

*Review Article*

**Maintenance Performance Measurement: A Review**

**Hasnida Abdul Samat, Shahrul Kamaruddin\* and Ishak Abdul Azid**

*School of Mechanical Engineering, Universiti Sains Malaysia,  
Engineering Campus, Nibong Tebal,  
14300 Penang, Malaysia  
\*E-mail: meshah@eng.usm.my*

**ABSTRACT**

Maintenance is a vital system in a manufacturing company. The maintenance objectives are to ensure that the machine is in good condition, serviceable and safe to be operated in producing quality products. However, the system usually imposes a high cost system due to its ineffective activities. Therefore, this paper was written to review the factors affecting the maintenance effectiveness and methods used to measure its performance. In this paper, maintenance performance measurement methods are categorized into three groups, based on holistic, machine, and value factors. Each group is discussed based on the principles and techniques of the maintenance performance measurement methods, along with the example of its applications in the industry. The most common methods used are the holistic approach, overall equipment effectiveness (OEE), and balance score-card (BSC). These various methods have their own benefits and drawbacks, according to the area of measurement.

**Keywords: Balanced-score card (BSC), maintenance effectiveness, overall equipment effectiveness (OEE), performance measurement, reliability**

**INTRODUCTION**

Competition can be found everywhere. In the manufacturing industry, not being at the forefront signifies a loss of opportunities and profits. Thus, one of the ways for a company to lead the market is by reducing waste in its operations to be able to offer products at the lowest price possible. In doing so, the company also needs to maintain their business and customer loyalty by producing good quality and reliable products. The most efficient way to improve business performance is to have an effective maintenance activity that will aid in the process of reducing cost, improving productivity, and maintaining business profile (Swanson, 2001).

The efficiency and effectiveness of a maintenance system play a pivotal role in the company's success and survivability (Parida & Kumar, 2006). Therefore, maintenance activities in a company need to be monitored, controlled, and improved from time to time to produce an effective system. A suitable and effective maintenance performance measurement (MPM) is needed to monitor the maintenance activities and the planning for more successful improvement. In fact, the results from maintenance performance measurement will signify where the organization is and where it is heading (Kutucuoglu *et al.*, 2001). It functions as a guide to gauge whether the organization is en route to achieving its goals or not.

This paper is aimed at reviewing available maintenance performance measurement methods in the literature and highlighting the common methods used. It is divided into seven sections. In the first section, the discussions are provided to describe maintenance and maintenance performance.

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\*Corresponding Author

In the second section, factors affecting maintenance performance are elaborated. Next, literature reviews concerning the commonly used MPM methods are given based on both literature study and industrial practices. The methods are classified into three groups in order to provide a comprehensive analysis of MPM. Finally, conclusions concerning MPM are given.

### MAINTENANCE PERFORMANCE

A concise translation of the word maintenance from Oxford dictionary is the “activities done to keep equipment and machine in its existing state, preserve, and ensure it to continue operating in good condition while at the same time protecting it from potential damage.” Maintenance in time perspective is no longer seen as a necessary evil like that known in 1950s, but it is referred to as a partnership system that works as a profit contributor in manufacturing organization (Waeyenbergh & Pintelon, 2002). Thus, it is really important to monitor and improve maintenance activities from time to time to ensure an effective operation.

Maintenance can be monitored and improved based on its performance. The definition of performance is the level to which the aims and objectives are attained (Dwight, 1999). Therefore, in the context of this paper, maintenance performance can be defined as the state or the condition of the action or the process in conducting maintenance function, when measured from time to time. The levels of maintenance effectiveness towards manufacturing operation illustrate the performance, and it is necessary to establish appropriate metrics for the purpose of measuring the maintenance performance (Chan *et al.*, 2005). Maintenance performance reflects the capabilities of the maintenance system to ensure continuous production of quality products and to reduce total operating cost at the same time.

The issue of maintenance performance measurement has gained a great amount of attention and discussion from researchers and practitioners alike because the fact that what cannot be measured cannot be managed effectively (Parida & Kumar, 2006). Meanwhile, measurement process tells the status of the activities carried out, the type of actions to be taken and where those actions should be targeted at (Kumar, 2006). Therefore, management requires performance information to be able to improve their maintenance activities. The absolute value of such performance information can then be compared to a previous situation or a trend. The value can be used to glean the maintenance performance levels and to ensure a continuous improvement plan (Arts *et al.*, 1998).

