ARTICLE IN PRESS

Int. J. Production Economics ▮ (▮▮▮▮) ▮▮▮–▮▮▮

Contents lists available at ScienceDirect

Int. J. Production Economics

journal homepage: www.elsevier.com/locate/ijpe

Development of maintenance function performance measurement framework and indicators

Peter Muchiri [a,*], Liliane Pintelon [a], Ludo Gelders [a], Harry Martin [b]

[a] Centre for Industrial Management, Katholieke Universiteit Leuven, Celestijnenlaan 300A, 3001 Heverlee, Belgium
[b] Open Universiteit Nederland, 6401 DL, Heerlen

ARTICLE INFO

Keywords:
Maintenance
Performance measurement
Indicators

ABSTRACT

The performance and competitiveness of manufacturing companies is dependent on the reliability, availability and productivity of their production facilities. To ensure the plant achieves the desired performance, maintenance managers need a good track of performance on maintenance process and maintenance results. This can be attained through development and implementation of a rigorously defined performance measurement framework and indicators that are able to measure important elements of maintenance function performance. The purpose of this paper is to demonstrate that performance indicators are not defined in isolation, but should be the result of a careful analysis of the interaction of the maintenance function with other organisational functions, most evidently with the production function. In this paper, a conceptual framework that provide guidelines for choosing maintenance function performance indicators is proposed. It seeks to align maintenance objectives with manufacturing and corporate objectives, and provides a link between the maintenance objectives, maintenance process/efforts and maintenance results. Based on this conceptual framework, performance indicators of the maintenance process and maintenance results are identified for each category.

1. Introduction

In the face of the current global competition and increasing demands from stakeholders, there is a basic business demand to improve manufacturing performance. The performance and competitiveness of manufacturing companies is dependent on the reliability and productivity of their production facilities (Coetzee, 1997; Madu, 2000; Fleischer et al., 2006). This need to improve the production system's performance that has brought the maintenance function into the limelight. There is consensus among authors (Madu, 1999; Cooke, 2000; Madu, 2000) that equipment maintenance and system reliability are important factors that affect organization's ability to provide quality and timely services to customers and to be ahead of competition. Maintenance function is therefore vital for sustainable performance of any manufacturing plant.

Maintenance is defined as a combination of all technical and associated administrative activities required to keep equipments, installations and other physical assets in the desired operating condition or restore them to this condition (BSI, 1984; Pintelon et al., 1997; Pintelon and VanPuyvelde, 2006). The Maintenance Engineering Society of Australia (MESA) gives a definition that indicates that maintenance is about achieving the required asset capabilities within an economic or business context (MESA, 1995). They define maintenance as the engineering decisions and associated actions, necessary and sufficient for optimization of specified equipment 'capability'. The "capability" in this definition is the ability to perform a specified function within a range of performance levels that may relate to capacity, rate, quality and responsiveness (Tsang, 1998).

Charged with this responsibility of ensuring that the plant achieves the desired performance, maintenance managers need a good track of performance on maintenance operations and maintenance results. In addition, it is in the interest of asset managers to know the relationship between the input of the maintenance process and the outcome in terms of total contribution to manufacturing performance and business strategic objectives (Dwight, 1995; Tsang, 1998; Parida and Chattopadhyay, 2007). This can be realised through development and implementation of a rigorously defined performance measurement system and indicators that are able to measure important elements of maintenance function performance. It is the objective of this paper to demonstrate that performance indicators are not defined in isolation, but should be the result of a careful analysis of the interaction of the maintenance function with other organisational functions, most evidently with the production function. This is done

* Corresponding author. Tel.: +32 16 322567; fax: +32 16 322986.
E-mail address: peter.muchiri@cib.kuleuven.be (P. Muchiri).

0925-5273/$ - see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.ijpe.2010.04.039

by developing a maintenance performance conceptual framework that aligns maintenance objectives with manufacturing strategy, and provides a link between the maintenance objectives, maintenance process/efforts and maintenance results.

This paper first explains the maintenance function of a manufacturing plant based on its objectives, strategies and various maintenance actions. Second, the literature on maintenance performance measurement is reviewed. Finally, the conceptual framework that provide a guideline for developing performance indicators for maintenance function is introduced. Based upon this conceptual framework, the performance indicators of maintenance process and maintenance results are identified for each category.

2. The maintenance function

Deterioration of manufacturing systems' condition, and hence its capability, begins to take place as soon as the system is commissioned. In addition to normal wear and deterioration, other failures may occur especially when the equipments are pushed beyond their design limits or due to operational errors. As a result, equipment downtime, quality problems, speed losses, safety hazards or environmental pollution become the obvious outcomes. All these outcomes have the potential to impact negatively the operating cost, profitability, customers' demand satisfaction, and productivity among other important performance requirements. To ensure the plant operates at the required condition while meeting its production targets at an optimal cost, maintenance management has to make conscious decisions regarding the maintenance objectives and strategies that need to be pursued.

