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Empirical analysis of maintenance performance measurement in Belgian industries

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Performance measurement is a fundamental instrument of management. For maintenance management, one of the key issues is to ensure the maintenance activities planned and executed have given the expected results. This can be facilitated by effective use of rigorously defined key performance indicators (KPI) that are able to measure important aspects of maintenance function. In this paper, an industrial survey was carried out to explore the use of performance measurement in maintenance management. Based on survey responses, analyses were performed on popularly used KPI, how these KPI are sourced or chosen; the influence of manufacturing environment and maintenance objectives on KPI choice and effective use of these KPI in decision support and performance improvement. It was found that maintenance performance measurement is dominated by lagging indicators (equipment, maintenance cost and safety performance). There is lesser use of leading (maintenance work process) indicators. The results showed no direct correlations between the maintenance objectives pursued and the KPI used. Further analysis showed that only a minority of the companies have a high percentage of decisions and changes triggered by KPI use and only a few are satisfied with their performance measurement systems. Correlation analysis showed a strong positive linear relationship between degree of satisfaction and process changes/decisions triggered by KPI use, with the least satisfied people having the least decisions and changes triggered by KPI use. The results indicate some ineffectiveness of performance measurement systems in driving performance improvement in industries.

Keywords: maintenance; performance measurement; key performance indicators (KPI)

1. Introduction

Due to intense global competition and increasing demands from stakeholders, companies are striving to improve and optimise their productivity in order to stay competitive. The performance and competitiveness of manufacturing companies is dependent on the reliability and availability of their production facilities (Coetzee 1997, Madu 2000, Fleischer *et al.* 2006). Though production facilities are designed to ensure successful operation through the anticipated service life, deterioration begins to take place as soon as

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they are commissioned due to normal wear or operational errors. As a result, equipment down time, quality problems, slower production rate, safety hazards or environmental pollution becomes the obvious outcomes. These outcomes have the potential to impact negatively on the operating cost, profitability, customers' demand satisfaction, and productivity among other important performance requirements. It has been asserted by some authors (Campbell 1995, Madu 1999, 2000) that equipment maintenance and system reliability are important factors that affect the organisation's ability to provide quality and timely services to customers and be ahead of the competition. Maintenance is therefore vital for sustainable performance of a production plant.

To ensure the plant achieves the desired performance at an optimal cost, maintenance managers need to keep track of performance information on maintenance operations and equipment performance. One of the key issues is to ensure and verify that the maintenance activities planned and executed have given the expected results. The performance information may be focused on maintenance organisation, technical and economical factors with addition to other factors of interest like safety and environmental performance.

Like in other manufacturing functions, performance measurement is an important instrument in maintenance management. 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 strategies and management action and thus support implementation and execution of improvement initiatives (Kaplan 1983, White 1996, Neely *et al.* 2005). Further, they can potentially help maintenance managers to focus maintenance staff and resources to particular areas of production system that will impact manufacturing performance. This can only be realised through effective use of rigorously defined performance indicators that are able to measure important elements of maintenance and equipments' performance. For effective decision making by maintenance managers, the measures need to be accurate, reliable and current information that is presented in an understandable way.

With the use of an industrial survey, the objective of this research is to first establish the most important indicators or category of indicators used in managing maintenance performance. The second point of interest is to investigate how these indicators are chosen, sourced or derived. This is done by establishing the correlation between manufacturing environment and maintenance focus, based on maintenance objectives and indicators used. Finally, the effective use of maintenance indicators will be investigated based on measurement frequencies, maintenance actions triggered and managers satisfaction in the use of indicators. It is in the interest of this research to establish the role of maintenance performance measurement in continuous improvement of maintenance efficiency and ultimately equipments' performance.

2. Literature review

2.1 *Maintenance operating environment*

The scope of maintenance in a manufacturing environment is illustrated by its various definitions. British Standards Institute defines maintenance 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). 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 optimisation 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, safety and responsiveness (Tsang 1999). Similarly, Kelly states that the objective of maintenance is to achieve the agreed output level and operating pattern at minimum resource cost within the constraints of the system condition and safety (Kelly 1989). The desired production output is achieved through high availability, which is influenced by equipment reliability and maintainability. Maintenance is also partly responsible for technical system safety and to ensure the plant is kept in good condition and acceptable system image (Visser and Pretorious 2003).

We can summarise the maintenance objectives under the following categories (based on Kelly 1998):

- Ensuring the plant functions (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).

For production equipment, ensuring the system function is the prime maintenance objective. Maintenance has to provide the required reliability, availability, efficiency and capability of production system in accordance to the need of these characteristics. Ensuring system life refers to keeping the equipment in good condition to achieve or prolong their design life. In this case, cost has to be optimised to meet the desired plant condition (Dekker 1996). Plant safety is very important in case failures have catastrophic consequences. The cost of maintenance has to be minimised while keeping the risks within strict limits and by meeting the statutory requirements. Finally, maintenance has a role of ensuring the other plant factors like effective utilisation of energy, materials and maintenance resources are met.

We assume that the maintenance performance measures/indicators used in a given plant are directly influenced by the maintenance objectives they wish to pursue in accordance with the needs of its manufacturing environment. It is the interest of this research to investigate the influence of operating environment on the choice of maintenance performance indicators.

2.2 *Maintenance performance measurement*

The importance of maintenance performance measurements have been discussed extensively by many authors (Arts *et al*. 1998, Tsang 1999, Visser and Pretorious 2003, Weber and Thomas 2006, Parida and Chattopadhyay 2007). Maintenance managers require performance information to monitor and control maintenance processes and results, and provide indication towards improvement. Performance measures support the building of actions needed to attain equipments performance as required by the strategic goals. It is in the interest of managers to measure the efficiency and effectiveness of maintenance process, establish the relationship between maintenance inputs and outputs, and therefore justify investments in maintenance (Parida and Chattopadhyay 2007). Apart from providing information, performance measures influence what people do and thereby serve as a motivational tool that drives decisions and actions that are consistent with the strategy of the organisation.

