Total Productive Maintenance Practices in Manufacture of Electronic Components & Boards Industry in Malaysia

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Abstract**—The Electrical and Electronics (E&E) industry continues to be a key driver of Malaysia's Industrial development and contributes significantly to GDP growth, export earnings, investment, and employment. Malaysia has become a major global manufacturing hub for the E&E industry and four decades and continues to be a preferred E&E investment destination. In order to sustain and stay competitive, the Malaysian semiconductor companies are urged to implement world class maintenance techniques that will improve equipment utilization and thus reducing capital expenditure. Total Productive Maintenance (TPM) is one of the effective maintenance strategies for enhancing the overall equipment effectiveness (OEE) to achieve a significant competitive advantage. The aim of the study is to determine the effectiveness of TPM to improve OEE in the E&E industry. This study used the real time data for two types of die attach equipment models, namely CANON and ESEC. The data was collected from an E&E company in Malaysia. The real time data was recorded by software known as Global Operator User Interface (GOUI) system. GOUI system captures the real time data directly from the machine. The result shows that the implementation of TPM gives a significant difference in OEE for both different equipment models. In addition, this study also shows that the three TPM practices namely planned maintenance, autonomous maintenance, and focused maintenance are able to explain 91.2% of the total variation of OEE in the E&E industry.**

Index Terms**—Autonomous Maintenance; Focused Maintenance; Overall Equipment Effectiveness; Planned Maintenance; Total Productive Maintenance**.

I. INTRODUCTION

Malaysia is one of the most vibrant countries that strategically located in the heart of South-East Asia and is a dynamic country with excellent political stability, which ensures the sustained and progressive economic growth. This had led Malaysia to accomplish significant economic and social progress over the past decades. In order to sustain and elevate country to developed-nation status by 2020, Malaysia government launched the Economic Transformation Programme (ETP) in 2010. The ETP is driven by two components: the 12 National Key Economic Areas (NKEAS), which representing economic sectors that accounts for significant contribution to Gross National Income (GNI) and the six Strategic Reform Initiatives (SRIs) that made up of supportive policies, which can help to create an efficient, competitive and business-friendly environment in Malaysia that will allow world-class, local champions to thrive and attract valuable foreign investment. These can help to drive Malaysia's global competitiveness. The 2015 ETP annual report states that Malaysia achieved a healthy Gross Domestic product (GDP) growth of 5 percent in 2015. Between 2010 and 2015, GDP grew 30 percent from RM 797.3 billion to RM 1.13 trillion [1].

One of the sectors that ETP has made great strikes is the Electrical and Electronics (E&E) NKEA industry, which has helped in the growth of small and medium-sized enterprises (SMEs). In an overview of various sectors in ETP, the Electrical and Electronics (E&E) NKEA sector is one of the key contributors to offset the hit taken from low oil price and the growth of Malaysia economy with the current GNI value at RM 53 billion [2]. Hence, some measures have been implemented by the Electrical and Electronics (E&E) NKEA to enhance the capability and capacity of electronic manufacturing companies, pushing them to produce better quality and high value-added products to achieve the world-class standards. With these measures, investors will be confident that the government is firm yet flexible to accommodate their needs [3].

The Electric and Electronics (E&E) industry continues to be a key driver of Malaysia's Industrial development and contributes significantly to GDP growth, export earnings, investment, and employment. Since the establishment of the first semiconductor plant in Penang in 1972, Malaysia has become a major global manufacturing hub for the E&E industry. Four decades on, Malaysia continues to be a preferred E&E investment destination. In New Straits Times [4], Malaysia External Trade Development Corp (Matrade) stated that E&E sector contributed 44.6 percent to the country's total manufacturing export, 23.4 percent to the country's gross domestic product and created more than 780,000 jobs in 2016. Figure 1 also indicated that the E&E industry has the highest exports, which is the key contributor towards the Malaysian economy. The chart shows that the E&E sector accounted for 34.8% and contributed to total exports of RM49.48 billion [5].