Good maintenance assumes that maintenance objectives and strategies are not determined in isolation, but are in some way derived from factors such as company policy, manufacturing policy and other potentially conflicting demands and constraints in the company (Swanson 1997; Johnsson and Lesshamar, 1999; Swanson 2001; Pinjala et al., 2006). According to some authors (Kelly 1989; MESA 1995; Tsang, 1999; Visser and Pretorious, 2003), maintenance objectives are related to attainment of production target (through high availability) at required quality, and within the constraints of the system condition and safety. Further, maintenance resources are utilised so that the manufacturing equipments are in good condition, the plant achieves its design life, the safety standards are met, the energy use and raw material consumption are optimised among other factors (Dekker, 1996).

We summarize the maintenance objectives under five headings (as shown in Fig. 1): ensuring the plant functionality (availability, reliability, product quality etc); ensuring the plant achieves its design life; ensuring plant and environmental safety; ensuring cost effectiveness in maintenance and effective use of resources (energy and raw materials). We assume that the maintenance objectives pursued at a given plant influences the kind of performance indicators used.

Once the maintenance objectives are outlined, maintenance strategy formulation (Pinjala, 2008) is necessary to help decide which type of maintenance needs to be done, when to do it, and how often it can be done. According to Pintelon and VanPuyvelde (2006), maintenance decision making can be broadly explained in terms of maintenance actions (basic elementary work), maintenance policies and maintenance concepts. Maintenance policies are the rules or set of rules describing the triggering mechanism for the different maintenance actions. Examples of these policies are failure based maintenance (FBM), use based or time based maintenance (UBM/TBM), condition based maintenance (CBM), design out maintenance (DOM) (Coetzee, 1997; Madu, 2000; Waeyenbergh and Pintelon, 2002; Pintelon and VanPuyvelde, 2006; Savsar, 2006). A maintenance concept entails the general decision structure for both maintenance actions and policies (Gits, 1984; Gits, 1992). Some examples are reliability centred maintenance (RCM), total productive maintenance (TPM), life cycle costing (LCC) and business centred maintenance (BCM) among others. Some maintenance decision elements are carried out at the operational level, for example the basic maintenance interventions done by technicians. Other decision elements, for example the maintenance policies and concepts, apply to strategic level.

Once the objectives and strategies have been established, the success of the maintenance function is dependent on the maintenance work management. The maintenance work management cycle, as outlined by Campbell (1995), consists of work identification, planning, scheduling, execution and closing the job. Maintenance work is identified from the preventive, predictive and failure finding work orders that are usually generated by proactive maintenance. Repair work arises as a result of failure. At the heart of the maintenance function are work planning and scheduling, which defines what gets done and when. To complete the work cycle, effective work execution is vital in ensuring that required equipment condition and performance is attained.

From the review of maintenance objectives, maintenance decision making and work management, we get some insights in the complex environment under which the maintenance department functions. We presume that these elements are essential ingredients for developing maintenance performance measurement system and indicators. Likewise, they form a potential basis for performance evaluation.

3. Maintenance performance measurement review

Performance measurement is a fundamental principle of management. Like other manufacturing functions, performance measurement is important in managing the maintenance function. Well-defined performance indicators can potentially support identification of performance gaps between current and desired performance and provide indication of progress towards closing the gaps. In addition, performance measures provide an important link between the strategies and management action and thus support implementation and execution of improvement initiatives (Kaplan, 1983; White, 1996; Neely, 1999; Neely et al., 2005). Further, they can potentially help maintenance managers to focus maintenance staff and resources to particular areas of the production system that will impact manufacturing performance.

Difficulties arise when quantifying and measuring the input and output of the maintenance process. This is attributed to the complex relationship between maintenance and manufacturing (Daya and Duffuaa, 1995; Pintelon et al., 1997; Al-Najjar, 2000; Pintelon and VanPuyvelde, 2006). Some authors term the relationship between maintenance and production as paradoxical (Dunn, 1998; McGrath, 1999), since the more maintenance contributes positively to the overall strategic goals of an organization, the less noticeable it becomes to top management as a value adding activity other than just adding to the cost. On the other hand, poor maintenance can obstruct addition of value, retard the advantage of capital resource and destroy a business strategy (Al-Najjar, 2002; Alsyouf, 2004). Since maintenance is a service function for production, neither the merits nor the shortcomings of the service rendered are immediately apparent (Pintelon et al., 2000). There is a consensus among authors that there is a need for a holistic performance measurement that assesses the contribution of the maintenance function to manufacturing and business strategic objectives (Tsang, 1998; Tsang, 1999; Muthu et al., 2000).