Parida & Kumar (2006) revealed some of the reasons that stir the demands for maintenance performance measurement shown in *Fig. 1*. Maintenance system is in relation with other systems in the company, like production, marketing, and management. Therefore, the necessity to gauge maintenance effectiveness comes from the demands by every department in an organization. For example, maintenance helps the maintenance department to justify the investments for their activities by measuring maintenance cost and value. It also helps management team to improve resource allocations in the future towards a better maintenance performance.

### FACTORS EFFECTING MAINTENANCE PERFORMANCE

Since maintenance is related to many departments in the organization of a company, it is obvious that there are many factors affecting its performance. The main question in this area is “what to measure for a proper maintenance performance level?” Parida (2007) outlines seven main criteria for measuring maintenance performance, which are:

1. machines or process related,
2. cost or finance related,
3. maintenance task related
4. customer satisfaction,

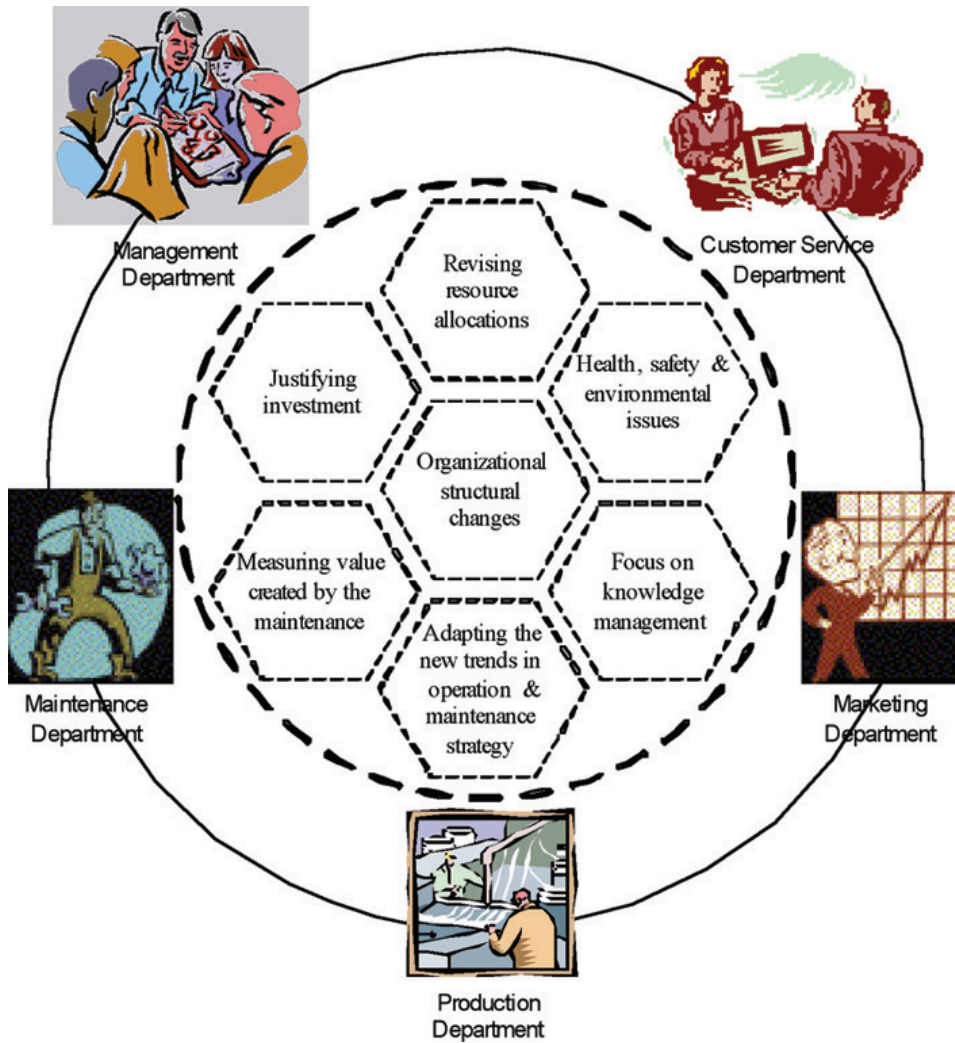


Fig. 1: Important factors behind demands on maintenance performance measurement (Source: Parida & Kumar, 2006)

5. learning, growth and innovation,
6. health, safety and environment issues, and
7. employee satisfaction factor.