Different categories of maintenance performance measures/indicators can be identified from literature. The total productive maintenance (TPM) concept (Nakajima 1988), launched in the 1980s, provided a quantitative metric called overall equipment effectiveness (OEE) for measuring productivity of manufacturing equipments. It identifies and measures losses of important aspects of manufacturing namely availability, performance/speed and quality rate. This supports the improvement of equipment effectiveness and thereby its productivity. The OEE concept has become increasingly popular and has been widely used as a quantitative tool essential for measurement equipment performance in industries (Huang and Dimukes 2003, Muchiri and Pintelon 2008). Arts and Mann use the time horizon to classify maintenance control and performance indicators into three levels namely strategic, tactical and operational (Arts *et al*. 1998). Some indicators proposed for operational control are; planned hours over hours worked, work orders (WO) executed over WO scheduled, preventive maintenance (PM) hours over total maintenance hours among others. Parida proposes a multi-criteria hierarchical framework for maintenance performance measurement (Parida and Chattopadhyay 2007) that consist of multi-criteria indicators for each level of management (i.e. strategic, tactical and operational). These multi-criteria indicators are categorised as equipment/process related (e.g. capacity utilisation, OEE, availability, etc.), cost related e.g. maintenance cost per unit production cost), maintenance task related (e.g. ratio of planned and total maintenance tasks), customer and employee satisfaction, and health safety and environment. Indicators are proposed for each level of management in each category.

Campbell classifies the commonly used measures of maintenance performance into three categories based on their focus (Campbell 1995). These categories are:

- measures of equipment performance (e.g. availability, reliability, etc.),
- measures of cost performance (e.g. maintenance, labour and material cost) and
- measures of process performance (e.g. ratio of planned and unplanned work, schedule compliance, etc.).

Coetzee outlines four categories of maintenance performance measures with detailed indicators for each category (Coetzee 1997). These category of indicators are:

- maintenance results (measured by availability, mean time to failure (MTTF), breakdown frequency, mean time to repair (MTTR) and production rate),
- maintenance productivity (measured by manpower utilisation, manpower efficiency and maintenance cost component over total production cost),
- maintenance operational purposefulness (measured by scheduling intensity (scheduled tasks time over clocked time), breakdown intensity time (spent on breakdown over clocked time), breakdown severity (breakdown cost over total maintenance cost), work order turnover, schedule compliance and tasks backlog), and
- maintenance cost justification (measured by maintenance cost intensity (maintenance cost per unit production), stock turnover and maintenance cost over replacement value).

Ivara Corporation developed a framework of defining the key performance indicator for managing maintenance function based on the physical asset management requirements and asset reliability process (Weber and Thomas 2006). They propose 26 key maintenance performance indicators and classify them into two broad categories of leading and lagging indicators. Leading indicators monitor if the tasks are being performed that will 'lead' to results (e.g. if the planning took place or if the scheduled work was completed on time) while lagging indicators monitor the results or outcomes that have been achieved (e.g. the number of equipment failures and down time). Leading indicators are classified as work identification (e.g. percentage of proactive work done), work planning (e.g. percentage of planned work), work scheduling and work execution (e.g. schedule compliance). Lagging indicators are classified as equipment performance (number of functional failures, safety and environmental incidents, and maintenance related downtime) and cost related measures (e.g. maintenance cost per unit output, maintenance cost over replacement value and maintenance cost over production cost). Dwight (1995, 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 (e.g. direct maintenance cost), profit-loss and visible cost impact performance (e.g. total failure/down time cost), instantaneous effectiveness measures (e.g. availability, OEE), system audit approach (e.g. percentage of planned work and work backlogs) and time related performance measurement (e.g. life cycle costing and value based performance measurement). The main finding of Dwight (1999) concerned the variation in lag between an action and its outcome.

The maintenance performance literature shows that different authors have different ways of classifying maintenance indicators. Furthermore, differences can be seen from the choice of indicators. However, some indicators and category of indicators have popularly been recognised by all authors as vital for management of maintenance function. For example, much emphasis has been laid on equipment performance in terms of number/frequency of breakdowns, MTTF, availability and OEE. Similarly, maintenance cost-related measures are deemed important. Measures of maintenance efforts are considered important by many authors though different authors used different terminologies (e.g. maintenance productivity and operational purposefulness (Coetzee 1997), maintenance efforts (Campbell 1995), maintenance work management (Weber and Thomas 2006)) to describe them. However, it was observed that the literature mainly proposes lists of KPI but lacks a methodological approach of selecting or deriving them. As a result, users are left to decide the relevant KPI for their situation. So, one of our survey objectives is to investigate how maintenance KPI are sourced and chosen.

Based on the literature, we summarise the commonly used maintenance performance indicators into two major categories. We define the maintenance process or effort indicators as leading indicators and maintenance results indicators as lagging indicators (as shown in Figure 1). Using the definition of Weber and Thomas (2006), leading indicators monitor if the tasks are being performed that will lead to expected outcome while lagging indicators monitors the outcomes that have been achieved. Under maintenance process indicators, we have three categories of indicators namely:

(1) work identification,
(2) work planning and scheduling, and
(3) work execution indicators.

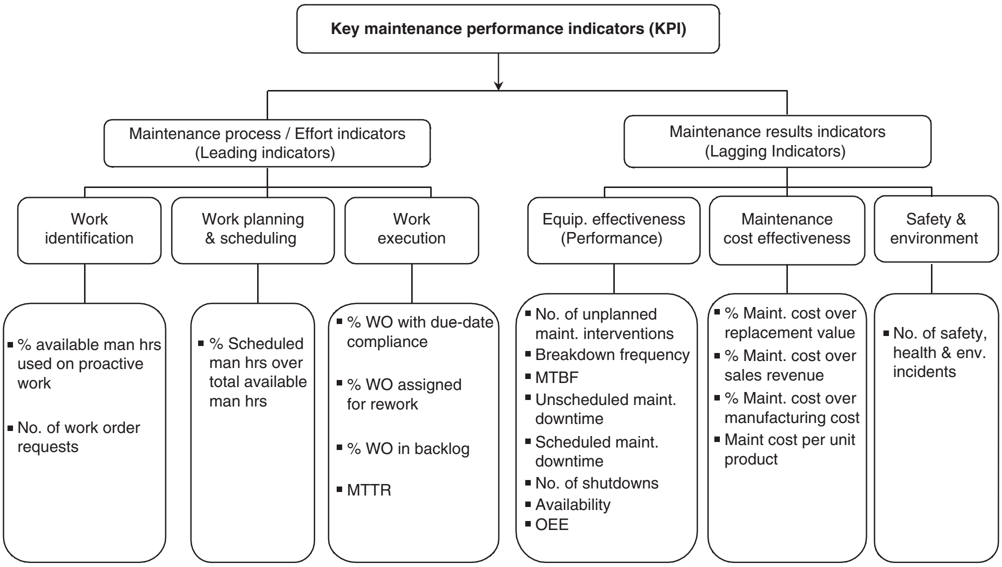

Figure 1. Key maintenance performance indicators in literature.

