Quantification of Machine Performance Through Overall Equipment Effectiveness

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Abstract — **Overall Equipment Effectiveness (OEE) is a hierarchy of metrics to measure the production machine performance in manufacturing industry. OEE measurement is inspired by the Total Productive Maintenance (TPM) and used as a key machine performance tool which measures availability, performance and quality rate. This study was conducted in a manufacturing company producing a broad range of packaging products. The main issue found relating to machine productivity was where availability shows a significant decrease since the purchase date.. Thus, data were collected for 12 months from the corrugator's machine and analysed using Microsoft Excel Software to determine the value of the output table, and presented graphically. The results of this study revealed that availability achieved an improvement of 5 per cent over the world standard OEE of 90 per cent, while the machine performance and quality rate each accounted for 10 per cent and 5 per cent decrease in the 'Ideal' value of OEE. Moreover, the comparisons with the 'Ideal' value of OEE were an indication level of total productivity improvement.**

Keywords-component: Overall equipment effectiveness; Performance measurement; Total productive maintenance

I. INTRODUCTION

In the past two decades, Performance Measurement (PM) has received a great amount of attention from researchers and practitioners. Major issues related to this field concern what to measure and how to measure it [1] in a practically feasible and cost-effective way. Improper implementation and management of measurement system development aiming to use new measures to reflect new priorities often generate insignificant results. This is due to the failure of the organisation to discard measures reflecting old priorities, uncorrelated and inconsistent indicators, and inadequate measurement techniques [2]. Measurement gives the status of the variable, compares the data with target or standard data, and points out what actions should be taken and where they should be taken as corrective and preventive measures. This is extremely difficult without adequate data to develop models for supporting the decision-making process [3]. The characteristics of performance measures include relevance, interpretability, timeliness, reliability and validity [4]. An operational PM system acts like an early-warning system.

Several frameworks have been developed for measuring performance over the years. Until 1980, the PM was based on mostly financial measures. The balanced scorecard, with its four perspectives, focuses on financial aspects, customers, internal processes, and innovation and learning [5]. Besides that, Overall Equipment Effectiveness (OEE) created by [6] focuses on waste, and on inefficiencies in the manufacturing process; in essence, it focuses on the wasted time when the machine is not producing. OEE is defined as a measure of total equipment performance [7] that provides information about the process.

[8] reported companies that using an integrated balanced PM system perform better than those that do not measure their performance. To be competitive, company performance depends on the availability of their production facilities [9] and the need to improve and optimise their productivity [10]. OEE takes the most common sources of manufacturing productivity losses and places them into three categories: Availability, Performance, and Quality. These losses are activities that absorb resources but create no value. As the implementation of OEE varies from one industry to another [10], this study explores OEE in general to identify the inefficiencies process that helps to monitor and manage machine improvement.

This study was conducted in a manufacturing company producing a broad range of packaging products. The core business of the company is manufacturing corrugated boards, corrugated cartons, die-cut containers and paper pallets. This research focused on the corrugated cartons production line and the corrugators' machine was considered because this machine is the most critical for the production of the products. The corrugation process is a continuous and highly automated one. As the implementation of OEE varies from one industry to another [10], this study explores the OEE to identify the inefficiencies process that helps to monitor and manage machine improvement. In this study, IEE measures the productivity of the machine to determine the initial performance, so that this can then be compared with ideal OEE values. These values then act as indicators for the performance of the next maintenance phase, the Total Production Maintenance.

This paper reports on empirical findings and is organised as follows. The literature review sets out the background of OEE. Next, the methodology discusses the research design and six big losses. The data analysis presents and discusses the OEE results. Finally, the conclusions of this paper are drawn.

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II. LITERATURE REVIEW

A. Overall Equipment Effectiveness (OEE)

According to [6], the OEE measure is the basic building block of a manufacturing improvement approach called Total Productive Maintenance (TPM). TPM is based on three interrelated concepts:

- Maximising equipment effectiveness;
- Autonomous maintenance by operators; and
- Small group activities.

Therefore, OEE can be considered to combine the operation, maintenance and management of manufacturing equipment and resources [11]. The key criterion for success and long-term effectiveness of TPM activities is the accuracy of the data [12].

