EVALUATION OF OVERALL EQUIPMENT EFFECTIVENESS PERFORMANCE IN THE MALAYSIAN PALM OIL MILL: A CASE STUDY

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ABSTRACT

Palm oil consumption is increasing worldwide, urging Palm Oil Mills (POM) to maximise efficiency in equipment and resources utilisation towards fulfilling demands and sustaining competitiveness in the global market. Employment of Overall Equipment Effectiveness (OEE) that focuses on availability, performance, and quality rate of a production system is one of the most important strategies to approach this challenge. The main objective of this paper is to evaluate the current performance level of OEE the selected Malaysian POM. The calculation of OEE performance is established according to data suitability and important part of the POM process. The results of OEE measured is benchmarked to the world-class OEE scale. Then, the study investigates the crucial factors that affect the OEE performance in the Malaysian POM. The data is gathered from the POM production records for three years period. The results show that the OEE performance in the POM is in the range of 60% to 85%, mostly in the Level 2 relating to the world-class OEE scale. Among three elements of OEE, the availability rate of the POM shows the lowest value, 58.20%, that contributed to the lower OEE level. The decrease of OEE performance to level 3 is observed during the period between the months of November until March for these three years. The key factor that affect the availability rate contributes to the lower OEE performance, especially during these periods is long waiting time. Besides, unscheduled maintenance activities also affected the availability rate thus reduce the OEE performance of the POM. The practical implication of the study from the presented OEE evaluation approach will serve as a useful guide to the managers in the Malaysian POM to recognise the crucial losses in the production line that require further improvement. Furthermore, the analysis provides practitioners overview in decision making process for continuous improvement of productivity and quality.

Keywords: *Overall Equipment Effectiveness, Malaysian Palm Oil, Performance Measurement*

INTRODUCTION

Palm oil, one of the main agro-industrial commodities in Malaysia, plays a major part of the country's economic backbone and created nation's wealth. Malaysian palm oil industry exported Crude Palm Oil (CPO) to more than 140 countries, holding 45.3% of the global market share (RSPO, 2020) and contributing 6.4% to the Malaysian gross domestic product (Omran et al., 2021). Comparing to other vegetable oil, palm oil demand is constantly high due to its flexibility applications and low-priced. It has been forecasted that the palm oil production will continue to rise to more than 200% by the year 2035 to supply the growing demands in both edible and non-edible industrial application (Gan and Li, 2014). Palm oil usage is not only for cooking oil, but has been utilised as ingredients in numerous food products, bio-based cosmetics, soaps, detergent, and other household products. Additionally, biodiesel from CPO has been receiving great attention as alternative for renewal energy. At present, 426 Palm Oil

Mills (POM) around Malaysia are actively producing 24.97 million tonnes of CPO annually. It is a challenge for the Malaysian POM to have the top performance equipment to perform ordered task efficiently in fulfilling rising worldwide demand (Mahmood et al., 2020).

Overall Equipment Effectiveness (OEE) has been widely acknowledged as a simple but precise performance measure in the manufacturing system. It was introduced by Nakajima (1988) as a tool for recognising and eliminating six big losses that contributing to system inefficiency. The implementation of OEE is increasing within various industry with systematic monitoring on how well the production system is operating wholly targeting towards greater availability, equipment performance and product quality (Prasetyo et al., 2020). Generally, OEE identify and analyse factors affect equipment effectiveness in the manufacturing operation from the six big losses. Researchers are continually refining the OEE measurement approach and the application of OEE performance measurement in various industries has been reported (Ng et al., 2020). It is observed that different industry might have diverse factors affecting the OEE performance and use different data set for OEE calculation approach.

In the case of POM, the production system is complex that includes several functional areas which are mutually dependent to each other from raw materials acquisition to the finish products shipment. Although analysis of OEE performance for POM system has been reported in the literature (Baluch, 2012 and Susilawati et al. 2019), however, the prominent factors which causes the interruption in the POM operation that affect the equipment effectiveness performance has not been discussed. Furthermore, the results presented by Baluch (2012) showed the average of OEE measure for different mills based on daily data collected. The downtime for Preventive Maintenance (PM) was prerequisite for production, but was only carried out on certain day, which entails that the OEE value for this given day is unreasonably low. Therefore, this study is conducted to address these issues. The objective of this study is to evaluate the current performance of OEE in the selected Malaysian POM using the data of three years (2014 to 2016) obtained from the case study. The aggregated data of longer period is employed for OEE analysis. The analysis including benchmarking the OEE performance in the POM and the world class OEE performance to detect performance gaps and recognize areas for improvement. Further, the study investigates the factor that affect the OEE level.