For maintenance results, we have three categories of indicators namely:

(1) equipment performance,
(2) maintenance costs, and
(3) safety and environment indicators.

For each category, performance indicators have been outlined. Among the survey objectives is to investigate the extent in which these indicators are used in industries, establish the most frequently used, i.e. popular indicators, and investigate how effectively they are used in maintenance management.

3. Research methodology

3.1 *Survey approach*

The objective of this paper is to explore the use of indicators in managing maintenance performance in the industries, investigate how these indicators are sourced or chosen and the influence of manufacturing environment/maintenance objectives on KPI choice, and finally investigate the effective use of these indicators in managing the maintenance function based on measurement frequencies, maintenance actions triggered and managers satisfaction in the use of indicators. Survey research strategy was chosen as a valuable means to seek insights on the use of maintenance performance indicators in practice. Thus, this research work can be classified as an exploratory study, where information is collected using literature, interviews or surveys to find out what is happening, seek new insights into and assess the whole phenomenon in a new light (Robson 2002). Further, we can classify this research as a deductive research, where literature is used to identify theories and theoretical framework of OEE, which are tested using survey data (Saunders *et al*. 2007). Survey research strategy was chosen as it allows collections of a large amount of data from a sizeable population through the administered questionnaire (Saunders *et al*. 2007).

Since the data is standardised, it allows easy comparison and quantitative analysis using descriptive and inferential statistics.

The focus of the survey was on maintenance managers, maintenance engineers and other senior professionals within the maintenance function. This rank was chosen since high-ranking informants are considered to be a reliable source of information according to Phillips (1981). The survey was intended to reach as many potential candidates as possible in Belgium and other European Industries to ensure diverse sample. Therefore, the sampling methodology used was simple random. To boost the response rate, questions were made as clear and concise as possible. Closed questions were used, since according to Dillman (2000), they are quicker and easier to answer, as they require minimal writing. Responses are also easier to compare, as they are predetermined. For the closed questions, lists, ratings and quantity types of questions (Saunders *et al.* 2007) were used in the questionnaire to acquire the various data required. When appropriate, the five-point Likert scale was used.

The respondents were offered anonymity to increase response rate (for those who prefer confidentiality) and to increase veracity of responses. To ensure clarity of the questionnaire, an in-depth interview and pilot study were conducted in six companies to further improve the questions. The self-administered questionnaires were used in the survey and administered to the respondents through email and in other cases by hand delivery. The unit of analysis was at company level and thus one questionnaire was delivered to an individual respondent at each company.

3.2 *Data*

A sample of 400 companies were identified using the Belgium Maintenance Association (BEMAS 2007) due to its diverse network of maintenance managers and engineers from all manufacturing sectors. The standard European industrial classification code (NACE 2008) was used to classify the type of industry in the manufacturing sector for the various respondents. The companies targeted deals with the manufacture of:

- food products,
- pulp and paper products,
- coke and refined petroleum products,
- chemical products,
- basic metal and fabricating metal products,
- machinery and equipments,
- automotive industry,
- pharmaceutical,
- mining,
- electricity generation, and
- nuclear sectors.

These sectors have substantial amount of maintenance activities. Using the BEMAS network, some consultants in maintenance management were also contacted. The potential participants were contacted by email and phone calls were later done as a follow up to boost response rate.

In total, 41 responses were returned, representing a response rate of 10.25%. The profile of the respondents is shown in Table 1. Based on the profile of the respondents, the

Table 1. The profile of respondent companies.

	Respondent (%)
Manufacturing sector of respondents	
Manufacturing of food	2.4
Pulp, paper and paper products industry	2.4
Cokes, refined petroleum industry	2.4
Chemicals, man-made fibres industry	36.6
Manufacturing of basic metals and fabricating metal products	7.3
Manufacturing of machinery	4.9
Automotive industry	9.8
Consulting	2.4
Pharmaceutical industry	7.3
Mining industry	0.0
Electricity production	5.0
Nuclear sector	0.0
Other	19.5
Company size of respondents	
<50 employees	7.3
50–100 employees	12.2
100–250 employees	9.8
250–500 employees	26.8
500–1000 employees	17.1
>1000 employees	26.8

respondents were dominated by the chemical industries with a rate of 36.6% of the respondents. This was contrary to our expectation of proportionate distribution of respondents among the various sectors. We suppose that the chemical industries have more interest in maintenance performance measurement due to its critical operations and machinery. The second highest group of 'others' (19.5%) consisted of companies in glass production, medical devices and construction materials. On another note, most of the respondents (82.5%) have more than 100 employees while 26.8% have more than 1000 employees. This shows that most of the respondents are from large companies.

4. Results analysis

This section consists of four sets of analysis, which pertains to the objectives of this research. These analyses are related to maintenance environment, maintenance performance measurement, the influence of the maintenance environment on the choice of KPI and the effective use of performance measurement in maintenance management.

4.1 *The maintenance environment*

To gain insights into maintenance work environment and its influence on performance measurement, the respondents were asked to indicate the types of production disruptions they encounter and their level of importance (on a Likert scale ranging from 1 to 5) to the manufacturing systems. Likewise, they were asked to indicate on a Likert scale the frequency of occurrence of these disruptions in their plants. For both the importance and frequency of these disruptions, weighted average for each type of disruption was calculated