On other research, Kumar (2006) divided the factors affecting maintenance performance into two main categories, namely internal and external factors. The internal effectiveness factors gauge maintenance activities based on its performance during the manufacturing processes, while the external effectiveness factors cover the issue after a product is sold. Fig. 2 illustrate the divisions of the total maintenance effectiveness, together with a list of common factors affecting it.

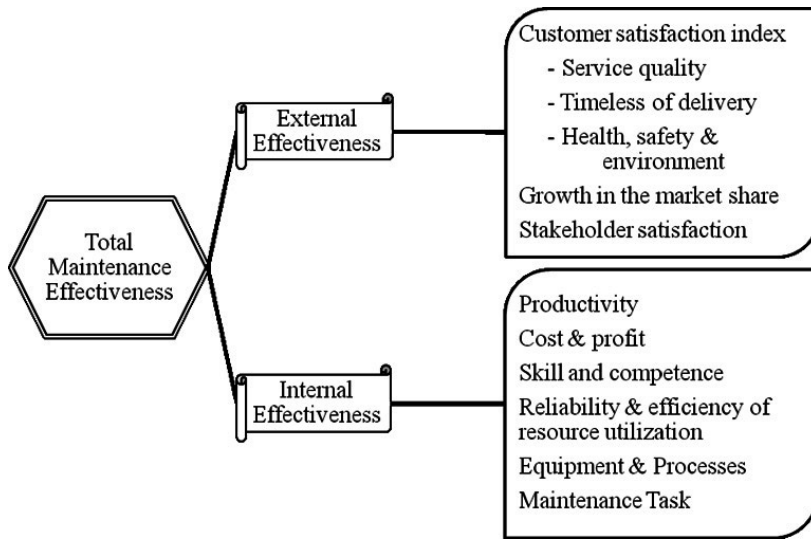


Fig. 2: Total maintenance effectiveness based on an organizational effectiveness model (Source: Kumar, 2006)

The internal effectiveness factors are directly related to maintenance operation. It is based on productivity, cost, and profit. Maintenance performance is measured based on saving or expenditure for the maintenance activities. The other factors are employee skill and competency during maintenance activities. As maintenance is conducted by human, employees' capabilities therefore need to be measured and improved to eliminate human errors. Reliability and efficiency of resources utilization are also the considered as factors in internal effectiveness. The resources for maintenance activities are like tools, material, and spare parts. The usage of resources during maintenance should be done according to its specifications at its maximum capability. In this way, less cost allocated for maintenance is required.

According to Coetzee (1998), from various factors discussed in the literature, machine, and processes are the most significant factors affecting maintenance performance. This is because machine receives direct impacts from maintenance activities. Thus, any misconduct during maintenance can be accurately measured by calculating the performance and effectiveness of the machine during the operation. The final internal factor affecting maintenance is its task efficiency. This factor considers a bigger scope of the maintenance system which includes the planning process, the type of maintenance techniques chosen, time allocation, and spare-parts selected for maintenance.

The second category affecting maintenance performance is external effectiveness which is mainly affected by customer satisfaction. Kumar (2006) stated that the external factors need to be measured to counter the internal factors which were claimed to be inadequate. It can be gauged by service quality, timeless of delivery, health, safety, and environmental issues. The factors include the long-term effects of maintenance done because effective activities ensure the manufacturing of quality and reliable products.

There is also an index of maintenance effectiveness which was developed based on the market share growth. The growth signifies the increase of the product demands in the industry (Parida & Kumar, 2006). Kennerly & Neely (2000) also discussed on the external factors and put emphasis on

stakeholder satisfaction to drive performance towards effective maintenance. For large companies, stakeholders' opinion and satisfaction are really important for business because they hold the key for a company's mission and vision. Therefore, the authors suggest that maintenance system be planned and conducted based on stakeholder satisfaction.

### **MAINTENANCE PERFORMANCE MEASUREMENT (MPM) METHODS**

With various factors affecting maintenance effectiveness, there are also various types of maintenance performance measurement (MPM) methods discussed in the literature and practiced in the industry. Oke (2006a) stated that maintenance could be gauged in variety of methods. Among them is the economic, technical, and strategic approach. There are also practices of the system auditing by conducting surveys and questionnaire to collect data on maintenance effectiveness. The other approach is by doing statistical analysis, reliability, and maintainability function of machine.

