandable by all organization members, (ii) measurements should be accepted by the individual involved, (iii) rewards and measurements should be compatible and (iv) measures should be result oriented. It is important to note that the calculation of so-called overall equipment effectiveness (OEE) in Total Productive Maintenance (TPM) as the product of availability, quality performance and speed, is not really a complete analysis. It does not take account of costs and profits, and so is not a complete measure by which competitive machines or systems should be compared, or the deterioration of systems over time should be monitored (Sherwin, 2000).

In this paper, an overview based on literature study and industrial practice, of commonly-used performance measurement systems is taken with some of their examples. Next, the overviewed concepts are classified in order to provide a comprehensive approach for measuring maintenance performance. Finally, conclusions and recommendations concerning the proposed approach will be provided.

Maintenance Performance Indicators (MPI) in detail

Maintenance performance is generally hard to measure, as one should not only consider quantifiable parameters but also the quality of the performed maintenance and its organization. As maintenance is a logistic function integrated into a production process, its efficiency is hard to appreciate in absolute value. Consequently, performance parameters cannot be chosen among operational figures. They must be defined in relative values, i.e. through ratios (Groote, 1995). Maintenance is a service function for production. Both the merits and shortcomings of the service rendered are not immediately apparent. Because of the time-lag effect it is difficult to specify the amount and intensity of the service (and the corresponding required amount of money) needed for ensuring proper plant performance. Another aspect which makes it difficult to measure maintenance output is the fact that maintenance activity is closely related to production activity and organization, which in turn is affected by still other functions (e.g. sales). Maintenance managers often have access to many data, but seldom receive the information they need: data often have to be collected from many different sources, and are often not structured and not aggregated. This means that processing the data to obtain useful management information, e.g. a few typical performance indicators, is a time-consuming business. Data accuracy and report timeliness are other frequent problems encountered in

maintenance performance reporting. Furthermore, the maintenance manager often lacks the tools (e.g. query facilities for the computer systems) or time to draw up the required reports. Fortunately the ever improving MMIS (maintenance management information systems) assist in solving these problems (Pintelon, 1997). In the following, MPI is more demonstrated through the means of productivity ratios.

Productivity

Productivity is the value output(s) divided by the value input(s). In the case of maintenance workers, the output can be considered as the number of tasks completed, while the input is the time taken to complete them using the same scale of measurements. Visser (1998) models maintenance as a transformation process encapsulated in an enterprise system. In the input-output model, the resources deployed to maintenance include labour, materials, spares, tools, information and money. The way maintenance is performed will influence the availability of production facilities, the volume, quality and cost of production, as well as safety of the operation. These, in turn will determine the profitability of the enterprise. Since the use of external service providers has always been an option in maintenance decisions, the inputs to the maintenance process should also include these external resources (Figure 1).

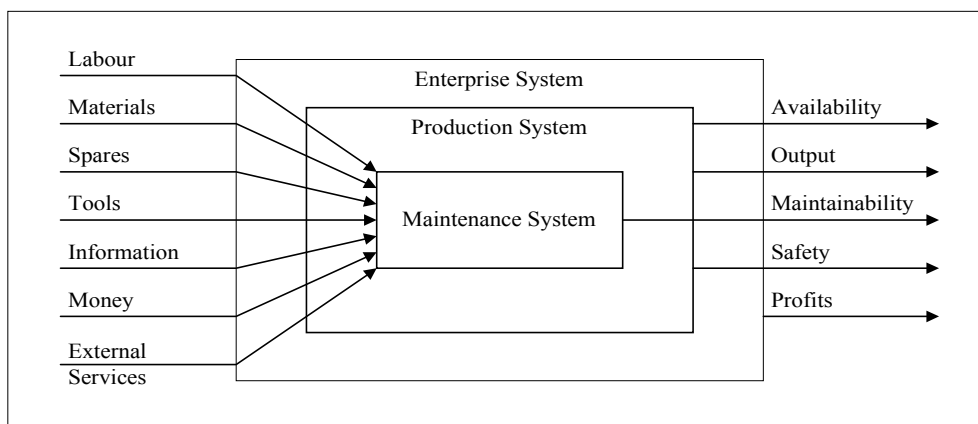


Figure 1. Input-output model for the enterprise system (Visser, 1998; Tsang, 2002)

Good productivity when planning maintenance is vital. Good productivity is reached when the total maintenance costs and down-time costs are reduced to a minimum with a given minimum level for the state of the production system, i.e. the minimum production rate is fulfilled (Lofsten, 2000). Some difficulties, such as finding all inputs and outputs, organizations use other measures than total productivity (Dunn, 1987). Productivity measurement attempts to answer the basic question of how much input is required to achieve a particular output. This question may be posed for a single machine, manufacturing cell or an entire economy. A useful measure of productivity is partial productivity. This measures the total output divided by one kind of input.

$$\text{Partial factor productivity} = \frac{\text{Total output}}{\text{Single input}} \quad (1)$$

However, there are two categories of ratios under which the performance indicators can be presented:

- (1) Economic ratios, which allow the follow-up of the evolution of internal results and certain comparisons between maintenance services of similar plants.
- (2) Technical ratios, which give the maintenance manager the means of following the technical performance of the installations.