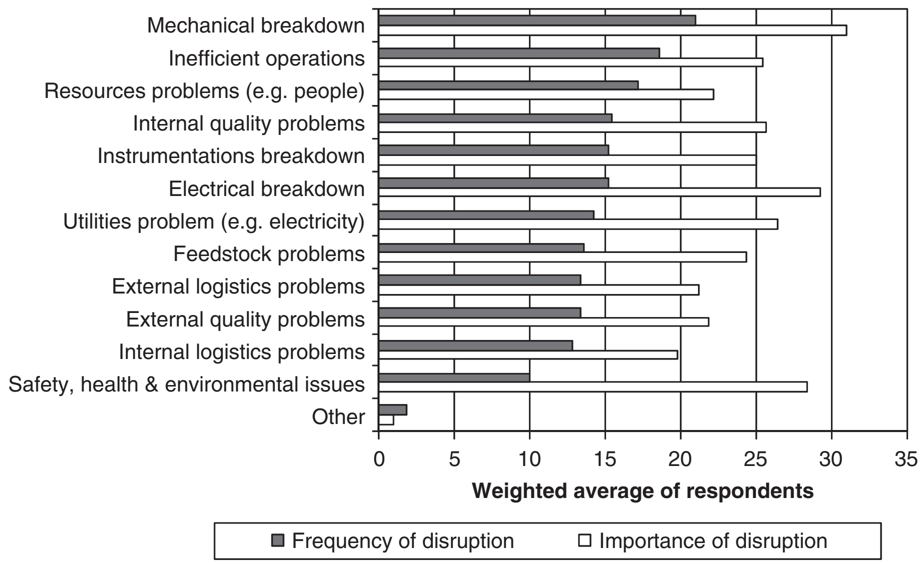

Figure 2. The level of importance and the frequency of production disruptions encountered by the plants.

by multiplying the number of respondents with the level of importance attached to each type of disruption.

From the results (see Figure 2), it is shown that mechanical breakdowns, electrical breakdown, utilities problems and safety, health, and environmental (SHE) issues are perceived to have the highest impact on plants' operations. On the other hand, internal logistics and resources (e.g. manpower) are perceived to have lesser impact on plants' operation. When compared with the frequency of disruption, mechanical breakdown still leads with the highest frequency of occurrence. This indicates that mechanical breakdown is a very important aspect of plant functionality and signifies the need for plant reliability and maintenance. Instrumentation and electrical breakdown are also among the top five highly occurring problems, which indicates the importance of maintenance function. On the production side, inefficient operations and quality problems are among the highly frequent problems. Though SHE problems have a high impact on the plants, they have the least frequency of occurrence.

The respondents were asked how they counter the production disruptions and the results are shown in Figure 3. It is shown that preventive and predictive maintenance are the most preferred options of countering production disruptions especially those emanating from equipment failures. Training of operators is also a highly rated means of countering disruption. These top-three means of countering disruptions are related to performance improvement of the existing resources (machines and people). The other options (e.g. redundant machines, buffers and large inventory) are related to capital investments. Though a substantial number of companies prefer capital investment options improving their output, the majority opt for performance improvement initiatives like equipment's reliability improvement and staff capacity development.

To check the maintenance objectives pursued by the various companies, the respondents were asked to rank the importance of the various objectives in their plants

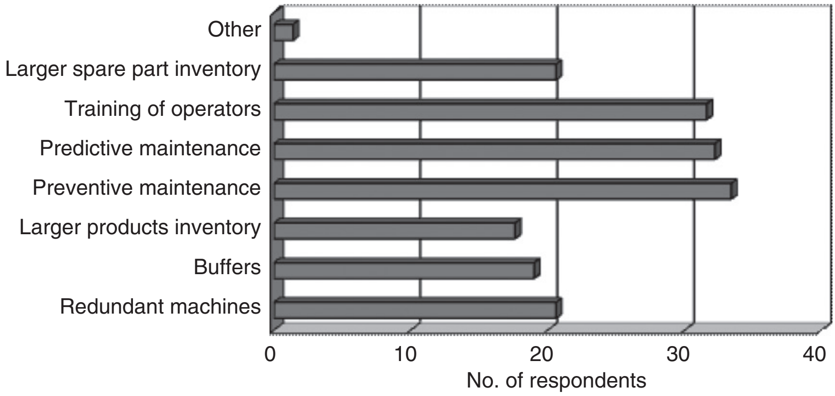

Figure 3. The preferred alternatives of countering production disruptions by different plants.

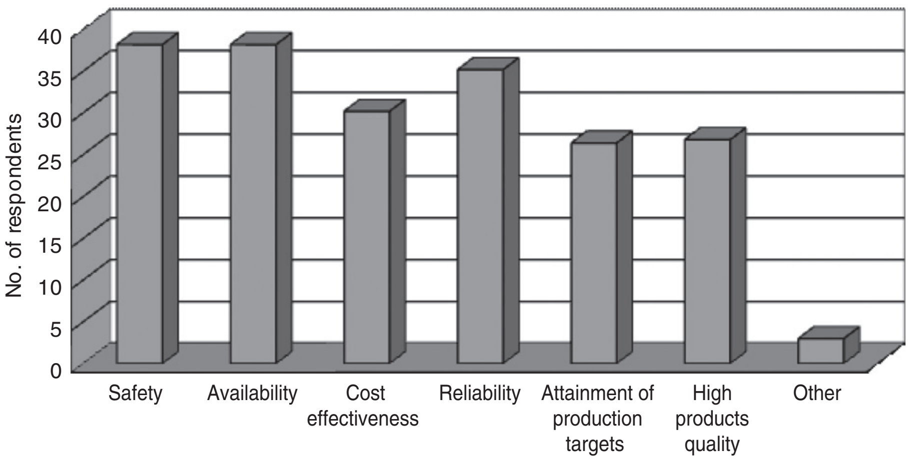

Figure 4. The maintenance objectives pursued by different plants.

(on a Likert scale 1 to 5). The weighted average of the results is shown in Figure 4. It was found that safety, availability and reliability are the highly rated maintenance objectives. This is in agreement with literature on the objective of maintenance function. It was also found that cost effectiveness, attainment of production targets and products quality are important objectives of maintenance managers.

Having analysed the maintenance environment and objectives, the next study focuses on maintenance performance measurement and the influence of the environment on KPI choice.