Following this introduction, literature review is presented. It discusses the current issues related to palm oil process and background of OEE as performance measurement. Material and methods section explain the data collection using case study approach and calculation method for measuring OEE in the POM. The world-class OEE level is presented for comparison with the OEE performance in the POM. Then, the results of the study present company background and POM process overview. The analysis of OEE performance in the POM benchmarking to the world class OEE is discussed and concluded.

LITERATURE REVIEW

The changing demands for sustainable palm oil products especially in the European Union countries for the past few years have put palm oil producers and exporter under pressure to meet newest market requirements. Palm oil industry has become the subject of several controversies and has been extensively criticised on several sustainability issues between the economic profit and the associated environmental degradation due to pollutions from the palm oil process, and aggressive deforestation for plantation purpose, and destruction of natural resources by such agro-industrial activities (Jafar et al.,2020). The production of CPO generated wastes including empty fruit bunches, fibre and palm shell and increasing volume of palm oil residue accumulation is gaining significant attention worldwide. Various sustainability programs and practices from the upstream and downstream of palm oil industry have been introduced and directed towards sustainability development in the Malaysian palm oil industry. However, rigorous proactive and preventive sustainability actions need to be implemented instantaneously. The goal is not only for better environmental protection, but also for social welfare, economic advantage, and technical excellence (Mahmood et al., 2020).

The technical excellent of manufacturing system operation are certainly associated with the efficiency of equipment and machineries. Interruption of the operation can be eliminated through analysis the system performance and identify the main losses thus improve productivity and quality. The losses are known as six big losses in Total Productive Maintenance (TPM) concept. These losses include breakdown, set-up and adjusted, minor stoppage, reduced speed, start-up rejecting, and production rejects (Nakajima, 1988). The fundamental of OEE measurement is measuring these losses using matrix of system availability, equipment performance and production quality rate. It is a key performance indicator to monitor the actual performance of an equipment and resources relative to its performance capabilities under optimal manufacturing conditions. The measurement of OEE performance from real-world setting has been reported in many studies from various industries. Chikwendu et al. (2020) analyse OEE factors in the pharmaceutical companies to solve maintenance issues and eliminating losses in the production system. The study aimed at improving the quality rate by adopting TPM tools. Tsarouhas, 2019 utilised OEE assessment in the croissant production line to support advancement on maintenance management. The data was gathered according to the production records and analysed based on 15 months period. Other improvements on the OEE measurement has been proposed by Sari & Darestani (2019). The research evaluated the OEE matrices using intelligent system approach. It is suggested that the Artificial neural network and fuzzy interference systems could solve problems from the manual and automatic monitoring and data collection. This approach also could solve issues related to uncertain input and output of OEE calculation.

The revolution of the industry in this century is focusing towards digital transformation. The Industry 4.0 embarks the application of automation, artificial intelligence, machine learning, and internet of things (IoT) for smart manufacturing goals. The employment of the industry 4.0 benefits the organisations to attain optimal productivity and OEE improvement while minimising negative impact on the environment (Jena et al., 2020). Yazdi et al. (2018) suggested that the from the adoption of the smart manufacturing, the performance of the OEE has been noticed. the reduction of the downtime and idle time in the system has benne recorded after installation of intelligent material handling that use agent-based algorithm. The research on palm oil industry moving towards the fourth industrial revolution has been performed by Lim et al. (2021). The study highlighted the potential of the Industry 4.0

adoption in the palm oil industry both in upstream and downstream setting. Latest technologies related to palm oil industry was assessed and reviewed. However, the palm oil industry has been moving slowly in this revolution due to several barriers. Abdul-Hamid et al. (2020) suggested that most important challenges for palm oil industry including lack of automation and computerised system, uncertain economic benefit of digital venture, process design inadequacy, unbalanced relationship among businesses and employment conflicts.