Aside from the methods, Oke (2006b) reviewed on the value-based approach. More complex approach uses a mathematical model in composite formulation of maintenance performance. There is also a partial maintenance productivity measurement where maintenance is measured based on manufacturing availability and production rate in a company. The variation of ideas shows that researchers tend to discuss maintenance performance from various factors which are according to their own interpretation and area of research. From the reviews conducted for this paper, maintenance performance measurement methods can actually be divided into three categories, namely, holistic approach, machine factor, and maintenance value group.

### **METHODS BASED ON HOLISTIC APPROACH**

Holistic refers to an overall maintenance performance measurement based on multi-factors. Tsang *et al.* (1999) and Coetzee (1999) suggested the approach because they claimed that the measurement based on certain factors could not produce the required results when used in larger managerial context. Tsang *et al.* (1999) focused on a direct relationship between maintenance performance and organization performance to provide useful information in making effective decisions and shaping desirable employee behaviour. Maintenance was looked as a physical asset management, and thus, the scope was considered to have covered every stage in the life cycle of technical systems, specification, acquisition, planning, operation, performance evaluation, improvement, replacement, and disposal.

Meanwhile, Coetzee (1999) insisted on auditing and analyzing all the critical parts of maintenance simultaneously, such as policy, procedures, maintenance plan, maintenance information or operation systems, and maintenance operation. Thus, the technique proposed is to apply a variety of techniques to a small part of the maintenance instead of applying one technique over the total operation and then improving the overall maintenance system. Other than that, Kutucuoglu *et al.* (2001) measured maintenance effectiveness using the matrix of Quality Function Deployment (QFD) technique. The functions deployed are machine, task, cost, as well as customer impact and learning, and growth related issues. All the factors were analyzed and structured to measure and evaluate maintenance activities. Using QFD, the main reason for maintenance ineffectiveness were selected and further improved.

Arts *et al.* (1998) proposed an MPM from the overall perspective that reflects strategic, tactical, and operational planning. The process includes considering organization's aims and objectives, whether it is decided based on strategic, tactical, and operational and then comparing it with maintenance performance. For instance, if the strategic planning was to operate with the minimum cost possible, the factor to be considered for maintenance performance also included how the activities would save costs during the operation. Meanwhile, De Groote (1995) gauged maintenance

performance based on economic and technical factors. In the literature, performance calculations include the ratio of direct maintenance cost over added or replacement value of production, as well as the cost of resources, maintenance personnel and spare parts over maintenance cost. The authors also suggested the economic approaches which involve calculating the machine performance using overall equipment effectiveness (OEE) elements comprising of machine's availability, performance, and quality rate.

From the literature reviewed on the holistic approach, it has been observed that it necessitates rigorous and large number of data collection. In fact, it requires multiple inputs and outputs that cause complexity in quantifying the level of importance of each factor that contributes to maintenance performance. As a result, the measurement process does not portray the real maintenance function scenario due to the inaccuracy of the calculation. This also causes longer time for improvement plan and consumes more resources to achieve the targets. Thus, maintenance performance measurement based on certain factor or partial measurement is considered as better because it focuses on only one or two attributes of the factors that affect maintenance activities.

### **METHODS BASED ON MACHINE FACTOR**

Aside from the holistic approach, machine is another factor for maintenance performance measurement. As discussed earlier on, machine is the main function in maintenance activities. High availability and utilization percentages of machine ensure the maximum production output and increase the company's profit. Tsang (1998) identified some common measures of machine performance based on availability, reliability and overall equipment effectiveness (OEE), measures of cost performance by calculating labour and material cost, and finally measurement of process performance like ratio of the planned and unplanned work or schedule compliance. Machine performance is commonly gauged by using the OEE and reliability principle.

#### *Overall Equipment Effectiveness (OEE) Method*

Nakajima, the father of the Total Productive Maintenance (TPM) has introduced Overall Equipment Effectiveness (OEE) as a powerful yardstick for tracking work progress and improvement (Nakajima, 1988; Pomorski, 1997). OEE has been related to TPM in many discussions (Dal *et al.*, 2000; Chand & Shirvani, 2000; Kwon & Lee, 2004; Tsarouhas, 2007), and it is actually a measure of the factors that determine and influence machine effectiveness. In the literature, OEE was proposed as a measurement system for evaluating the effectiveness of a system, as well as for establishing priorities for improvement (Eldridge *et al.*, 2005).