In order to sustain and stay competitive, Malaysian semiconductor companies are urged to implement world class maintenance techniques that will improve equipment utilization and thus reduce capital expenditure [2].

Liyanage and Kumar [6] stated that the maintenance becomes an integral part of the business that influences the production activities in any industries. According to Al-

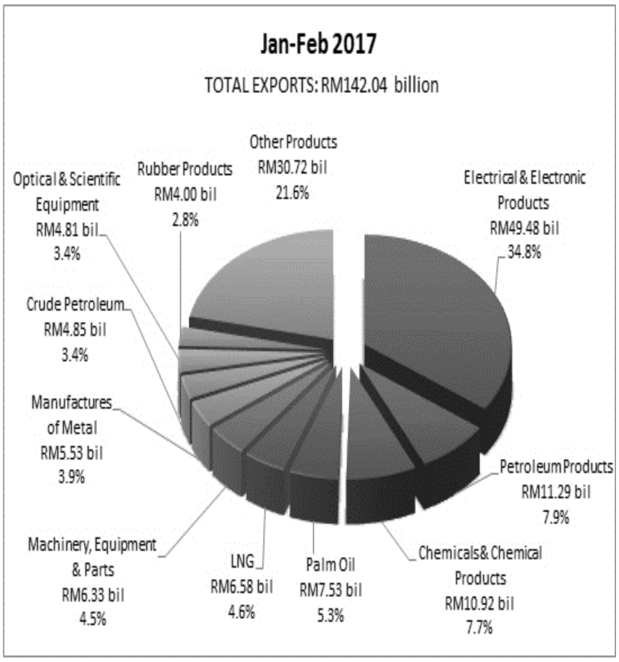

Figure 1: Distribution of the top 10 major exports from Jan-May, 2017. (Source: http://www.matrade.gov.my/en/28-malaysian-exporters/trade-statistics/3789-top-10-major-export-products-2017)

Najjar and Alsyouf [7], the maintenance function is critical in keeping and improving the availability, product quality, safety equipment, and plant cost effectiveness level as maintenance costs constitute a crucial part of operation budget in manufacturing company. Hence, Nakajima [8] (1988) had developed the core concept of total productive maintenance (TPM) in which aim for the improvement of the production performance. This concept is nowadays very well-known for its powerful result and widely extended in manufacturing industries. It also offered the measureable metric of overall equipment effectiveness (OEE) to measure the level of competitiveness of the company. Implementation of TPM in the machines line would be able to increase the power plant performance [9] and to enhance the competitive position [10]. However, recent trends indicate that most of the system in use is not performing as intended, so far as cost effectiveness in term of their operation and support is concerned, in a manufacturing system, some of the equipment often not fully utilized, with low productivity and thus the costs of producing products are high. Therefore, Electrical and Electronics Strategic Council (EESC) was established in 2016 to facilitate Malaysian-based companies to be part of the global supply chain to strengthen and enhance the E&E industry to the next level [2]. With the increased of global competition, the semiconductor companies are forcing to implement world class maintenance techniques to improve equipment utilization and thus reducing capital expenditure. The purpose of this study is to examine the impact of TPM towards OEE for two types of machine models namely CANON and ESEC in an E&E semiconductor company in Malaysia.

Section II presents literature review about TPM and OEE. Following section III we explain the methodology of this study. Then section IV is the finding and discussion of the results. Finally, the last section is about the conclusion of the study.

II. Literature Review

TPM is a tool for avoiding losses and to increase productivity in an auto-parts machining line [11]. Maintenance is the execution of activities that ensure the physical assets continue to do what their users want them to do. The implementation of TPM is important in a manufacturing company and has the significant impact and relationship on manufacturing performance, in term of OEE [12]. Hence, the main goal of TPM is to maximize equipment effectiveness, and OEE is used as a measure.

TPM is an innovative strategy that developed at Nippondenso, Japan in 1971. Ahuja et al. [13] stated the TPM contains three words, start with the word TOTAL which is emphasized to involve overall workforces from top to bottom in every aspect of equipment maintenance. Next word is PRODUCTIVE which signifies to ensure the operation is efficient maintenance problems/costs. While the last word MAINTENANCE is to ensure the equipment is keeping in good condition.