Previous studies have pointed out that OEE works for single pieces of equipment [10, 13, 14, 15] and highly automated processes [10]. As suggested by [16], for the machines that process work individually, OEE can identify which machine's performance is worst and indicates where to focus the TPM resources.

In order to establish an accurate OEE rate, the six big losses must be measured accurately [17, 19, 20] since they consume resources without adding any value to the final product. Table 1 shows the Six Big Losses for the corrugators' machine.

TABLE 1: The Six Big Losses for the corrugators' machine

<table>
<tr><th>Equipment</th><th colspan="2">Big Six Losses</th><th>Computation of OEE</th></tr>
<tr><td rowspan="2">Downtime losses</td><td>Planned downtime</td><td>Breakdown</td><td rowspan="2">Availability efficiency = Actual operating time/Planned operating time</td></tr>
<tr><td>Unplanned downtime</td><td>Changeover</td></tr>
<tr><td>Speed losses</td><td colspan="2">Machine wear</td><td rowspan="3">Performance efficiency = Actual speed/ Theoretical speed</td></tr>
<tr><td></td><td colspan="2">Substandard material</td></tr>
<tr><td></td><td colspan="2">Operator Inefficiency</td></tr>
<tr><td>Quality losses</td><td colspan="2">Uncounted wastage</td><td rowspan="4">Quality efficiency = (Total number of product produced- number of scrapped)/ Total number of product produced</td></tr>
<tr><td></td><td colspan="2">Original defect</td></tr>
<tr><td></td><td colspan="2">Forklift defect</td></tr>
<tr><td></td><td colspan="2">Single face defect</td></tr>
<tr><td colspan="4">OEE = Availability efficiency x Performance efficiency x Quality efficiency</td></tr>
</table>

B. Ideal Value for OEE Ratios

Reference [6] suggested the following ideal values for the OEE component measures:

- availability in excess of 90 per cent;
- performance efficiency in excess of 95 per cent;
- quality in excess of 99 per cent.

Other than the ideal values of OEE suggest from [6], [17] indicate that the mean availability rate is 80 percent, the average performance efficiency was 68 per cent; and the quality with an average value of 99 per cent.

According to [6], such levels of availability, performance and quality would result in an OEE of approximately 85 per cent. However, some authors have discovered different OEE values; greater than 50 per cent [18], between 30 per cent and 80 per cent 12], and between 60 per cent and 75 per cent, respectively [17]. Since the varying norms in every industry would pose difficulties in establishing an optimum OEE rate for reference [11], therefore, this study refers to [6] "Ideal Value" for OEE value.

III. METHODOLOGY

The single case study was employed for data collection which was undertaken over 12 months' data. It employed a number of collection techniques including observation, document analysis (annual, monthly and weekly reports), and interviews.

Table 2 shows the categories of data that have been collected by the researcher. The collected data provide information about the design and use of the respective performance measurement systems during the corrugation process. The analysis was done with Microsoft Excel Software that provides results in an output table and graphical presentation.

TABLE 2: Categories of Data

Number of production order	The number of production orders received per month.
Length per production order	The length of paper roll used per production order.
Planned stop	The time during the shift where production is halted due to a planned event such as planned maintenance, cleaning, training, safety drills, meeting, R&D trial, and stock check.
Changeover	The adjustment time between one batch ends to next batch run.
Down time	The time where downtime can occur during the process.
Actual speed	The length of paper roll to be produced per minute,
Ideal speed	The target speed of corrugators to produce optimum output,
Produced Quantities	The quantity of product processed and the volume against each production order.
Wastage	Quantity of defect product and comment regarding the defective product.

IV. DATA ANALYSIS

A. Corrugators OEE Analysis

The three main categories of corrugators-related losses which are downtime loss, speed loss, and defect or quality loss are the main factors for determining the overall equipment effectiveness [19]. Overall equipment effectiveness was calculated by combining three factors that reflect these losses: the availability, the performance, and the quality [20].

Availability

Availability of corrugators is the amount of time the machine is available for production; accordingly it is a measure of how big the downtime losses are. The availability analysis report and graph of availability analysis for corrugators are shown in Figure 1.