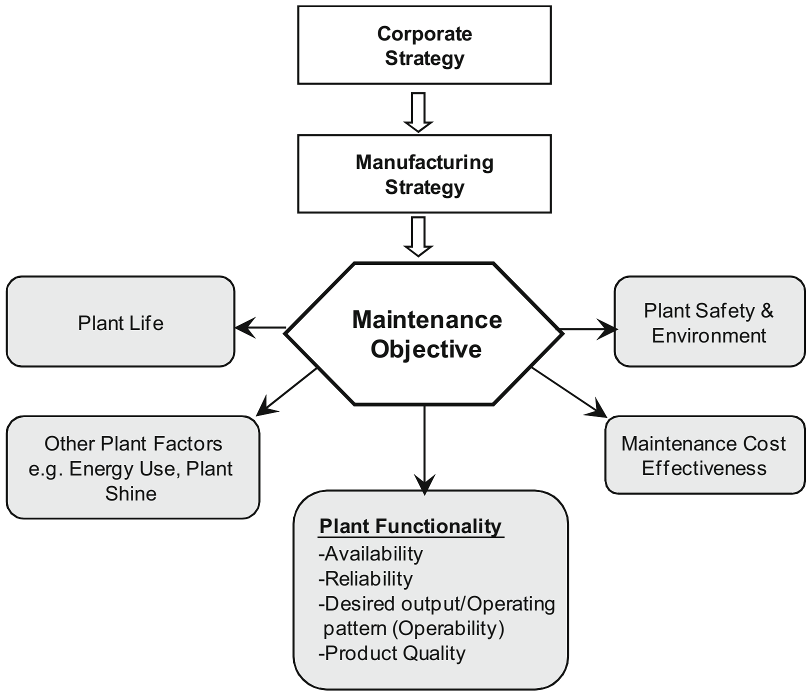

Fig. 1. A summary of maintenance objectives for a maintenance department.

Some approaches of measuring maintenance performance have been proposed in literature. Dwight (1999) proposed the use of a system audit approach in measuring the performance of maintenance system contribution to organisational success called value-based performance measurement. It takes into account the impact of maintenance activities on the future value of the organization. The main finding of Dwight's (1999) work surrounded the variation in lag between an action and its outcome. Some authors advocate use of aggregated measures like the maintenance productivity index, which measures the ratio of maintenance output to maintenance input (Lofsten, 2002). The main shortcoming of this approach is that it gives a very limited view of maintenance performance and the obvious challenge of quantifying different types of maintenance inputs. Tsang (1998) proposes a strategic approach of managing maintenance performance by the use of the popularly known balanced scorecard (Kaplan and Norton, 1992; Kaplan and Norton, 1996). The success of the balanced scorecard approach is dependent on the fact that strategy has a strong and positive effect on a firm's performance. Weber and Thomas (2006) developed a framework of defining the key performance indicator for managing the maintenance function based on physical asset management requirements and asset reliability process. The framework consists of maintenance planning, process improvement, and maintenance control. For each process, key performance indicators are defined. This framework is focused on aligning the maintenance function with the business goals and support management in measuring and managing maintenance function. A recent research (Al-Najjar, 2007) proposes a model to describe and quantify the impact of maintenance on business's key competitive objectives related to production, quality and cost. The model can be used to assess the cost effectiveness of maintenance investment and in strategic decision support on choice of different improvement plans.

Different categories of maintenance measures can be identified from literature. Arts et al. (1998) use the time horizon to classify maintenance control and performance indicators into three levels namely strategic, tactical and operational. Maintenance measures have also been derived to support control at each level. A good example is the multi-criteria hierarchical framework for maintenance performance measurement (Parida and Chattopadhyay, 2007) that consist of multi-criteria indicators for each level of management (strategic, tactical and operational). Komonen (2002) presented a hierarchical system of maintenance performance indicators and classifies indicators into three main dimensions of maintenance performance (OEE, production costs and production quality). The objective of the system is to explain the purpose and significance of various indicators at different hierarchies. Dwight (1999) classifies performance measures into a hierarchy according to their implicit assumptions regarding the impact of the maintenance system on the business. He gives five levels in the hierarchy namely overt (visible) bottom-line impact, profit-loss and overt cost impact performance, instantaneous effectiveness measures, system audit approach and time-related performance measurement.

Campbell (1995) classifies the commonly used measures of maintenance performance into three categories based on their focus. These categories are measures of equipment performance, measures of cost performance and measures of process performance. The European standard for maintenance key performance indicators (EN:15341, 2007) provides three main categories of indicators namely economic indicators, technical indicators and organisational indicators. For each category, a list of indicators is given to choose from. The other commonly used classification is leading and lagging indicators. Leading indicators monitor if the tasks are being performed that will 'lead' to results. On the other hand, lagging indicators monitor whether the results or outcomes that have been achieved. Both leading and lagging indicators are therefore important for managing the performance of the maintenance function. Moreover, the leading indicators are even more important than lagging indicators because they have the potential to avoid unfavourable situations from occurring.

This review shows the different maintenance performance measures and frameworks proposed in literature. The different categories of measures show different areas of interest in maintenance performance in both literature and practice.