Basically, the practices of TPM often known as the pillars or elements of TPM. Through its unique eight-pillar methodology, TPM is used for excellent planning, organizing, monitoring and controlling practices [14]. Pillar 1- autonomous maintenance: It is based on the concept that the equipment operators accept and share responsibility with the maintenance of the performance and health of the equipment. Pillar 2- Focused Maintenance: This concept aims for small improvement by carried out continuously and involve the entire workforce. Pillar 3- Planned maintenance: Is a system where the maintenance jobs and equipment stoppages are scheduled based on predicted or measured failure rates. Pillar 4- Quality Maintenance: Focus on achieving the zero defects and address the equipment problem and root causes. Pillar 5- Education and Training: Provide the knowledge of what daily maintenance is required for the operators to ensure the optimal operating condition of equipment. Pillar 6- Safety, Health, and environment: Is used to create a safe workplace and an environment that will not be damaged by the process and procedure. Pillar 7- Office TPM: Focus on the improvement of the productivity and efficiency of administrative functions. Pillar 8- Development Management: Encourage the continuously developing ideas and procedure that can lead to the creating of maintenance improvement initiatives.

While the OEE methodology incorporates metrics from all equipment manufacturing states guidelines in a measurement system that helps the company to enhance the equipment performance and thus, reduce the equipment cost of ownership [14]. The OEE concept is becoming well-known and his widely used as a quantitative tool that important for productivity measurement especially in semiconductor manufacture operations [15]. Firstly, OEE used as a "benchmark" by comparing the initial OEE measures with future OEE values, thus quantifying the level of improvement required. This led to the improvement of maintenance policy and affected continuous improvement in the manufacturing system. Secondly, OEE values of one manufacturing line can use to compare with the other line performance across the operation, which can help to identify the poor line performance and improvement needed [16]. Thirdly, OEE measurement is an effective way of analyzing and identifying the efficiency of a single machine and then help in indicating where to focus on TPM resources. OEE tool is designed to identify the disturbances to the manufacturing process as the disturbances often lead to a serious problem that can reduce the equipment effectiveness. The losses are measure by OEE, in where it is calculated by obtaining the product of availability of the equipment, performance efficiency of the process and rate of quality products. Equation (1) shows the calculation of OEE

$$OEE = Availability\ (A) X \quad Performance\ Efficiency\ (P) X \quad Rate\ of\ Quality\ (Q) \tag{1}$$

III. Research Methodology

This study used primary data in an E&E company in Malaysia. Real time data was recorded by software known as Global Operator User Interface (GOUI) system to provide valuable equipment data for improvement. It is a middleware system between Equipment Tracking Interface (ETI) and different company's system. The main purpose of GOUI is to control equipment, process monitoring, manage user, verify material, data logging, efficiency losses measurement and so on without referring back to the machine vendor. Besides, the SECS/GEM standard is also used as the interface protocol for equipment to communicate with the host and vice versa. It defines messages, equipment state and scenarios to enable factory software to control and monitor production equipment. With this software, the system can be measure and evaluate in all areas of production and offers users a comprehensive overview of the efficiency of production equipment at any time. Besides that, the main applications for the semiconductor industry – electronic manufacturing and micro-systems technology standard (SEMI E10 and SEMI E58 standards) is also applied. It is an ideal measurement in where it can assist manufacturing to monitor the machines and automatically determine availability indicators (SEMI E10, 1992) [17].

The data was collected and monitored weekly and from two different models of machines in the die attach process-CANON and ESEC. Since Canon was a new machine model that started to run production on September 2016, hence the data started collected from the September 2016 and end on March 2017 due to time limitation of this study.

Figure 2 shows the TPM's variables used in this study are maintenance (FM), autonomous maintenance (AM), and planned maintenance (PM).