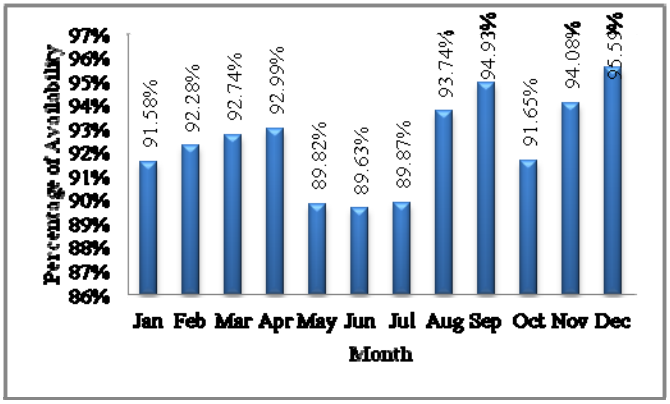

Figure 1: Percentage of Availability for corrugators

The availability of corrugators is 92.15 per cent on average. The highest availability percentage of corrugators is 95.59 per cent in September. Meanwhile, the corrugators showed the lowest percentage of availability in June, with 89.63 per cent.

By comparing the *planned* operating time to *actual* operating time, the availability component of OEE allows for a determination of lost production due to downtime. The downtime could be separated into planned downtime (65 per cent) and unplanned downtime (35 per cent) as shown in Figure 2. At the Company, the actual operating time is derived by subtracting equipment downtime (unplanned downtime) from loading time (planned downtime). Equipment downtime involves equipment stoppage losses resulting from failures, set-up and adjustment procedures, and changeover, while the loading time includes the time lost in maintenance activities and break times.

Performance

The performance rate measures corrugators transform input to output, which compared the real production output to the theoretical output. The machine performance analysis data and graph analysis for the corrugators are shown in Figure 3.

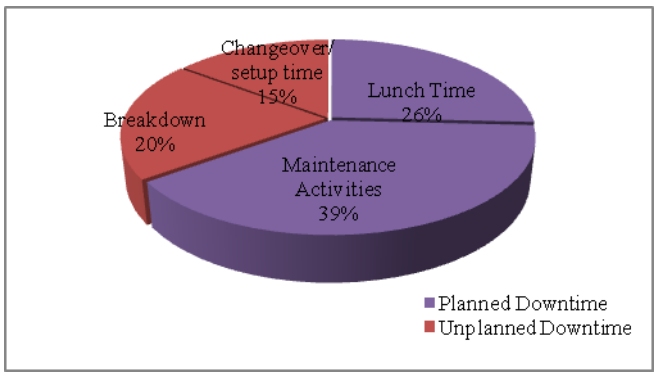

Figure 2: Percentage of Categories of Downtime

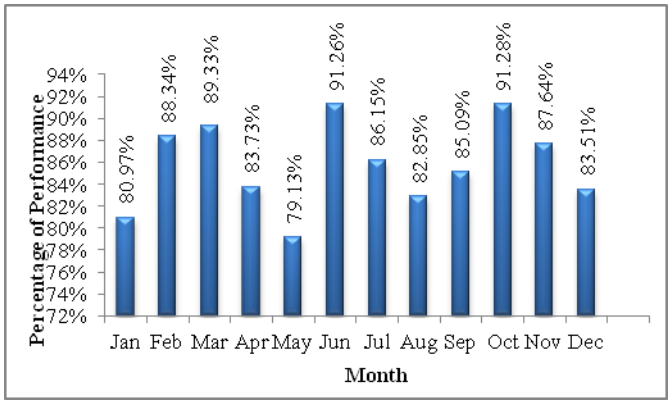

Figure 3: Percentage of Performance for Corrugators

The performance of corrugators was considered consistent over the 12 months. The average performance of corrugators is 85.77 per cent. The corrugators perform well in October, at 91.28 per cent. However, the data showed that the corrugators had the worst performance in May. Performance takes into account speed loss, which includes any factors that cause the corrugators to operate at less than the maximum possible speed shown in Figure 4 and Figure 5.