Economic ratios

Ratios linked to maintenance costs

Among the economic ratios that exist, those which seem to be the most representative have been chosen hereafter. These types of ratios must obviously be completed by a 'customizing' for each company. Here are some examples of this type of ratio:

$$\frac{\text{Direct cost of maintenance}}{\text{Added value of production}}$$

The direct cost of maintenance comprises: cost of manpower, cost of materials (spare parts, lubricants, miscellaneous), cost of subcontracted work and overheads. The added value of production constitutes the total cost of production less the cost of raw materials. This ratio fixes the importance of maintenance in a plant. Using the added value and not the total cost of production eliminates the important fluctuations in the plant itself as well as between enterprises due to the fluctuation in the price of raw materials.

$$\frac{\text{Cumulative costs of maintenance of a production unit since start - up}}{\text{Number of operating hours since start - up}}$$

This ratio links the total direct costs of maintenance to a time unit. Another important ratio is:

$$\frac{\text{Total maintenance manpower cost}}{\text{Total direct maintenance cost}}$$

Ratios in relation to spare parts

Some examples of this type of ratio are:

$$\frac{\text{Average stock value}}{\text{Replacement value of production equipment}}$$

This ratio takes into account the components of maintenance costs in relation to exterior ones. Likewise, it has a comparative value for similar plants or for a developing enterprise.

$$\frac{\text{Cumulated value of issued spares over a 12 - month period}}{\text{Average stock value over a 12 - month period}}$$

This ratio gives the stock rotation. This means the number of times the value of the stock is issued per year.

$$\frac{\text{Cumulated value of issues over 12 months} \quad \text{Cumulated value of issues of safety parts over 12 months}}{\text{Average stock value without safety parts}}$$

This ratio eliminates the safety-parts issues in the ratio of stock rotation. These parts are generally supplied together with the production equipment. From the accountancy point of view, they are often considered together with the fixed assets. A substantial reduction in the stock value then arises without decreasing the value of the issues. Here too the stock rotation would not reflect the real situation. Even if it is sometimes difficult to define and classify the safety parts with precision, the last ratio will be more precise than the previous one. When considering two types of spare parts classifications, it can be seen that the last ratio is hardly influenced by variations, whereas the previous ratio is very sensitive. In other words, any error in classification of safety parts will have a limited impact on the last ratio and a strong impact on the previous one. Also, ratios in relation to spare parts, such as consumption of store items are important:

$$\frac{\text{Total store issues and direct purchases}}{\text{Total direct maintenance cost}}$$

Ratios in relation to manpower

Some examples of this type of ratio are:

$$\frac{\text{Cost of subcontracting (manpower)}}{\text{Direct cost of maintenance}}$$

This ratio follows the evolution of the policy adopted for subcontracting. Subcontracting is defined as the total amount of maintenance operations which are given to outside companies. It should be mentioned that 'subcontracting' often means manpower and material. In order to have a good idea about the impact of each component on the maintenance cost, it would be good to consider them apart.

$$\frac{\text{Cost of maintenance personnel}}{\text{Direct cost of maintenance}}$$

This ratio gives an idea of the impact of fixed or temporary personnel.

Technical ratios

The technical ratios, far more numerous than the economic ratios, are also much more varied. This is why only those considered to be fundamental and applicable to all companies are described hereafter. Contrary to the economic ratios, which are often in relation to the whole plant maintenance, the technical ratios often concern single lines, machines or apparatus.

Basic MPI: Effectiveness

Effectiveness is a function of utilization (U), performance (P) and method level (M). Utilization (U) is a measure of how much of the available time is spent working (as distinct from waiting or idling). It is influenced by late starts, early finishes and extended breaks:

$$\text{Utilization} = \frac{\text{Total work hours}}{\text{Total work hours} + \text{delay hours}}$$

Utilisation is the ratio of actual output to designed capacity. The designed capacity of the machine is the maximum output that could, ideally, be achieved in a week. This ignores the time needed for maintenance and setups. The effective capacity is the maximum output that could reasonably be expected. This takes into account the time needed for maintenance and setups (Hartmann, 1987; Meeks, 1984). The aim of capacity planning is to match available capacity to forecast demand, but is not focused in this paper. Al-Muhaisen (2002) also suggested an adjusted factor to be multiplied by the above function.