OEE was introduced as a method to calculate and monitor the actual performance of machine relative to its capabilities under optimal operation condition. It is a function of machine's availability, performance rate, and the quality of product produced. OEE has also been applied with the integration into implementation framework and computer system. Konopka & Trybula (1996) and Giegling *et al.* (1997) discussed OEE and cost measurement. The researchers used a productivity analysis framework called the Capability Utilization Bottleneck Efficiency Systems (CUBES) to investigate and prioritize productivity efficiency based on machine performance.

Jeong & Philips (2001) stated that the original definition of OEE is not appropriate for capital-intensive industry because it does not include scheduled maintenance time for preventive maintenance and important non-scheduled time, such as off-shift and holiday. The researchers further stated that an accurate estimation of machine utilization is very important in the capital-intensive industry since the identification and analysis of hidden time losses are initiated from these estimates. Thus, CUBES was used. The framework was constructed on the total calendar time-based approach

and it helps the company to plan their maintenance according to exact operation time minus their break time and holidays.

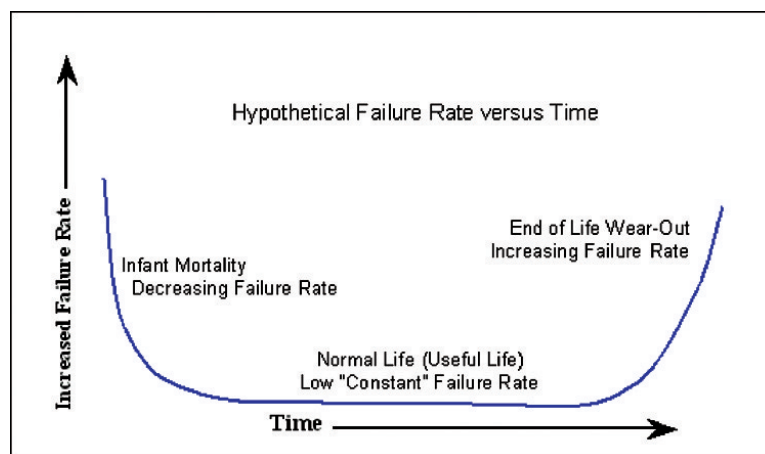
OEE has also been modified to suit a foundry in a semi-conductor plant where machines are operated in a linked and complex arrangement. This situation makes it difficult to calculate the OEE for each machine. Similarly, Oechsner *et al.* (2003) discussed the transformation of the overall equipment effectiveness (OEE) to overall fab effectiveness (OFE). The solution proposed by the authors was to use the OFE to obtain results for the cost per die out. Just like the OFE, the overall line effectiveness (OLE) was also introduced by Nachiappan & Anantharaman (2006). OLE is an approach that is used to measure continuous line-manufacturing system. The approach assumes that all the machines in the line are operating with the same performance.

#### *Machine's Reliability Method*

The second method utilized in measuring maintenance performance based on machine factors is by calculating the reliability of a machine. The reliability of a machine is the characteristic of design, operating conditions, and maintenance philosophy. Endrenyi *et al.* (1998) stated that the purpose of maintenance is to extend the lifetime of a machine, or at least the mean time to the next failure. Oyebisi (2000) stressed that the prime function of maintenance is the control of the reliability of machine and facilities. Therefore, to have a desirable level of the machine's effectiveness, adequate attention must be given to factors affecting the maintenance performance at all stages of its life cycle.

The ideal capability and lifespan of a reliable machine is one that does not experience any failures during operation. Failure means the action or state of not functioning which is caused by breakdown or malfunction. *Fig. 3* shows the Bathtub Curve which is the graphical representation of reliability principle. The curve shows three stages of failure rate that are named as infant mortality, normal or useful life, and the end of life wear-out stage (Dhillon, 1999; Booker *et al.*, 2001).

As shown in *Fig. 3*, a high number of failure rates were observed at the Infant Mortality period which is the very early stage of production. Also known as the burn-in period, the failure rate will decrease rapidly relative with time. In the second stage, which is named as the Normal Life of Useful Life stage, low and constants failure rate can be witnessed because machines start to function according to the specification and producing products in acceptable quality limits.