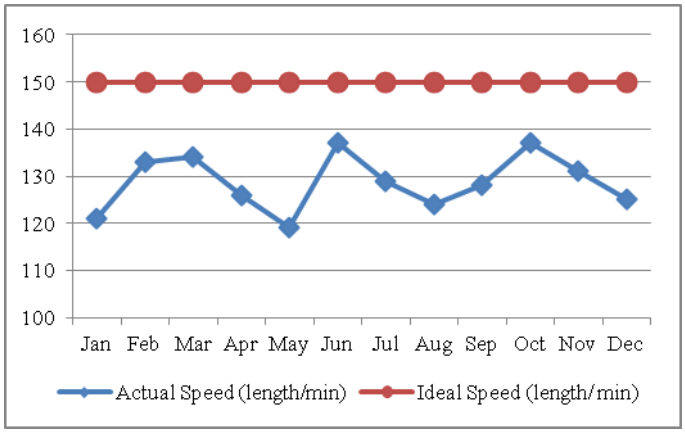

Figure 4: Actual speed vs ideal speed

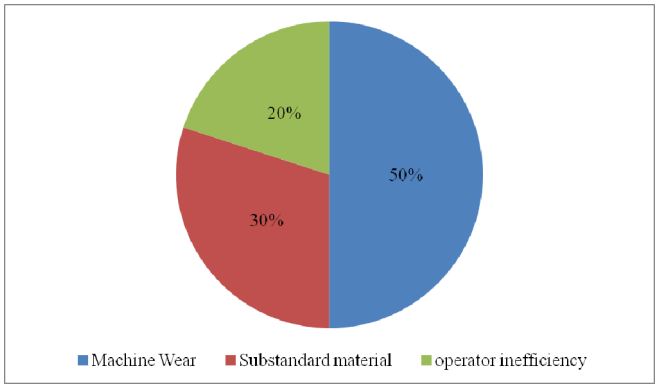

Figure 5: Reasons that lead to speed loss

Quality

The quality factor takes into consideration the rate of rejected items due to quality defect. Figure 6 shows the percentage of quality for corrugators over a 12-month period.

The average percentage of quality is 94.29 per cent. The highest percentage of quality for corrugators is 95.07 per cent recorded in the month of January and the lowest percentage of quality was in of August, at 93.53 per cent. Quality takes into account Quality Loss, which accounts for produced pieces that do not meet quality standards, including pieces that require rework, called wastage. According to the data, the wastage can be categorised into five categories - uncounted wastage, origin defect, forklift defect, single face, and dry end, shown in Figure 7.

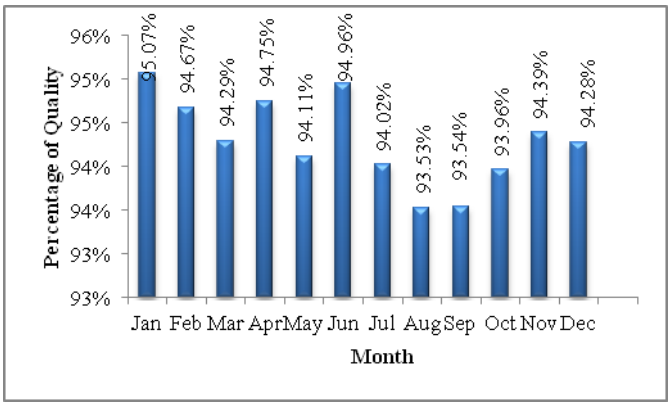

Figure 6: Percentage of Quality for Corrugators

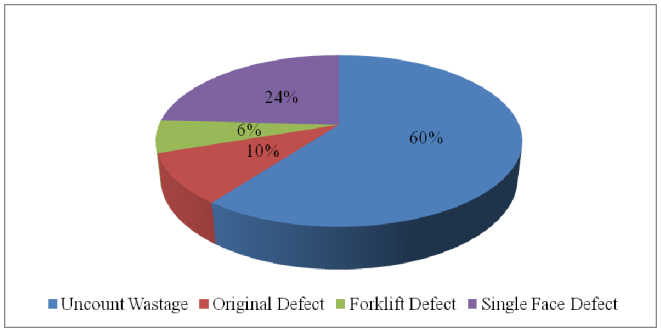

Figure 7: Percentage of Wastage

B. OEE Analysis

OEE measurement is made up of three factors: availability, performance, and quality. Each one is expressed as a percentage and accounts for a different kind of waste in the corrugation process discussed before. Table 3 shows the overall OEE analysis.