Performance (P) is a measure of the speed at which people work. It is determined by the conditions surrounding their work, by the level of their innate and acquired skills, and by the effort which they put into the task.

$$\text{Performance} = \frac{\text{Standard hours}}{\text{Actual hours}}$$

Method level (M) is the method used compared to good maintenance practice. Availability and quality of standard practices is determined by the types of tools, equipment and work sequences used. Its values range from 90 per cent for poor to 100 per cent for a good maintenance system. Thus:

$$\text{Effectiveness} = P \times M \times U$$

The most common method used to calculate the two indices (U and P) is a statistical sampling of the current work.

Advanced MPI: Overall Equipment Effectiveness (OEE)

Technical ratios can be placed under two categories:

- (1) Those which interest the users of the equipment and are a measure of the efficiency of maintenance.
- (2) Those which more directly interest the maintenance manager in measuring the efficiency of maintenance policy.

Both are covered by an overall equipment effectiveness indicator (OEE), which is a company or production sector performance indicator (Nakajima, 1989). However, to eliminate waste, Toyota became one of the first companies to implement TPM (Nakajima, 1988). Toyota measures six categories of equipment losses throughout its production system. These include: (a) equipment failures, (b) setup and adjustment, (c) idling and minor stoppages, (d) reduced speed, (e) defects in the process, and (f) reduced yield (Nakajima, 1986; Ben-Daya and Duffuaa, 1995). OEE takes into account all the six losses has been defined as (Nakajima, 1986; Groote, 1995; Blanchard, 1997; Ollila and Malmipuro, 1999; Park and Han, 2001):

$$\text{OEE} = \text{Availability} \times \text{Speed or amount of production} \times \text{Quality rate}$$

Where

$$\text{Availability} = \frac{\text{Planned Production time} - \text{Unplanned downtime}}{\text{Planned production time}}$$

$$\text{Speed} = \frac{\text{Actual amount of production}}{\text{Planned amount of production}}$$

$$\text{Quality rate} = \frac{\text{Actual amount of production} - \text{Non accepted amount}}{\text{Actual amount}}$$

Availability is the degree to which the operation is ready to work. An operation or machine is not available if it has either failed or is being repaired. There are several different ways of measuring availability depending on how many of the reasons for not operating are included. Lack of availability because of planned maintenance or changeovers for example. Availability is one dimension of the multidimensional measure state and we have to transform the state to availability. In the maintenance case, there are only nonlinear functions between preventive maintenance and state, state and availability and so on (Lofsten, 2000). Also, when production systems are designed so that they run in a trouble-free manner, and can be easily rectified when necessary, they are said to have a high maintainability. This can be quantified by the mean time to repair. The measure of reliability, the mean time before failure, can also be combined with the mean time to repair to give the overall measure of an operation's availability.

The total company or production sector performance is then given by $OEE \times P$ with P = Planning indicator:

$$\frac{\text{Theoretical production time} - \text{Planned downtime}}{\text{Theoretical production time}}$$

Referring to Nakaiima's (1988), an OEE of 85 per cent is considered as being world class and a benchmark to be established for a typical manufacturing capability; nevertheless, the inference from Kotze (1993) article is that an OEE of less than 50 per cent is more realistic.

Some examples of the technical ratios

A number of other technical indicators are interesting to follow up. Hereafter some examples are given. They often consider partial components of the OEE:

$$\frac{\text{Theoretical production time} - \text{Hours for maintenance (planned and unplanned)}}{\text{Theoretical production time}}$$

By "hours theoretically available in a period of time" is meant the hours during which, if the machine is technically in working condition, it can really be used. For a 30-day month in a factory running at full capacity, this corresponds to 720 hours. The hours for maintenance are considered as downtime due to breakdown, preventive maintenance, repairs, inspection, lost time awaiting spares and waiting time for maintenance personnel. Detailed analysis of causes of downtime will highlight whether the reasons are of a maintenance or production origin. The above ratio indicates the time during which the equipment should normally be in production. It is one of the principal performance ratios of maintenance.

$$\frac{\text{Number of gross operating hours}}{\text{Number of gross operating hours} + \text{Downtime for maintenance (planned and unplanned)}}$$