4.2 *Maintenance KPIs used in practice*

One of the survey questions was to check the popularly used performance indicators from the given list of 20 popularly mentioned maintenance KPIs. The respondents were asked to indicate the KPI they use in their plants, the frequency of measurement and whether they

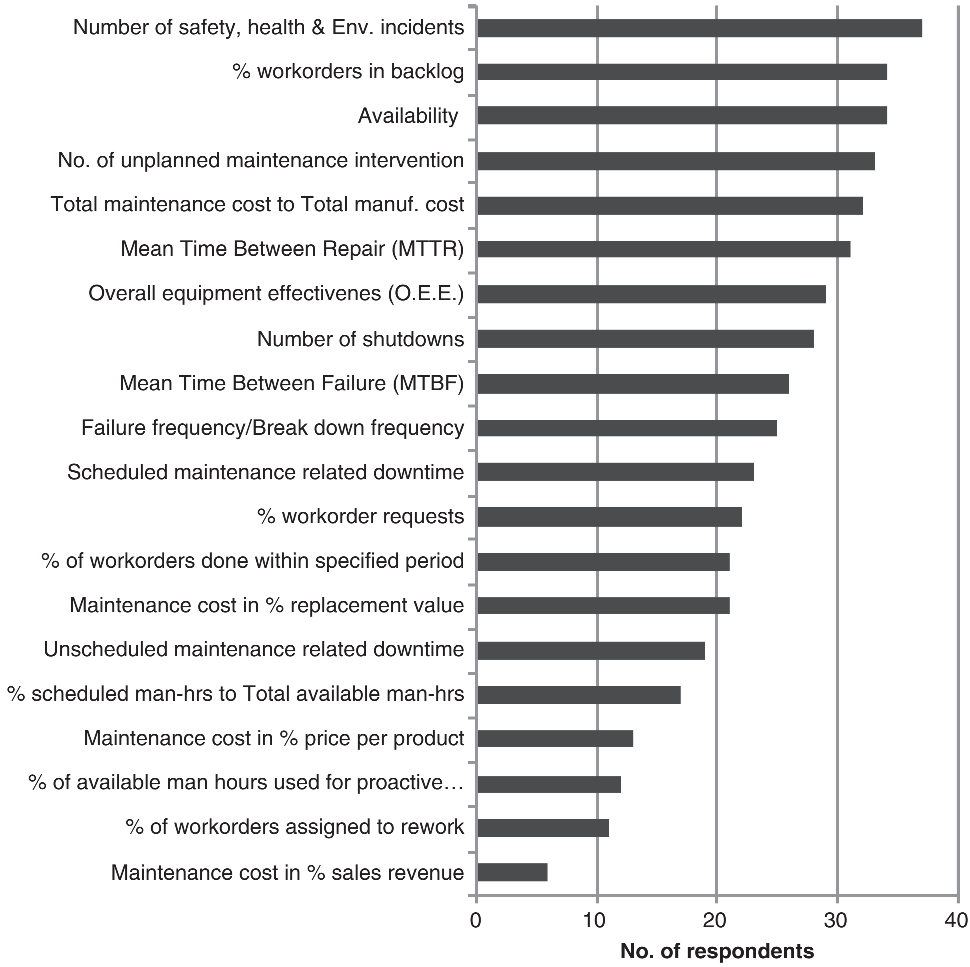

Figure 5. Usage of maintenance KPIs.

are reported to the senior management or not. The popularity of these KPIs was analysed as shown in Figure 5.

SHE incidents are the most measured items with a response rate of 90%. This may be attributed to the statutory requirements by regulating authority to monitor and report these incidents. Further, SHE incidents are regarded highly in many of these major plants due to the criticality of the processes, such as chemical and petrochemical plants. The second popular KPI is the percentage of work orders in the backlog with a response rate of 83%. This being a measure of maintenance effectiveness in executing work requests within the given period, it is in the managers interest to monitor how well the work is executed. Equipment availability also polls second with a response rate of 83%. Availability is highly advocated in literature as a key indicator of maintenance result in ensuring the equipment is available for production. It is controlled by:

- monitoring the number of unplanned maintenance interventions (used by 80% of the respondents);

- mean time to repair, MTTR (with a response rate of 76%);
- the number of shut downs (with a response rate 68%);
- breakdown frequency and MTBF (with a response rate of 63%).

From the results, it is seen that OEE is indeed an important indicator with a 73% usage together with another 12% of respondents using its variants. This adds up to 85% response rate of OEE usage. Some companies use the OEE indicator as advocated by Nakajima (1988) while other companies integrate other types of losses. Some companies have customised it to fit their requirements and even use other names to describe it. With an 85% usage rate, OEE is regarded as an important indicator able to measure different types of losses experienced by the plant and give an indication towards improvement. Overall, equipment performance-related indicators are very popular in practice.

Among the maintenance cost-related indicators, percentage of maintenance cost to the total manufacturing cost is popularly used with a response rate of 78%. This may be attributed to the desire by many companies to control the overall manufacturing cost by monitoring the various cost centres like maintenance. Though highly advocated in literature, maintenance cost as a percentage of replacement value had a low response of 51%. Other cost indicators like maintenance cost as a percentage product cost and maintenance cost as a percentage of sales revenue are among the five least used indicators. Surprisingly, percentage of work orders assigned to rework (being a measure of the quality of maintenance work done) is among the least used indicator. Likewise, percentage of scheduled man-hours to total available man-hours (being a measure of manpower utilisation) is among the least used indicator. In general, it is seen that the maintenance performance measurement is dominated by lagging indicators (equipment performance, maintenance cost and HSE issues), while not much of the leading indicators (maintenance work process) is measured.

The frequency of measurement of the top 15 indicators are analysed in Figure 6. It is seen that many indicators are mostly measured on a monthly basis and rarely on a quarterly basis. For example, 82% of the respondents measure percentage of maintenance cost to total manufacturing cost on a monthly basis. Likewise, high percentage of respondents measure percentage of work orders in backlog (57%); scheduled maintenance downtime (65%); unscheduled maintenance downtime (57%) on a monthly basis. We may therefore conclude that managers find monthly intervals a good time interval to evaluate performance. As would be expected, maintenance cost in the percentage of replacement value is measured at a longer time interval with 38% on a quarterly basis and 57% on a monthly basis. An indicator like the SHE incidents are monitored more regularly with 27% of respondents recording it on a daily basis, 22% on weekly and 46% on monthly, as per the requirements and criticality in the different plants. The OEE has the highest daily measurement frequency (39% of respondents). Since OEE integrates different elements of equipment productivity, managers have a high interest in analysing the effectiveness of their equipment at a shorter time interval. Based on the rate and frequency of usage, we may conclude that OEE, SHE and maintenance cost are important aspects of maintenance performance in practice. We may conclude that equipment performance indicators are measured on a shorter time interval (daily and weekly basis), probably to facilitate quicker corrective actions. Maintenance work process indicators are measured more on weekly and monthly basis while cost-related indicators are measured on a longer time interval (monthly and quarterly basis).