MATERIAL AND METHODS

Data collection

A case study was carried out on one of the POMs in Malaysia for data collection purpose. The POM was randomly selected after the proposal was sent to the FELDA headquarter office, the top palm oil producer in Malaysia. Field observation was adopted in the study to gain more in-depth information or knowledge on the related issues thus to increase the internal validity. The data collected in real-time through field observation were considered as primary data. The manufacturing process flow and the functions of the related system were studied through actual operation observations, production handbooks and operation manuals. Observation was done on the activities of machines and available data for operational efficiency was recorded. The study assessed the company's manufacturing processes by visiting production line to directly observing palm oil production process and operations. Discussions were carried out to contextualise the responses of the staff in relation to observations made during the visiting the POM. Archival records, documents and photographic evidence are reviewed. The documented data of three years' period were taken from the history records available such as production downtime, PM duration, Oil Extraction Rate (OER) and other data for determining OEE of the POM.

Calculation of OEE for POM

The measurement of the OEE performance can be determined by the ratio between actual manufacturing performance and the ideal manufacturing or, alternatively, as the fraction of time in which an equipment works at its full operating capacity. The tools and techniques to achieve a balanced view of process availability rate, performance rate and quality rate is shown in Equation 1.

$$OEE\ (\%) = Availability\ rate\ x\ Performance\ rate\ x\ Quality\ rate \quad (1)$$

Availability rate is measured in percentage of net operating time divided by the scheduled operating time. The schedule operating time, ScO_T is calculated based on the Equation 2, and net operating time, OP_T in Equation 3. Overall, Equation 4 shows the availability rate.

$$Scheduled\ Operating\ Time, ScO_T = Calendar\ Time - (Scheduled\ Preventive\ Maintenance, PM_T + Planned\ Shutdown, PS_T) \quad (2)$$

$$Net\ Operating\ Time, OP_T = Scheduled\ Operating\ Time, ScO_T - Downtime, DW_T \quad (3)$$

$$Availability\ rate\ (\%) = {OP_T}/{ScO_T} \quad (4)$$

Performance rate is the ratio between the actual number of units produced and the number of units that can be theoretically produced and is based on the standard speed the equipment is designed for. It can be expressed in percentage of actual production output per hour, OUT_A divided by scheduled or ideal production output per hour, OUT_S as shown in Equation 5.

$$Performance\ rate\ (\%) = {OUT_A}/{OUT_S} \quad (5)$$

The quality rate is the measure of the number of parts that meet the specification compared to total product produced per time frame. Quality rate in the POM is measured based on yields of oil recovery efficiency, known as OER. It is different approach of calculating the quality rate from one sector to another. In developing the model for formulating the OEE measurement, the quality rate of CPO production according to the OER. Measuring OER is the most important parameter for POM operation, estimates of oil losses in different stages of the process. The OER is measured by dividing the total CPO recovered and the total FFB processed, as shown in Equation 6. The quality rate can be measured by dividing actual OER achieved by the mill, OER_A, to the ideal OER, OER_I, as shown in the Equation 7.

$$OER = {Total\ CPO\ recovered}/{Total\ FFB\ proccessed} \quad (6)$$

$$Quality\ rate\ (\%) = {OER_A}/{OER_I} \quad (7)$$

The OER value is different for each country depending on several factors. The ideal OER can be considered as the standard value obtained from related authorities such as FELDA, Department of Environment Malaysia, etc. According to annually Jamaludin et al. (2016), FELDA targeted to increase the OER to more than 21.94%. Thus, in this study, the ideal OER as benchmark at 21.94%.

Benchmarking world-class OEE

The world-class OEE performance is considered as benchmark. According to Manzini et al. (2010), world-class OEE is 80% to 85%, roughly multiplying an availability rate of about 92% to 94%, a production efficiency rate of about 90% to 92%, and a quality rate of about 98% to 99%. Table 1 clustered the level of OEE to be used as a benchmark to achieve world-class standard. In accordance with the OEE method, if the performance below than 85% is considered ineffective and should be further improved. The remaining percentages are divided into four groups. Any equipment with the value below than 24% is considered to be at Level 5 and requires immediate risk or failure assessment.