Please cite this article as: Muchiri, P., et al., Development of maintenance function performance measurement framework and indicators. International Journal of Production Economics (2010), doi:10.1016/j.ijpe.2010.04.039

However, it was observed that the literature mainly proposes lists of KPI's but lacks a methodological approach of selecting or deriving them. As a result, users are left to decide the relevant KPI's for their situation. Further, an operational level-based maintenance measurement model that links maintenance objectives to maintenance process and results is lacking. Such a model could provide a basis to identify suitable performance measurement indicators for a maintenance function in a certain context.

4. Developing a basis of maintenance performance measurement

To develop a structured approach of measuring performance of the maintenance function, it is imperative to have a well-formulated maintenance strategy based on corporate and manufacturing strategy. The approach should then encapsulate a coherent theory of maintenance processes that are critical success factors towards contribution to manufacturing and business success. Recent research (Pinjala, 2008) have shown how maintenance strategy can be developed and aligned with manufacturing and corporate strategy by use of cognitive mapping and analytical network process (ANP).

The maintenance performance conceptual framework proposed in this paper (see Fig. 2) identifies key elements and processes that drive the maintenance function towards delivery of performance demanded by manufacturing objectives. The conceptual framework advocates alignment of maintenance objectives with the manufacturing and corporate objectives and thus directs the maintenance efforts towards attaining the required performance and continuous improvement of the production equipment performance. The conceptual framework has three main sections that include: maintenance alignment with manufacturing, maintenance effort/process analysis and maintenance results performance analysis.

The first section of the conceptual framework seeks to align the maintenance objectives with the corporate and manufacturing strategy. By reviewing the composite requirements of the various stakeholders, the performance requirements of the manufacturing system can be defined. Based on these manufacturing requirements, the maintenance objectives for the maintenance function are derived. Cognitive mapping is an important tool of mapping the cause and effect relationship among various strategic elements (Ackermann et al., 2005). We refer to the research of Pinjala (2008) for the mapping and alignment of maintenance objectives and processes to corporate objectives. The maintenance objectives help the maintenance management to set performance targets and benchmarks for the desired maintenance results. The performance targets are related with the equipments' condition and performance, and maintenance resource utilization (cost) and they are used as a standard against which the maintenance results are analyzed.

To attain the desired results and maintenance objectives, management of maintenance process (efforts) is important. These maintenance processes equate to critical success factors that drive maintenance performance. The key steps for the maintenance process are outlined as work identification, work planning, work scheduling and work execution (Campbell, 1995). *Work identification* deals with identifying the right work to be performed at the right time by the maintenance staff based on maintenance objectives. It identifies and controls failure modes affecting the equipments ability to perform their intended function at the required performance. Activities are evaluated based on the consequences of failure on equipment performance so that maintenance resources are directed to effective use. This in turn ensures that the maintenance activities contribute effectively towards the performance results. *Work planning* develops procedures and work orders for the maintenance activities identified. This involves identification of resource requirements, safety precautions and instructions required to carry out the job. *Scheduling* evaluates the availability of all resources required for the work and the time frame for executing it. The schedule also evaluates the impact of maintenance work on the production schedule. *Work execution* ensures the scheduled activities are carried out within the allocated time and through effective use of resources. This process forms a complete loop of maintenance process and ensures maintenance work is done effectively. To manage the maintenance process, performance indicators need to be defined for each step. Since maintenance processes are the determinant of the maintenance outcomes and results, the indicators related with the maintenance process are referred to as *leading indicators*.

Once the maintenance processes are completed, the *maintenance results* for a given period need to be monitored. The results are measured in terms of equipments' condition and performance, together with maintenance cost and effective use of maintenance resources. Careful analysis of maintenance results is important since it supports identification of performance gaps and hence supports continuous improvement of equipments' performance. The performance analysis involves comparison of the achieved

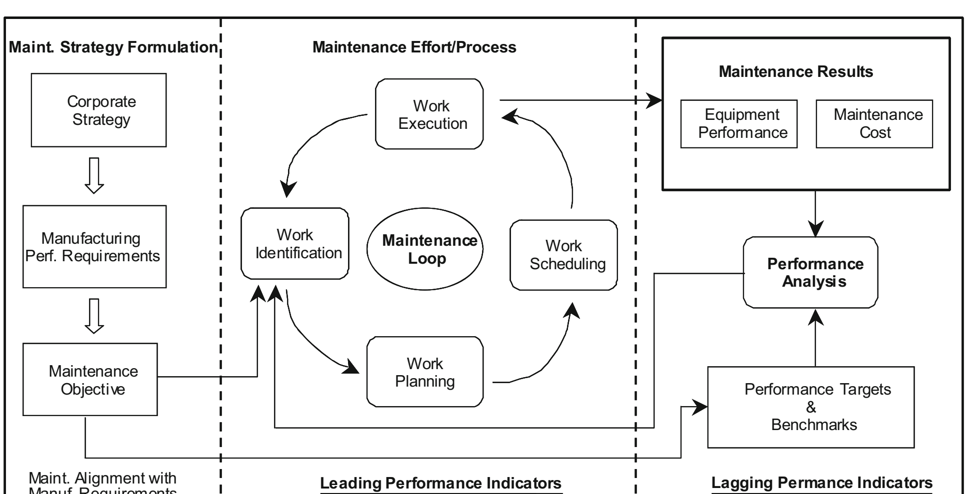

Fig. 2. The Performance measurement framework for the maintenance function.

results with the targets, comparison with the historical data, analysis of the trends and review of the maintenance activities' costs. The indicators related with the maintenance results are referred to as *lagging indicators* since they are known after a given period has passed or events happened. The framework outlines the elements that need to be considered to enable the maintenance function support manufacturing performance. With the use of this framework, the maintenance performance indicators can be identified for each element.