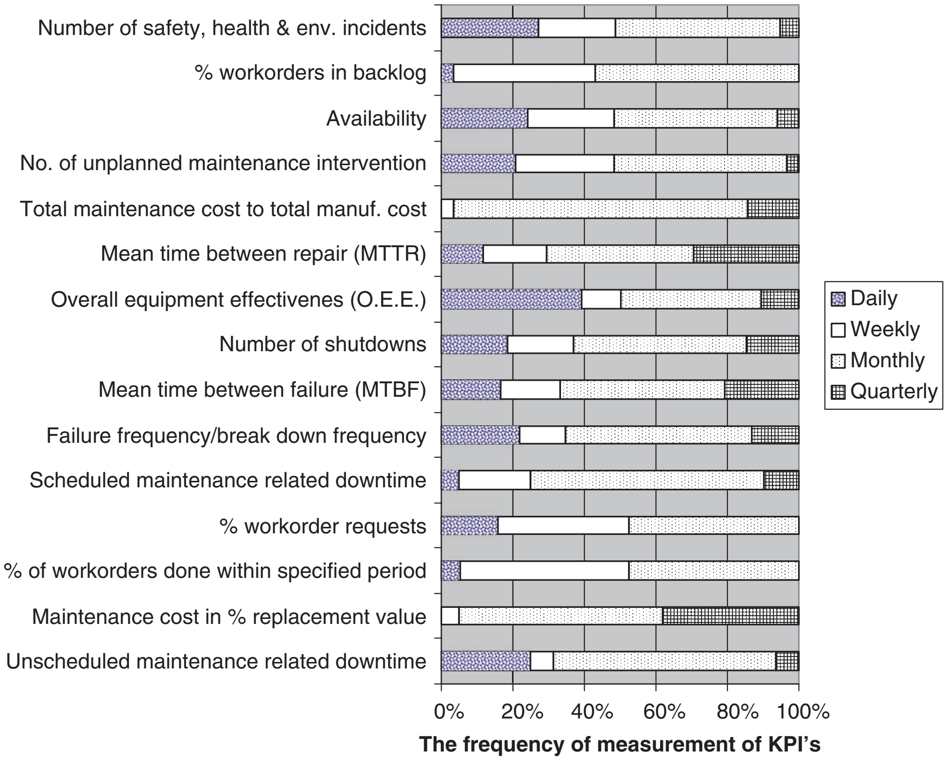

Figure 6. The frequency of measurement of the given KPIs.

4.3 *Source of maintenance KPIs*

Our next research interest was to establish the source of the used indicators and investigate how the choice of indicators is influenced by the manufacturing and maintenance-operating environment. The source of indicators is analysed in Figure 7. It is seen that 78% of the respondents developed some of the used indicators on their own. By using indicators from literature or benchmarks, they customise them to fit their industrial requirement. Some process software (e.g. SAP or ERP) are a popular source of KPI with a response rate of 56%. The third highest source of KPI are those proposed by the upper management (41% of respondents), standard benchmarks (32%) and theory (27%). The least used sources are other companies (17%) and outcome of a project (12%).

To check the influence of maintenance environment on the choice of KPI, the Spearman's rank correlation analysis was done among the different maintenance objectives as shown in Figure 8. It showed that availability has a high correlation with reliability (with $p = 0.0008$). Since the Likert scale used has a small data range (1 to 5) that could lead to lots of tied ranks, the Kendall's tau rank correlation analysis was also done. (From Liebetrau (1983), both Spearman's rank correlation and Kendall's tau correlation are recommended for the analysis of ordinal data). Using Kendall tau correlation, it was likewise found that availability is correlated with reliability (with $p = 0.0015$). This is an indication that companies pursuing availability are interested in reliability as well. This finding underlines the importance of reliability in attaining equipment availability. Availability was also found to be correlated with cost effectiveness (with $p = 0.0164$,

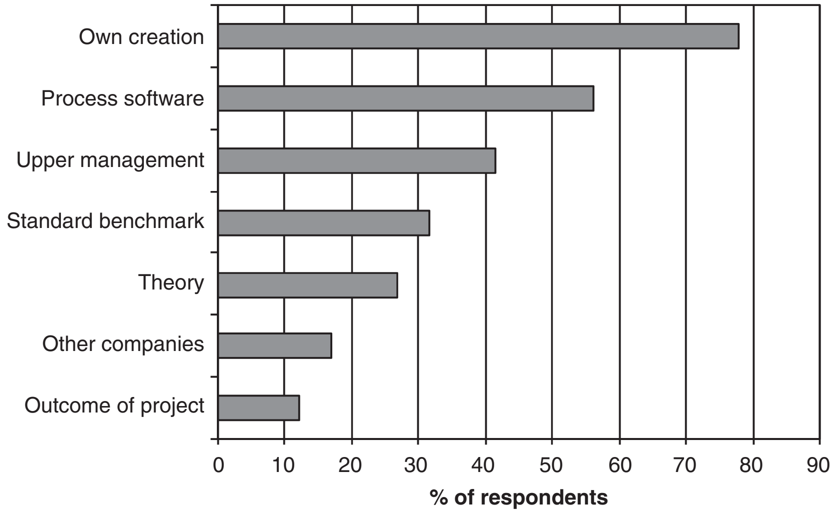

Figure 7. The source of KPIs.

Spearman correlation coefficients, N=41 Prob>|r| under H0: Rho=0						
Maintenance objectives	**Q81**	**Q82**	**Q83**	**Q84**	**Q85**	**Q86**
Q81 Safety	1.00000	0.06982 0.6644	0.37045 **0.0171**	0.19370 0.2250	–0.24251 0.1266	–0.07038 0.6619
Q82 Availability	0.06982 0.6644	1.00000	0.37268 **0.0164**	0.50160 **0.0008**	–0.08789 0.5848	0.07506 0.6409
Q83 Cost effective	0.37045 **0.0171**	0.37268 **0.0164**	1.00000	0.17708 0.2680	0.05184 0.7475	–0.02848 0.8597
Q84 Reliability	0.19370 0.2250	0.50160 **0.0008**	0.17708 0.2680	1.00000	0.13741 0.3916	0.14346 0.3709
Q85 Production target	–0.24251 0.1266	–0.08789 0.5848	0.05184 0.7475	0.13741 0.3916	1.00000	0.67644 **<.0001**
Q86 Product quality	–0.07038 0.6619	0.07506 0.6409	–0.02848 0.8597	0.14346 0.3709	0.67644 **<.0001**	1.00000

Figure 8. The Spearman correlation of the different maintenance objectives.