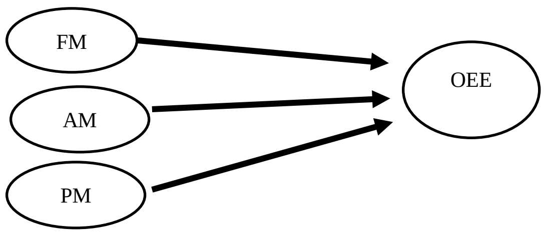

Figure 2: Theoretical Framework

IV. Results And Discussion

In this part, the data for both model types of equipment are combined, and two sample dependent or pair mean analysis was performed to determine the effect of the implementation of TPM pillars and OEE.

The independent t-test was used to compare the means between two unrelated group (CANON and ESEC) on the same continuous, dependent variables (OEE). The hypothesis for this study can be express as:

H_0: $\mu_{CANON} = \mu_{ESEC}$ (Means of CANON and ESEC are equal.)

H_1: $\mu_{CANON} \neq \mu_{ESEC}$ (Means of CANON and ESEC are not equal.)

In the sample data, two variables had been used: Model and OEE. The Model variable consists of CANON and ESEC, which function as the independent variable in this T test, while the OEE is functioned as dependent variables and is a numeric duration variable (%). The result of the analysis is summarized in Table 1 and 2.

Table 1
Group Statistics

Model OEE	n	Mean	Standard Deviation	Standard Error Mean
CANON	31	75.488	8.420	1.512
ESEC	31	81.825	3.525	0.633

The first section, Group Statistics, provides basic information about the group comparisons, including the sample size (n), mean, standard deviation, and standard error for OEE by the group. In this study, 31 weeks data had been collected for CANON and ESEC, respectively. The mean of OEE for CANON is 72%, and the mean OEE for ESEC is 82%.

Table 2
Independent T-Test Output

Test	Statistical Test	OEE	
		Equal variance assume	Equal variance not assumed
Levene's Test Equality of Variances	F	9.648	
	Sig.	0.003	
t-test for Equality of Means	t	-5.695	-5.695
	df	60	40.202
	Sig. (2-tailed)	0.000	0.000
	Mean difference	-9.33677	-9.33677
	Std. Error Difference	1.63945	1.63945
	95% Confidence Interval of the Difference		
	Lower	-12.61615	-12.64970
	Upper	-6.05740	-6.02385

The second section, Independent Samples Test, displays the results most relevant to the Independent Samples t Test. There are two parts that provide different pieces of information: Levene's Test for Equality of Variances and t-test for Equality of Means. This study showed that the P= .003 is less than the significance level of 0.05. Hence, the null of Levena's test is rejected and concluded the variance in OEE of CANON is significantly different than the ESEC. This also means that the data need to be referred the "Equal variance not assumed" row for the t-test results. The negative sign of T-values indicated that the mean of OEE for the first group, CANON is significantly lower than the mean of OEE for the second group, ESEC. Based on the result, the following statements can be concluded: -

There was a significant difference in mean of OEE between CANON and ESEC T (60) = -5.695, P=.003, which is less than the established significant level of 0.05.

Following is the results for multiple regression analysis for the pair model as shown in Table 3. F- Ratio in the ANOVA Table 3 is used to determine the overall regression model is a good fit for the data. The table showed that independent variables statistically significantly predict the dependent variable, F (3, 58) = 159.525, p< .05. It indicated that the regression model is a good fit for the data.

Table 3:
ANOVA of Multi Regression Analysis for CANON and ESEC
ANOVA[a]

Model	Sum of Square	df	Mean Square	F	Sig.
Regression	3434.604	3	1144.868	159.525	0.000[b]
Residual	416.250	58	7.177		
Total	3850.854	61			

Notes: [a]Dependent variable OEE
[b]Predictors (Constant, FM, PM, AM)

The coefficient is a statistical measure of the degree to which changes to the value of one variable predict the change to the value of another [18]. Table 4 shows the impact of independent variables- PM, AM, and FM on the dependent variables of OEE. The results yielded from the multiple regression showed that the significance level of planned maintenance and autonomous are less than the established significant level of 0.05, so they had significant impact on OEE, in where planned maintenance: t(61) = 14.398, P= .000, autonomous maintenance: t(61) = 6.539, P= .000., and focused maintenance, t (61) = 7.538, P= .0.000, in where the P value<0.5. R^2=0.912.