4.1. *The maintenance performance indicators*

The maintenance performance framework developed here outlines the key elements that are important in the management of the maintenance function. The elements ensure the right work is identified (based on the set objectives) and effectively executed for guaranteed results that are in line with the manufacturing performance requirements. Each step is therefore important for successful management of the maintenance function. Both the maintenance process (leading) indicators and maintenance results (lagging) indicators are therefore important for measuring the performance of the maintenance function.

For each element, the main challenge is to identify the performance indicators that will tell whether the element is managed well. This raises the question of what makes a good performance indicator. Good indicators should support monitoring and control of performance, help identification of performance gaps, support learning and continuous improvement, support maintenance actions towards attainment of objectives and provide focus of maintenance resources to areas that impact manufacturing performance. The analysis of the various maintenance performance indicators is however beyond the scope of this paper. The indicators shown in this paper for each element are the ones that appear often in literature. Of course additional measures can be added if desired.

4.1.1. *Maintenance process (leading) indicators*

The maintenance leading indicators monitor whether the tasks are being performed well so that the desired production results can be attained. The maintenance process is addressed through: work identification (based on maintenance objectives and performance gaps), work planning, work scheduling, and work execution. Key performance indicators for each process are proposed to measure if requirements of each process are satisfied. This section proposes some examples of indicators from literature that may be relevant to the proposed framework.

For work identification, maintenance should identify potential failures, and immediately attend to most of the preventable causes of failure. Precautionary maintenance work is known to mitigate adverse failure consequences like high downtime, maintenance cost, safety and environmental hazards. Among the key performance indicators for work identification are the percentage man-hours dedicated to precautionary work over a specified period. Some recommended targets for this indicator

Category	Measures / Indicators	UNITS	Description	Recommended Targets
Work Identification	Percentage of Proactive work	%	Man-hours envisaged for proactive work/Total man hours available	75% - 80%
	Percentage of Reactive work	%	Man-hours used for reactive work/Total man-hours available	10% - 15%
	Percentage of Improvement work	%	Man-hours used for improvement & modification/Total man-hour available	5% - 10%
	Work request response rate	%	Work requests remaining in 'request' status for <5days/Total work requests	80% of requests
Work Planning	Planning Intensity/Rate	%	Planned work / Total work done	95% of all work orders
	Quality of planning	%	Percentage of work orders requiring rework due to planning/All WO	< 3% of all WO
	Planning Responsiveness	%	Percentage of WO in planning status for <5days/ All WO	> 80% of all WO
Work Scheduling	Scheduling Intensity	%	Scheduled man-hours/ Total available man-hours	> 80% of available man-hours
	Quality of scheduling	%	Percentage of WO with delayed execution due to material or man-power	< 2%
	Schedule realization rate	%	WO with scheduled date earlier or equal to late finish date/All WO	> 95% of all WO
Work Execution	Schedule Compliance	%	Percentage of wok orders completed in scheduled period before late finish date	>90%
	Mean Time To Repair (MTTR)	Hours	Total Downtime/No. of failures	
	Manpower Utilization rate	%	Total Hours spent on tasks / Available Hours	> 80%
	Manpower Efficiency	%	Time Allocated to Tasks/Time spent on tasks	
	Work order turnover	%	No. of completed tasks/ No. of received tasks	
	Backlog size	%	No. of overdue tasks/ No. of received tasks	
	Quality of Execution(Rework)	%	Percentage of maintenance work requiring rework	< 3%

Fig. 3. A summary of leading performance indicators for maintenance process.

Please cite this article as: Muchiri, P., et al., Development of maintenance function performance measurement framework and indicators. International Journal of Production Economics (2010), doi:10.1016/j.ijpe.2010.04.039

percentage is 85–90%, leaving 10–15% to reactive work (Weber and Thomas, 2006). The percentage of time spent on reactive work may give an indication of the breakdown intensity and maintenance responsiveness to unplanned work.

To ensure maintenance work is not left to chance, planning and scheduling elements are important. A high percentage of planning is instrumental in maximizing the maintenance efficiency and ensuring all the necessary resources are available before the work commences. Among the important indicators for work planning are the percentage of planned work, percentage of work orders requiring rework due to planning and planning rate (percentage of time planned for work over available time). For work scheduling, the important indicators are the scheduling intensity (percentage of scheduled man-hours to the total available man-hours) and percentage of delayed work orders due to lack of material or manpower. Work execution performance indicators help monitor the effectiveness (schedule compliance, quality of work done, etc.) and efficiency (manpower and resource utilization) of maintenance in carrying out the maintenance job. Among the key performance indicators are schedule compliance (percentage of work completed within the scheduled time), percentage of reworks, percentage of completed task over all received tasks, the number of overdue tasks and manpower efficiency. Maintenance process (leading) performance indicators are summarized as shown in Fig. 3 with recommended targets based on Weber and Thomas (2006).