(Spearman's rank), and 0.0165, (Kendall's tau). Though the analysis shows safety is highly correlated with cost effectiveness ($p = 0.0171$), other results (Section 4.2) show that there is wider company level interest in plant safety due to its high impact on people, equipments, production, statutory requirements among other factors. It was found that attainment of production target is highly correlated with product quality ($p = < 0.0001$ in both Spearman's and Kendall's tau rank correlation). This is an indication that companies interested in production output are interested in product quality as well. However, the results did not show a link between attainment of production target and equipment availability or reliability as would be expected.

To check the influence of maintenance objectives on the choice of KPI, cumulative logistic regression was done for each maintenance objective against the 20 given KPI's. (Cumulative logistic regression is a generalisation of logistic regression for ordinal outcomes, see Agresti (2002)). The objective of the analysis was to check whether companies pursuing certain maintenance objective prefer a certain set of KPIs over others. The analysis of the maximum likelihood estimates showed that reliability objective is significantly related to the following KPIs: the number of unplanned maintenance interventions (with $p = 0.0372$), unscheduled maintenance related downtime ($p = 0.0214$) and the number of HSE incidents ($p = 0.0225$). This is an indication that companies pursuing reliability as a maintenance objective use or measure these KPIs. The mean time between failure – MTBF(with $p = 0.813$) and failure frequency ($p = 0.311$) – however, are not statistically significantly related to reliability objective while literature proposes them as a measure of equipment reliability. For the other maintenance objectives, the analysis did not yield results that are statistically significant. This outcome was unexpected, especially on availability objective, since many of the used KPI are related with equipment performance (see Figure 5). These results indicate lack of direct alignment of maintenance objectives and the maintenance KPI used.

4.4 *Effective use of KPIs*

Our third research interest was to analyse the effective use of the maintenance KPI by checking how the KPI support the management of maintenance function. As shown in Figure 9, 80% of the respondents use KPI to improve equipment performance and monitor and control maintenance activities. KPI are also considered useful in:

- maintenance resource allocation (70% response rate),
- safety improvements (68%),
- response improvement (67%),
- decision support of process changes (63%), and
- improvement of manpower utilisation (60%) among others.

The response is in agreement with the known use of performance indicators. However, the analyses of the percentage of maintenance actions and process changes triggered by performance measurement shows contrary results on the use of KPI in practice.

As shown in Figure 10, only 10% of the respondents have high rate (above 75%) of decisions and process changes triggered by KPI use. The highest percentage of respondents (36%) have the least (less than 25%) decisions and changes triggered by performance measurement. These results are contrary to the general expectation of KPI's role in decision support on performance improvement as advocated in performance

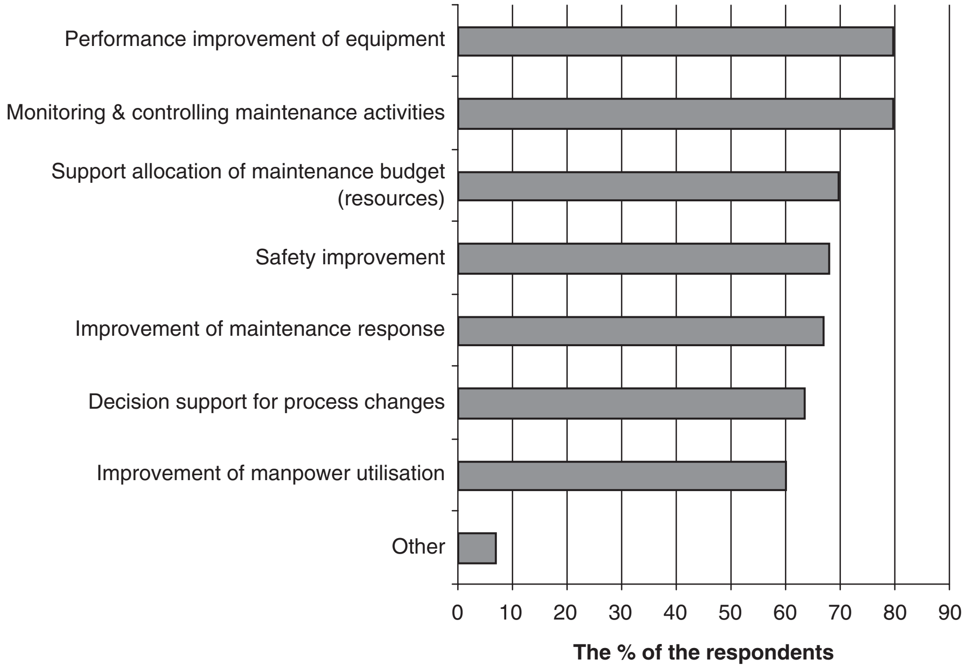

Figure 9. Use of KPIs in maintenance management support.

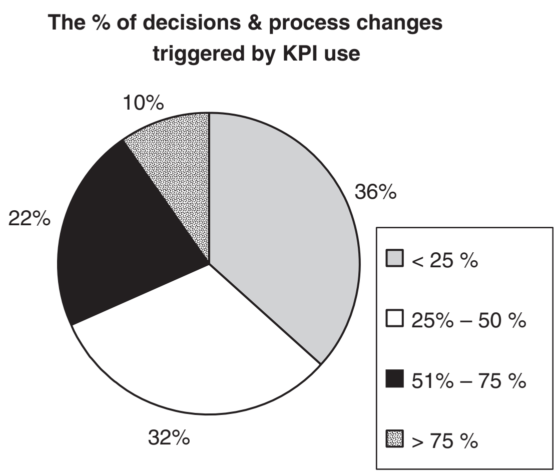

Figure 10. The percentage of decisions and process changes triggered by KPI use.

measurement literature. These are surprising results that cast some doubt on the utility value of maintenance performance measurement. In addition, the respondents were asked to indicate the degree of satisfaction with their measurement system. As shown in Figure 11, only 5% of the respondents indicated a very high degree of satisfaction and a further 22% with high degree of satisfaction. 42% of the respondents have medium (average) degree of satisfaction, 24% have low, and a further 5% have very low

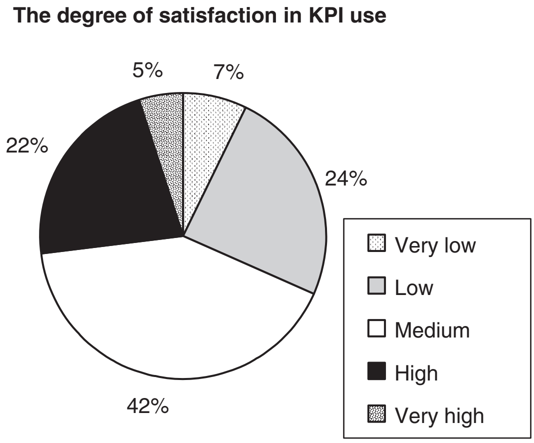

Figure 11. Degree of satisfaction with the maintenance performance measurement.

satisfaction in performance measurement. The result shows that there is a significant number of maintenance managers who are not satisfied with their performance measurement.