Table 4
Coefficients of Multi Regression Analysis for CANON and ESEC
Coefficients[a]

Model	β	Std. Error	Beta	t	Sig	95% Confidence Interval for β		Collinearity Statistics	
						Lower Bound	Upper Bound	Tolerance	VIF
Cons	11.586			.901	.372	-14.167	37.34		
PM	0.501	0.035	.775	14.398	.000	.431	.571	.643	1.555
AM	0.218	0.033	.429	6.539	.000	.151	.284	.433	2.309
FM	0.076	0.032	.437	7.538	.001	-.208	.361	.393	2.548

Notes: [a]Dependent variable OEE

Multicollinearity in regression is viewed as a disadvantage because it practically inflates unnecessarily the standard errors of confidents in regression. The tolerance and VIF are used to determine the multicollinearity. There is a various recommendation for the acceptable of VIF have been published in the literature. Perhaps more commonly, a value of 10 has been recommended as the maximum level of VIF [19-20]. However, a recommended maximum VIF value of 5 [21] and even 4 [22] can be found in the literature. In this study, the VIF of three independent variables (PM: T= .643, VIF= 1.555; AM: T= .433, VIF= 2.309; FM: T=.393, VIF= 2.548) are less than the established value of 10, so this indicated that there was no inter-correlation between the predictor of interest.

The general form of the equation to predict the relationship between the OEE and TPM variables (PM, AM, and FM) was shown as:

$$OEE = 11.586 + 0.501\,PM + 0.218\,AM + 0.176\,FM$$

where: OEE = overall equipment effectiveness
PM= Planned Maintenance
AM= Autonomous Maintenance
FM= Focused Maintenance

All variables are measured in percentage (%).

The regression equation established by taking all factors into account constant at zero, the OEE rate will be at 11.586. It also indicates that for every unit increase in planned maintenance practices would actually result in a .501 increase of OEE, while every unit increase in the implementation of autonomous maintenance would also result in .218 increase of OEE. Besides that, the OEE would also increase by .176 when there is an increase in the implementation of focused maintenance.

The finding of the study is supported by Paropate and Sambhe [23] who also performed a study on the implementation of TPM in a midsized cotton spinning plant in India. Their study proved that with established TPM, the overall equipment effectiveness improved from 68.9866% respectively before TPM implementation to 71.465% respectively after TPM implementation.

The study of Sharma et al. [24] also supports the result, in where the study is proved that TPM leads to an increase in efficiency and effectiveness of manufacturing system in term of OEE index. In addition, the finding of Ateka [25] also highlighted that the increased quality and improved productivity as the key benefits resulting from TPM implementation. The study was examined the adoption of TPM practices in large manufacturing firms located in Mombasa County and also stated that the most important critical success factor of TPM is co-operation and involvement of both the operators and the maintenance workers in equipment maintenance.

V. CONCLUSION

In a nutshell, this study shows that there is a significant positive relationship between the implementation of TPM practices and OEE at the semiconductor company. The improvement in OEE rates was witnessed in the organization during the time period from September 2016 to March 2017. The combined effect of the three TPM practices namely planned maintenance, autonomous maintenance, and focused maintenance are giving significant impact to OEE. This study proved that 91.2% (R^2=0.912) of the total variation of OEE could be explained by these three indicators of TPM, namely PM, AM, and FM.

This research is a cross-sectional study as the study will be carried out on a particular phenomenon and population at a particular time. Due to the time limitation and complexity of the data, the study could not be able to carry on for the whole production line in the company. Therefore, the study was only focused on the equipment models of the bottleneck process-die to attach. Furthermore, the study used primary data in the company. Due to the sensitivity of the information, and the obligations placed on the researcher and the custodians of the information, the study was not able to establish more data points, and to obtain data for a longer time period, thereby limiting the scope of the period is under the study.

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