4.1.2. Maintenance results (lagging) indicators

The results of the maintenance process can be summarized as reliability, availability and operability of the technical systems. These are the core elements that maintenance seeks to address and thus, give measures of maintenance process success. Since maintenance seeks to meet its objectives at an optimal cost, it is imperative to measure the cost effectiveness of the maintenance activities. The lagging indicators are therefore used to measure maintenance results in terms of equipment performance and maintenance cost. A summary of the commonly used lagging maintenance indicators are shown in Fig. 4.

4.1.2.1. Equipment performance indicators. The performance of production equipment can be explained by the popularly known overall equipment effectiveness indicator (OEE)(Nakajima, 1988) and some variant of OEE like the overall production effectiveness (OPE)(Muchiri and Pintelon, 2008). The OEE metric supports maintenance management in the measurement of equipment availability and planning rate, which are functions of the planned and unplanned downtime respectively. Among the key elements that maintenance seeks to monitor and control (see Fig. 5) are the equipment failure frequency (measured by MTBF and the number of unplanned maintenance interventions) and the repair time. These two elements determine the unplanned downtime of the equipment. The maintenance planning rate is determined by the number of planned maintenance activities and the PM time. The measurement of these performance elements in the OEE framework supports maintenance management to do root cause analysis for equipments availability and reliability improvement.

It is clear that maintenance is not responsible for all production losses experienced by equipment e.g. idle time or setup time. In some cases, e.g. speed and quality loss, maintenance may be a factor but is not the only contributor. For maintenance function to improve performance, it should focus on the portion of indicators they influence. However, the OEE diagram is instrumental in identifying maintenance function related losses. In addition to the maintenance related causes, the OEE metric gives a broader perspective of losses experienced by equipments and thus supports overall improvement of equipment productivity.

CATEGORY	MEASURES / INDICATORS	UNITS	DESCRIPTION
Measures of Equipment Performance	No. of Failures	No.	No. of Failures classified by their consequences: Operational, Non-operational, safety etc
	Failure / Breakdown Frequency	No./ Unit Time	No. of failures per unit time (A measure of Reliability)
	MTBF	Hours	Mean Time Between Failure (A measure of Reliability)
	Availability	%	MTBF/(MTBF + MTTR) = Uptime/(Uptime + downtime)
	OEE	%	Availability * Performance Rate * Quality rate
Measures of Cost Performance	Direct Maintenance Cost	$	Total corrective and Preventive Maint. cost
	Breakdown Severity	%	Breakdown cost / Direct Maint. Cost
	Maintenance Intensity	$ / Unit production	% of Maint. Cost per unit of products produced in a period
	% Maint. Cost component over Manufacturing cost	%	% Maint. Cost / Total Manufacturing cost
	ERV (Equipment Replacement Value)	%	Maint. Cost / New condition Value
	Maintenance Stock turnover	No.	Ratio of cost of materials used from stock within a period
	Percentage Cost of Personnel	%	Staff Cost / Total Maintenance Cost
	Percentage Cost of subcontractors	%	Expenditure of Subcontracting / Total Maintenance cost
	Percentage cost of Supplies	%	Cost of Supplies / Total Maintenance Cost

Fig. 4. A summary of lagging maintenance performance indicators.

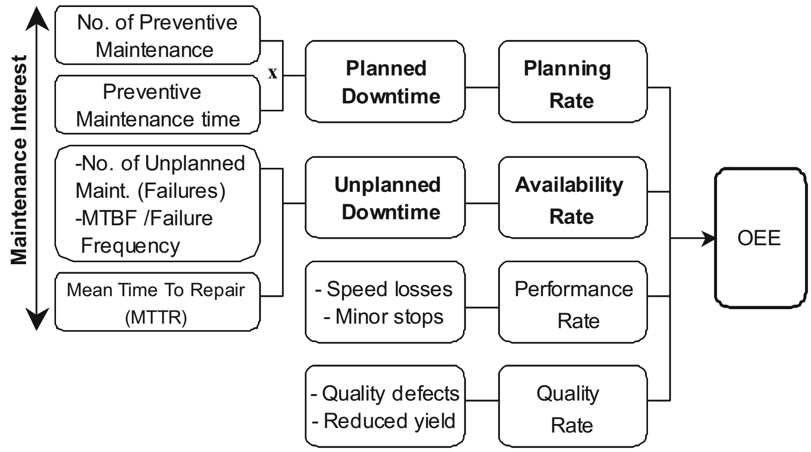

Fig. 5. Important maintenance performance indicators in the OEE metric.