TABLE 3: OEE analysis report

Month	OEE Analysis Report			
	Availability (%)	Performance (%)	Quality (%)	OEE (%)
Jan	91.58	80.97	95.07	70.50
Feb	92.28	88.34	94.67	77.17
Mar	92.74	89.33	94.29	78.12
Apr	92.99	83.73	94.75	73.78
May	89.82	79.13	94.11	66.90
Jun	89.63	91.26	94.96	77.67
Jul	89.87	86.15	94.02	72.79
Aug	93.74	82.85	93.53	72.64
Sep	94.93	85.09	93.54	75.56
Oct	91.65	91.28	93.96	78.60
Nov	94.08	87.64	94.39	77.82
Dec	95.59	83.51	93.93	74.98
Total	**92.15**	**85.77**	**94.29**	**74.52**

OEE = Availability x Performance x Quality
= 92.15% x 85.77% x 94.29%
= 74.52%

The OEE of the corrugators is 74.52 per cent, which means that the corrugators are running effectively only 74.52 per cent of its time.

The percentage of OEE for corrugators is shown in Figure 8. The data show that the OEE is 74.54 per cent on average. The corrugators achieve the highest percentage of OEE – 78.60 per cent in October, while the lowest OEE percentage of 66.90 per cent was achieved in May. Thus, OEE measures total performance of corrugators by relating the availability of a process to its productivity and output quality.

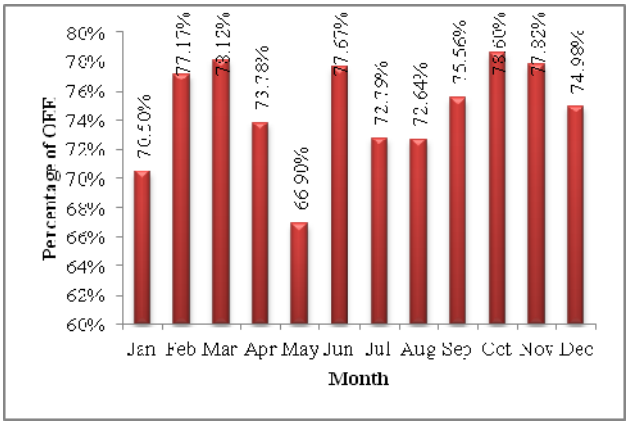

Figure 8: Percentage of OEE for Corrugators

By comparing the OEE of corrugators to the "Ideal OEE", there is around 10 percent of room for improvement in corrugation process. However, the availability of corrugators is 92.15 per cent which exceeds the "Ideal OEE" percentage of 90 per cent.

Meanwhile, the performance of corrugators is lagging behind the "Ideal OEE" by around 10 per cent. Last but not least, the quality factors for the corrugators only just achieve 94.29 per cent, which leaves 5 per cent room for improvement to achieve the "Ideal OEE". An isolation result is shown in Figure 9.

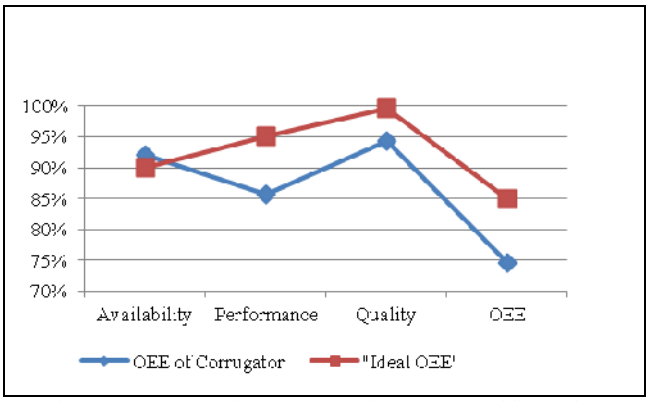

Figure 9: Comparison between OEE of Corrugators with "Ideal OEE"

V. CONCLUSION

The use of OEE to compute the performance of machine production is gaining in importance to optimise the productivity performance in corrugators industry. From the three OEE parameters obtained, it is shown that the differences in performance, where Availability rate does not change much, show an improvement when compared to the ideal level of OEE worldwide. On the other hand, the Performance and Quality rates show differences of about 10 per cent which demonstrates a significant reduction. However, in this study, with the application of the OEE measurement, both the operators and management were able to be fully aware of what constitutes waste and, subsequently, activities could be controlled and managed more efficiently. Hence, for future research, OEE will be implemented for each production machine measurement to ensure that the productivity performance is consistent.

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