It is the ratio of operational availability, influenced by maintenance. The number of operating hours is defined by the theoretical production time less planned and unplanned downtime (for maintenance and

other reasons). Downtime for maintenance includes: repairs, preventive and corrective maintenance, overhauls and troubleshooting due to micro failures.

$$\frac{\text{Number of hours of downtime for unplanned maintenance}}{\text{Number of gross operating hours}}$$

The numerator is calculated based on total downtime for maintenance reasons, less the hours for planned maintenance. This ratio represents the lost production hours due to unplanned downtime (breakdown) for maintenance reasons.

$$\frac{\text{Number of production stops}}{\text{Number of gross operating hours}}$$

This ratio characterizes the number of failures in the system per unit of time and is a measure of the failure or breakdown rate. It is generally preferred to the previous one wherever production of wastes (speed losses) at the time of shutdown or start-up is important and expensive.

$$\frac{\text{Number of maintenance hours (planned and unplanned)}}{\text{Number of gross operating hours}}$$

This ratio measures the evolution of the state of material. It can provide a forecast, by material group, of the maintenance workload for the personnel.

$$\frac{\text{Number of man hours for troubleshooting}}{\text{Number of man hours for planned maintenance}}$$

This ratio measures the efficiency of the maintenance policy. By ‘troubleshooting (unplanned maintenance)’ is meant the urgent interventions carried out because of the risk of serious accident or stoppage of production as well as those necessary to restart an apparatus under satisfactory conditions. Troubleshooting always causes an immediate disfunctioning in the production programme and maintenance personnel. ‘Planned maintenance’ includes all maintenance work except that which involves major overhauling work which can shut down the material for a long period.

$$\frac{\text{Man hours spent on prepared work}}{\text{Total man hours spent by maintenance personnel}}$$

This ratio measures the level of work preparation. It can be a sign of the efficiency of the maintenance organization.

$$\frac{\text{Sum total of time allocated for maintenance work}}{\text{Sum total of time actually worked for these jobs}}$$

This ratio gives an indication concerning the performance of interventions. From the foregoing discussion two aspects are apparent and must be considered:

- One is the interdependence of the ratios in general. A ratio on its own rarely signifies anything specific. It must always be backed up or confirmed by examining others in relation to the same topic.
- Another is the need for a precise terminology which is used in the numerators and denominators.

$$\frac{\text{Craft hours planned by planner}}{\text{Hours worked}}$$

This ratio will determine whether the field supervision is using the craftsmen on those work orders that were planned (Arts *et al.*, 1998).

$$\frac{\text{Standard labor hours}}{\text{Actual labor hours}}$$

This will determine whether the planners are capable and whether the productivity of the craftsmen has changed.

$$\frac{\text{Work orders executed as scheduled}}{\text{Total work orders scheduled}}$$

will determine whether the field supervision are following the approved schedule.

$$\frac{\text{Preventive maintenance hours}}{\text{Total maintenance hours}}$$

monitors the relative amount of preventive maintenance (PM) done by the unit. The profile of the plant will dictate what is an appropriate amount of PM.

$$\frac{\text{Total actual hours performed on planned work hours}}{\text{Total actual hours performed on work orders}}$$

The indicator gauges the effectiveness of maintenance management. An inadequate low score indicates a possible need for increasing productivity of planners or their number. Another explanation is that the fraction of corrective maintenance is too high, which would lead to revision of the maintenance concepts. The measurement of this fraction using the actual time worked is considered superior to calculating the fraction of the total number of work orders prepared, since, generally, there is a great variability in the duration of the work orders.

$$\text{Ineffective preventive maintenance} = \frac{\text{Number of corrective maintenance work orders due to failure of equipment for which preventive maintenance concept is in place}}{\text{Total number of work orders on equipment for which preventive maintenance concept is in place}}$$

$$\text{Work order backlog} = \frac{\text{Number of hours planned on eight weeks basis}}{\text{Total available hours on eight weeks basis}}$$

A possible need for additional labor (contractors) can be identified using the work order backlog. A value between 50 and 70 percent is thought to indicate a good performance, since corrective maintenance can likely be executed without endangering preventive maintenance tasks.