Since the primary function of maintenance is to reduce or eliminate failures and their resulting consequences, among the key maintenance result indicators are the number of failures (*N*), mean time between failure (MTBF), Breakdown frequency (*N*/unit time), availability and overall equipment effectiveness as summarized in Fig. 4.

4.1.2.2. Maintenance costs. Maintenance cost is in many instances influenced by the effectiveness and efficiency in which maintenance is performed. Maintenance cost and related indicators are therefore important measures of maintenance performance. Maintenance effectiveness is demonstrated by proactively identifying the right work and doing it at the right time. This in turn eliminates chances of secondary damage, safety and environmental consequences and thus minimizes the maintenance cost. Maintenance efficiency in planning and scheduling resources and manpower can potentially minimize the maintenance cost. Some of the important cost performance indicators are summarized as shown in Fig. 4.

The cost and equipment performance indicators are instrumental in doing performance analysis of the maintenance function and identifying the performance gaps that would trigger management actions. They provide a good basis of conducting a root cause analysis for establishing the reasons for performance gaps, which leads to learning and improvement of the maintenance function.

5. Conclusions

In this paper, a conceptual framework that provide guideline for choosing maintenance performance indicators, through alignment of manufacturing objectives and maintenance objectives, has been developed. The conceptual framework provides a generic approach of developing maintenance performance measures with room for customization with respect to individual company needs. The aim is to ensure that the key maintenance processes that may lead to desired results have been carried out and evaluated.

This research demonstrates that performance indicators are not defined in isolation, but should be the result of a careful analysis of the interaction of the maintenance function with other organisational functions. It seems evident that, in the overall interest of the organization, that maintenance performance criteria should be balanced with the requirements of the manufacturing objectives. Further research work is recommended on the methodological approach of choosing the right maintenance performance indicators among the given indicators listed in literature. Since the availability of maintenance performance frameworks and indicators may not necessarily guarantee performance improvement, a future research should investigate how performance measures are effectively used to drive performance improvement in practice.

References

Ackermann, F., Eden, C., Brown, I., 2005. The Practice of Making Strategy: A Step by Step Guide, London, UK. Sage Publication.

Al-Najjar, B., 2000. Impact of real-time measurements of operating conditions on effectiveness and accuracy of vibration-based maintenance policy: a Case study in paper mill. Journal of Quality in Maintenance Engineering 6 (4), 275–287.

Al-Najjar, B., 2002. Data coverage and quality, diagnosis and maintenance decision, and their economic Impact on the company's profits: case studies. Proceedings of the Conference of 16th International Euromaintenance 3–5 June, Helsinki, Finland.

Al-Najjar, B., 2007. The lack of maintenance and not maintenance which costs: a model to describe and quantify the impact of vibration-based maintenance on company's business. International Journal of Production Economics 107 (1), 260–273.

Alsyouf, I. (2004). Cost effective maintenance for competitive advantage School of Industrial Engineering. Sweden, Vaxjo University. Doctoral report.

Arts, R.H.P.M., Knapp, G.M., Mann, L., 1998. Some aspects of measuring maintenance performance in process industry. Journal of Quality in Maintenance Engineering 4 (1), 6–11.

BSI, 1984. Glossary of maintenance terms in Terotechnology. British Standard Institution (BSI), London; BS 3811.

Campbell, J.D., 1995. Uptime: Strategies for Excellence in Maintenance Management. Productivity Press, Portland, OR.

Coetzee, L., Jasper, 1997. Maintenance. Maintenance Publishers, South Africa.

Cooke, F.L., 2000. Implementing TPM in plant maintenance: some organizational barriers. International Journal of Quality & Reliability Management 17 (9), 1003–1016.

Daya, B., Duffuaa, S., 1995. Maintenance and quality: the missing link. Journal of Quality in Maintenance Engineering 1 (1), 20–26.

Dekker, R., 1996. Application of maintenance optimization models: a review and analysis. Reliability Engineering and System Safety 51, 229–240.

Dunn, R., 1998. How much are you worthy? Plant Engineering 52 (2).

Dwight, R., 1995. Concepts for measuring maintenance performance. In: Martin, H. (Ed.), New Developments in Maintenance: An International View. IFRIM, Eindhoven.

Dwight, R., 1999. Frameworks for Measuring the Performance of the Maintenance System in a Capital Intensive Organization, University of Wollongong, Australia, Doctoral Report.

EN:15341, 2007. Maintenance Key Performance Indicators. European Committee for Standardization (CEN), Brussels, Belgium.

Fleischer, J., U. Weismann, S., Niggeschmidt (2006). Calculation and Optimisation Model for Costs and Effects of Availability Relevant Service Elements. In: 13Th CIRP International Conference on Life Cycle Engineering; Proceedings of LCE2006.

Gits, C.W. (1984). On the maintenance concept for a technical system: a framework for design, Eindhoven University of Technology. Ph.D. Thesis.