The Spearman's rank correlation analysis between degree of satisfaction and decision/process changes triggered by KPI use was found to be significant with a *p*-value of 0.0063 and a positive coefficient of 0.412. Likewise, the Kendall's tau rank correlation was found to be significant with $p = 0.0064$ and coefficient of 0.366. Further cumulative logistic regression was carried out to detect the influence of the 'degree of satisfaction of maintenance performance measures' on the decisions and process changes triggered by KPI use and quantify its effects on the maximum likelihood fit. The analysis of the maximum likelihood estimates showed that least decisions/changes triggered by KPI ($< 25\%$) is statistically significantly related to the degree of satisfaction with $p = 0.0034$. This is an indication that the least satisfied people had the least decisions and changes triggered by KPI use. The results indicated a strong positive linear relationship between degree of satisfaction and process changes/decisions triggered by KPI use. Thus a higher degree of satisfaction in KPI use is likely to trigger more decisions and process. Likewise, least decisions/changes are likely when the satisfaction in KPI use is low.

These significant results on low decision/changes triggered by KPI use, coupled with low degree of satisfaction raises a question on the effectiveness of performance measurement systems in practice. First, the results cast some doubts on 'success story' of performance measurement as suggested in literature. Second, the result exposes some ineffectiveness of performance measurement systems in driving performance improvements and decision support in significant number of companies. This ineffectiveness can potentially negate the benefits expected from such systems like performance gap identification, decision support, focusing resources in important areas, and performance improvement initiatives.

Finally, the study shows that only a minority of managers said that high improvements originated from their quality systems. This shows there is something very wrong with quality management systems in practice, which necessitates further research to determine the cause of this ineffectiveness.

5. Conclusions

The objective of this research was to explore the use of performance measurement and indicators in management of maintenance function by the use of an industrial survey. This was done by investigating the key performance indicators (KPI) used in maintenance management; how these indicators are sourced or chosen; the influence of manufacturing environment and maintenance objectives on KPI choice; and finally, the effective use of these indicators in managing the maintenance function based on measurement frequencies, maintenance actions triggered and managers satisfaction with the use of indicators.

First, the literature review showed that different categories and types of maintenance KPI have been proposed by various authors. However, it was observed that a methodological approach of deriving the various KPI has not been explicitly done and the users are left to decide the relevant KPI for their situation from the given KPI lists. From the analysis of the manufacturing and maintenance environment, it was found that equipment breakdown is the most important cause of production disruption among other causes of disruptions (quality, feedstock, logistics, etc.). To counter production disruptions, managers prefer performance improvement of the existing resources (through preventive and predictive maintenance, and training of employees) over capital investment to buy redundant capacity or larger inventory in case of equipment unreliability. These findings signify the importance of maintenance function and the need of maintenance performance monitoring.

On the KPIs used by maintenance managers, SHE incidents are the most measured indicator with a response rate of 90% probably due to statutory requirements. The top 10 maintenance KPIs are dominated by equipment performance. OEE metric and its variants came out as the most popular equipment performance indicator capable of measuring different production losses, of which maintenance related losses are important. It was observed that maintenance performance measurement is dominated by lagging indicators (equipment performance, maintenance cost and SHE issues), while not much of the leading indicators are measured. This observation raises some questions on whether sufficient knowledge of maintenance process does exist and if sufficient knowledge exists, why is it rarely used in performance measurement systems? While both leading and lagging indicators are important in maintenance performance management, the leading indicators are even more important than lagging indicators because they have the potential to avoid unfavourable situations from occurring in the first place.

On the source of KPI used in industries, it was seen that most of the respondents use 'own-developed' KPI. They customise indicators from literature or standard benchmarks to fit their industrial requirements. Process softwares (e.g. SAP or ERP) were found to be an important source of KPI. The correlation analysis of the influence of manufacturing environment on the choice of KPI showed that reliability and availability are highly correlated. This signifies how these two equipment performance aspects are highly linked by maintenance managers. However, the results did not show a link between production output and equipment availability or reliability as it would be expected. Further regression analysis indicated that there is no direct alignment of maintenance objectives and the maintenance KPI used.

The most surprising results came from the analysis of the use of KPI in maintenance management. It was found that the highest percentage of respondents have the least decisions and process changes triggered by performance measurement. These results give an indication that much of the performance measurement data collected is not adequately used in decision support and performance management. Further analysis showed that there is a significant number of maintenance managers who are not satisfied with their performance measurement systems while much effort and resources are dedicated to such systems. Further regression analysis showed a strong positive linear relationship between degree of satisfaction and process changes/decisions triggered by KPI use. This indicates that higher (lower) degree of satisfaction in KPI use is likely to trigger more (less) decisions and process. The results showed that the least satisfied people had the least decisions and changes triggered by KPI use.

These significant results on low decision/changes triggered by KPI use, coupled with low degree of satisfaction raises some important questions on the effectiveness of performance measurement systems in practice. This ineffectiveness can potentially negate the benefits expected from performance measurement. It shows there is something wrong with performance management systems. At the time of this study, we had no indication why this is the case, and why it has not been noticed before. Further research is needed to determine the cause of this ineffectiveness. Among the issues proposed in future research is establishment of a methodological approach of deriving maintenance KPI from maintenance strategic objectives. Such an approach can potentially support managers in deriving relevant KPI for their manufacturing environment. Further research on maintenance processes that can lead to the expected maintenance results need to be conducted and consequently integrated in maintenance performance systems. Finally, a research on the overall performance management systems is necessary to establish the inadequate use of performance information in decision support and the cause of dissatisfaction in performance measurement systems by maintenance managers. This research could establish the effectiveness of feedback process in performance management and how performance information should be used to trigger changes.

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