*Fig. 3: The bathtub curve (Source: Dhillon, 1999)*

It is assumed that the failures occur randomly in the useful life phase. Some of the reasons for such failures are undetectable defects, low safety factors, high unexpected random stress, abuse, poor maintenance activities, and natural failures (Dhillon, 1999). The final stage in the Bathtub Curve is the End of Life Wear-Out, where failure rate starts to rapidly increase until machines' end of life. This phenomenon has always been related to aging of machine that is caused by poor maintenance activities. A research by Clarotti *et al.* (2004), based on the simple hypothesis of a model of step aging and Bayesian techniques, concluded that the initial development in the failure rate represents machine lifetime that is affected by maintenance performance.

Metwalli *et al.* (1998) used historical data of machine like failure time and maintenance cost to develop reliability analysis based on Weibull distribution. The Weibull parameters were analytically achieved to determine the reliability and hazard functions for each component and system in the machine. The plotted data were then analyzed and used for optimization technique and effective maintenance planning. Similar to that, Wiksten & Johansson (2006) discussed that failure function, which is the basic measurement of reliability, would increase if improper maintenance was conducted on the machine. The calculations used are on the mean time between maintenance, mean time between overhaul, maintenance free operating period, mean time between critical failure, and mean time between unscheduled removals.

The most extensive publication discussing maintenance performance in relation to reliability of machines is given by Endrenyi *et al.* (2001; 2004). Maintenance interval and duration are measured to show both the reliability and ability of machines. Meanwhile, machine values were plotted over its lifetime to show maintenance effectiveness. The results show that with less failure reported, any maintenance conducted is suitable and effective. Aside from that, Endrenyi & Anders (2006) implemented the reliability method of machine using the probabilistic representation of deterioration process on machine through discrete stages, while conceptual model called Asset Management Planner (AMP) and a mathematical model were proposed to relate maintenance tasks with reliability of machine. The models described the impact on the reliability of gradually deteriorating machine of periodic inspection, which could lead to various possible maintenance policies.

## METHODS BASED ON MAINTENANCE VALUE

The final group of maintenance performance measurement is based on value. The value-based methods emphasizes on the maintenance value rather than the cost of maintenance. It provides analytical viewpoint in measuring maintenance performance. The results from these methods can help companies to justify their investments in the operation. In this area of research, balanced-score card (BSC) is the most common method being practiced.

### *Balanced Scorecard (BSC) Method*

The BSC approach is a quantitative maintenance performance measurement (Arora, 2002; Amaratunga *et al.*, 2002; Oke, 2006a). The principle behind the BSC usage is to ensure maintenance is measured based on the requirement decided by the top management. Traditional measurement processes are usually built around financial measures and targets which abide little relation to company's progress in achieving long-term strategic objectives. Thus, most companies emphasize on short-term financial measures that leave a gap between the development of a strategy and its implementation (Kaplan & Norton, 1996a, b). BSC engenders the emergence of a strategic management system that links long-term strategic objectives to short-term action.



The BSC was proposed by Kaplan & Norton (1992). BSC is considered as a model that translates the mission and strategy of a business unit into a set of objectives and quantifiable measures. The measures are built on the investor’s views (financial perspective), the performance attributes valued by customers (customers’ perspective), as well as long- and short-term means to achieve previous objectives (internal processes perspective), and finally the capability of the maintenance activities to improve and create value (learning and growth perspectives) (Tsang *et al.*, 1999).

By using the template given in *Fig. 4*, Tsang (1998) introduced BSC as a framework for translating organization’s strategy into operational measures. The framework was used to evaluate the impact of maintenance activities on the future value of organization. Meanwhile, Oke (2006b) concluded that by directing managers to consider all the important measures together, the BSC guards against sub-optimization. The BSC puts strategy and vision at the centre and its emphasis is on achieving performance targets unlike conventional measures which are rather control oriented.

Strategic objectives	Measures (KPIs)	Targets	Action plans	Perspective
				Financial
				Customer
				Internal processes
				Learning & growth

*Fig. 4: The balanced scorecard template that links strategic objectives to short-term actions (Source: Tsang, 1998)*

Punniyamoorthy & Murali (2008) conducted a research to create a model called “balanced score for the balanced score card”. The four perspectives in the BSC are usually treated to be equal in weightings. In some cases, however, it does not portray the accurate level of importance which in the end will result in deviation between the actual and targeted performance. Thus, the researchers calculated the relative weight age for each perspective by creating sets of metrics and analyzing it using a pair-wise comparison method. The model is to assist in identifying the reasons for variations in the performance and the most important perspective and to set a more suitable target measure to be achieved.