Please cite this article as: Muchiri, P., et al., Development of maintenance function performance measurement framework and indicators. International Journal of Production Economics (2010), doi:10.1016/j.ijpe.2010.04.039

Gits, C.W., 1992. Design of Maintenance concepts. International Journal of production Economics 24, 217–226.
Johnsson, P., Lesshamar, M., 1999. Evaluation and improvement of manufacturing performance measurement systems—the role of OEE. International Journal of Operations & Production Management 19 (1), 55–78.
Kaplan, R.S., 1983. Measuring manufacturing performance: a new challenge for managerial accounting research. The Accounting Review 58 (4), 686–705.
Kaplan, R.S., Norton, D.P., 1992. The balanced scorecard—measures that drive performance. Harvard Business Review 70 (5), 71–79.
Kaplan, R.S., Norton, D.P., 1996. The Balanced Scorecard, Boston, MA. Harvard Business School Press.
Kelly, A., 1989. Maintenance and its Management. Conference communication London.
Komonen, K., 2002. A cost model of industrial maintenance for profitability analysis and benchmarking. International Journal of production Economics 79 (1), 15–31.
Lofsten, H., 2002. Measuring maintenance performance—in search for a maintenance productivity index. International Journal of Production Economics 63 (1), 47–58.
Madu, C., 1999. Reliability & quality interface. International Journal of Quality & Reliability Management 16 (7), 691–698.
Madu, C., 2000. Competing through maintenance strategies. International Journal of Quality & Reliability Management 17 (9), 937–948.
McGrath, R., 1999. Maintenance: The missing link in supply chain strategy. Industrial Management Jul/Aug.
MESA, 1995. Maintenance Engineering Society of Australia Capability Assurance: A Generic Model of Maintenance. Maintenance Engineering Society of Australia (MESA), Australia.
Muchiri, P.N., Pintelon, L., 2008. Performance measurement using overall equipment effectiveness (OEE): Literature review and practical application. International Journal of Production Research 46 (13), 3517–3535.
Muthu, S., Devadasa, S.R., Ahmed, Saleem, Suresh, P., Baladhanndayutham, R., 2000. Benchmarking for strategic maintenance quality improvement. Benchmarking 7 (4), 292–303.
Nakajima, S., 1988. Introduction to TPM: Total Productive Maintenance. Productivity Press, Cambridge, MA.
Neely, A., Gregory, M., Platts, K., 2005. Performance measurement system design: a literature review and research agenda. International Journal of Operations & Production Management 25 (12), 1228–1263.
Neely, A.D., 1999. The performance measurement revolutions: why now and where next. International Journal of Operation & Production management 19 (2), 205–228.
Parida, A., Chattopadhyay, G., 2007. Development of a multi-criteria hierarchical framework for maintenance performance measurement (MPM). Journal of Quality in Maintenance Engineering 13 (3), 241–258.
Pinjala, K.S. (2008). Dynamics of Maintenance Strategy. Katholieke Universiteit Leuven. Belgium. Doctoral Report.
Pinjala, K.S., Pintelon, L., Verreecke, A., 2006. An empirical investigation on the relationship between business and maintenance strategies. International Journal of Production Economics 104, 214–229.
Pintelon, L., Gelders L., Puyvelde F.V., (1997). Maintenance Management Leuven, Belgium, Acco.
Pintelon, L., Gelders, L., Puyvelde, F.V., (2000). Maintenance Management. Leuven, Belgium, Acco.
Pintelon, L., VanPuyvelde, F., (2006). Maintenance Decision Making. Leuven, Belgium, Acco.
Savsar, M., 2006. Effects of maintenance policies on the productivity of flexible manufacturing cells. Omega International Journal of management Science 34, 274–282.
Swanson, L., 1997. An empirical study of the relationship between production technology and maintenance management. International Journal of Production Economics 53 (2), 191–207.
Swanson, L., 2001. Linking maintenance strategies to performance. International Journal of Production Economics 70 (3), 237–244.
Tsang, A.H.C., 1998. A strategic approach to managing maintenance performance. Journal of Quality in Maintenance Engineering 4 (2), 87–94 (8).
Tsang, A.H.C., 1999. Measuring maintenance performance: a holistic approach. International Journal of Operations and Production management 19 (7), 691–715.
Visser, J.K., Pretorious, M.W., 2003. The development of a performance measurement system for maintenance. SA Journal of Industrial Engineering 14 (1), 83–97.
Waeyenbergh, G., Pintelon, L., 2002. A framework for industrial maintenance concept development. International Journal of Production Economics 77, 299–313.
Weber, A., Thomas, R., 2006. Key Performance Indicators: Measuring & Managing the Maintenance Function. Ivara Corporation.
White, P.G., 1996. A survey and taxonomy of strategy related performance measures for manufacturing. International Journal of Operations & Production Management 16 (3), 42–61.

Please cite this article as: Muchiri, P., et al., Development of maintenance function performance measurement framework and indicators. International Journal of Production Economics (2010), doi:10.1016/j.ijpe.2010.04.039