New methodology: A comprehensive model for maintenance performance measurement

Some properties cannot be represented by a single measure; two or more are required. Such a requirement can be revealed by careful analysis of the meaning of the concept. The 'state' of objects or production systems is such a property, i.e., a 'multidimensional property' (capacity, availability, etc.). On the other hand, we must realize that in the traditional approaches, MPI has been considered only a partial productivity index, and the firm may in fact have multiple objectives. However, in this

paper it is assumed that the ratios, both economic and technical permit maintenance managers to follow the evolution of maintenance performance and to knowingly make any decision necessary for improved management. Therefore, considering all types of MPI demonstrated, a comprehensive approach is summarized and suggested for measuring maintenance performance (Figure 2). As it is shown, it is also assumed that the elements in the basic approach are compatible with the elements in the new approach; hence the broken lines indicate this relationship. The new approach enables managers to balance their resources and activities with their planned objectives. In other words, considering the proposed approach, a maintenance manager could be able to achieve more objectives, technically and economically; and could optimize the maintenance activities in order to access to maximum possible values for both types of ratios, simultaneously, as well as gaining the individual benefits of indicators, which allow (Groote, 1995):

- the taking of any immediate necessary action to face emergencies;
- the request for analysis reports and detailed studies on certain topics;
- the correction of deviations, by specific actions, or verifying the effects of any previous links;
- the preparation, in detail and with justification, of budgets for operation and investment;
- the informing of management and other departments of the technical and economic progress of maintenance in the plant;
- the justification of reorganization or restructuring and follow-up of the results of these modifications by using existing ratios or by new ratios created for this purpose.

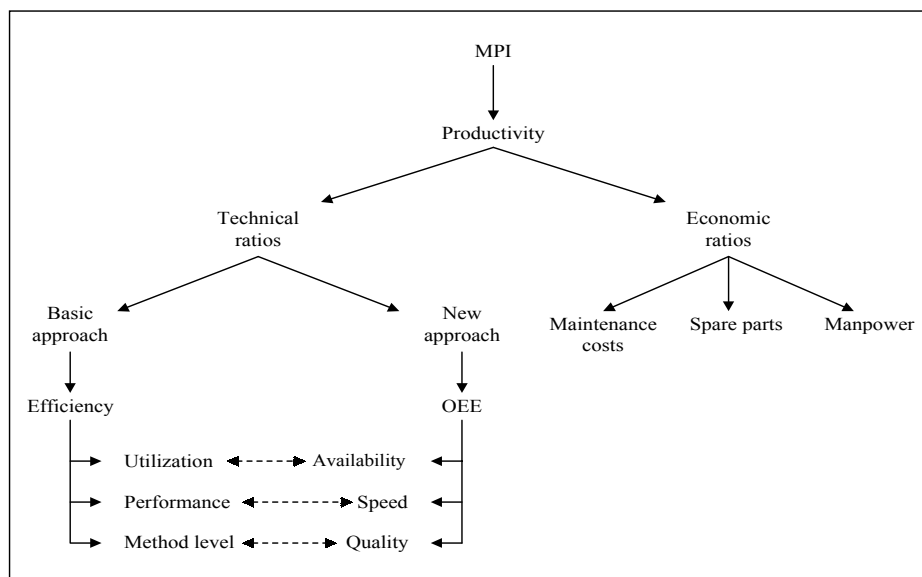


Figure 2. A comprehensive model for MPI

Conclusions

In this paper different types of maintenance performance indicators (MPI) was demonstrated in terms of productivity ratios. Some examples were presented for each types of the indicators, both technically and economically. Also, a comprehensive model was designed and presented for MPI. It seems that the use of the proposed model could make it possible for the maintenance managers to achieve more overall objectives, as well as individual objectives, in the traditional approaches.

However, the important point is that how each of those different indicators, i.e. technical ratios and economic ratios could affect each other as well as the final goals and strategies of organizations. This is something, which could provide a considerable opportunity for future studies.

Although the comprehensive approach is expected to provide great advantages to the organizations, one of the major problems is that a production process does not maintain a constant output per unit of input. Inputs and outputs vary, and this variation must be taken into account. Differences in productivity arising from specific local factors are therefore of less interest to management. In order to measure the degree to which the output has been maximized it is necessary to select a period with respect to which the measure is to be made. It is clear that in most cases one cannot consider only the short range effects of a decision but must also consider the 'long-range consequences'. On the other hand, Great care must obviously be taken when examining published ratios in international literature without further explanation. Care should also be taken when comparing ratios of maintenance departments from different enterprises.

Maintenance becomes a part of total performance approach together with other major topics such as quality, global cost, safety, and environment. Assessing maintenance performance is a matter of both an in-depth practical field experience as well as structured methodology for auditing. The future will increasingly focus on global company effectiveness which has already resulted in fundamental changes in management patterns. Executives, therefore, need efficient decision rules. Part of them will, without doubt, deal with maintenance due to its key role in this process. Assessing maintenance performance gains an important dimension in this framework and new approaches, such as 'comprehensive maintenance measurement' are expected to enhance existing approaches.

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