The application of BSC was also introduced as a framework for translating an organization’s strategy into operational measures so as to evaluate the impact of activities on the future value of organization. For the performance analysis, Data Envelopment Analysis (DEA), a non-parametric approach to compute multiple inputs and multiple output productivities was used (Garcia-Valderrama *et al.*, 2009). The researchers proposed various indicators in measuring research and development processes, with the addition of innovation perspective and build up efficiency model so that their achievement in multi-criteria and balanced view could be measured.

Other than that, the practice of BSC had also been suggested to be adopted with different perspectives like cost, operations, organizations, health safety, and environment. Thus, companies can pay more attention to the most important conditions within the business or internal factor in measuring maintenance performance (Oke, 2006b). This wide area of measurement will ensure more improvement plan for maintenance system in companies.

## DISCUSSION

Maintenance is one of the supporting functions in the manufacturing system. Moreover, effective maintenance has a positive impact on company's operation and profit. Thus, there are needs to monitor, measure, and control the maintenance performance using the available methods. However, the process is complex because it involves many parameters and factors. Maintenance performance is usually connected to the external and internal effectiveness of companies operation such as in customers' satisfaction, productivity, cost, profit, as well as machine reliability. Both the external and internal factors required different degrees of data collection and analysis.

Thus, this scenario contributes to the development of various branches of knowledge in the maintenance performance measurement methods. The methods can be divided into three main groups, based on the holistic approach, machine factors, and maintenance value. The holistic or overall approach was proposed by Arts *et al.* (1998), Tsang *et al.* (1999), and Coetzee (1999) who focussed on how maintenance activities were conducted to fulfil company's aims and objectives. The measurements are conducted based on both internal and external factors affecting maintenance performance.

Another group in measuring method is based on machine factor which is the internal factor of maintenance effectiveness. This is the most discussed approach and regularly practiced in the industry. The tools that are commonly used are the overall equipment effectiveness (OEE), and reliability principle. OEE, which has extensively been discussed by Nakajima (1988), Chand & Shirvani (2000), Eldridge *et al.* (2005) and Nachiappan & Aantharaman (2006), measures the maintenance performance from three elements, namely, availability, performance, and quality rate. The method includes machine performance, production process, and operating time. As for the reliability principle, it signifies the dependability of machine after maintenance has been conducted (Dhillon, 1999; Metwalli *et al.*, 1998; Clarotti *et al.*, 2004; Endrenyi *et al.*, 2001; 2004). The method measures the maintenance effectiveness based on the reliability of machine for manufacturing.

There is also performance measure which is based on maintenance value, and it known as the Balanced Score Card (BSC) method. First proposed by Kaplan & Norton (1992), the method derived maintenance performance from organization's strategic objectives towards maintenance effectiveness. The BSC applies a qualitative technique by balancing both the external and internal factors and uses them to gauge maintenance performance as conducted in the research by Tsang *et al.* (1999), Punniymoorthy & Murali (2008), as well as Garcia-Valderrama *et al.* (2009).

The main finding of this research work is, despite increasing research in maintenance performance measurement, that there is evidence that the methods proposed lack in various sides. For example, the methods in the holistic approach focus more on the external factors of maintenance performance, like customer and stakeholder satisfaction, whereas, internal effectiveness like machine performance that is directly linked to maintenance is not included. Hence, the measurement methods have failed to analyze the direct impact of maintenance action. Based on the machine factor, the methods focused on the direct impacts of maintenance towards machine performance, but the OEE emphasised merely on short-term performance, whereas reliability is for a long-term performance measurement. The methods have shown an imbalance measurement process which will give an inaccurate level of maintenance effectiveness. The last method is based on maintenance value. The

drawback in BSC that is it requires many data for measurement and extensive solutions, making it a rather complex measurement method.

## CONCLUSION

Maintenance is a way to help a company in achieving the ‘World Class Company’ status using its profit generator function. It is one of the major sources for cost saving process in a company because effective maintenance brings benefits which include assistances in conducting a proper production scheduling and ensuring a longer lasting lifetime of machine in the production. Therefore, maintenance performance measurement is an important area of research as it analyzes factors affecting the performance and the methods to measure it. From various literature reviewed, the maintenance performance measurement method can be grouped into different methods, based on the holistic, machine, and value factors.

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