Table 1: The Benchmark of the OEE Performance Level

World Class OEE (%)	Equipment performance level
85-100	Level 1
65-84	Level 2
45-64	Level 3
25-44	Level 4
Below 24	

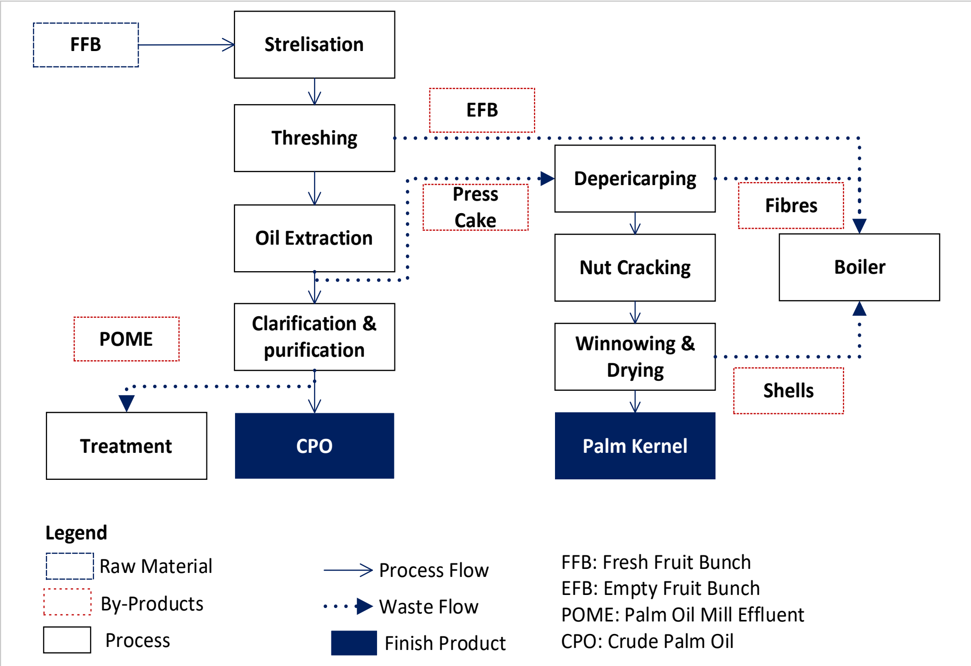
RESULTS AND DISCUSSION

Company background and POM process overview

The POM under study was operated since 1987 in East-Coast Malaysia with maximum capacity of 40 tonnes CPO extraction per hour and the mill processed average of 151,000 tonnes of fresh fruit bunches per year. The vital outputs of the selected mill are CPO and palm kernel. Besides, by-products from the production are including empty fruit bunches, fibre and shells used in the boiler. Some of these by-products are sell as fertilizer. The mill also produces 150,000-225,000 tonnes of palm oil mill effluent annually. The production line in the POM is constructed in a serial configuration consisting complex machineries. Understanding on the palm oil milling process flow and machines involved through actual operation observations, production handbooks and operation manuals. The process flow of the production process in the POM illustrated in Figure 1. From Figure 1, POM received the FFBs from the plantation located nearby. The proximity location of the POM and plantation is important to ensure that the freshly harvested FFBs will be extracted within 24 hours to maintain the quality of the crude palm oil (Nizam et al., 2021). The process flow starts with sterilising the FFBs. Prior to sterilisation, the FFBs are weighted and inspected for quality control. The FFBs are transferred to the cages for sterilisation. The sterilisation process performs heat pre-treatment process to the FFBs at designated temperature and pressure.

Threshing process is performed to separate the FFBs bunches other foreign solid. The extraction section with digestion process as the FFBs are crushed and warmed in the steam-jacketed drums for maximising the oil yield. Then, the press machines squeeze the FFBs to bring out all the liquid. These liquids are containing oil and water. The by-product from pressing process is called press cake that consist of fruit fibre and nuts. The press cake is moved to *depericarping* process. Meanwhile, the oil mixture is heated and separation of the liquid and other remaining solid in the settling and clarification tank. The settling time is stetted to 1 to 3 hours. The residual solids from the oil mixture are sieve using vibrating screen. The extracted oil is collected and moved to purification tank to get the finish product, CPO. The CPO is stored in the storage tank before shipment. The by-products from the oil extraction process is called Palm Oil Mill Effluent (POME). The POME is transported to the treatment plant for treatment process. The depericarping process of the press cake uses air classifiers and cyclones and fibre separator for nuts and fibres recovery. These nuts are cracked to separate the kernel and shells. The shells and fibres are utilised as boiler fuel. The palm kernel is sold after winnowing and drying process.

Figure 1: Material and Process Flow of the Palm Oil Milling Process



Analysis of OEE performance in the POM

In this study, the OEE performance was measured for full process cycle taking into consideration all losses within the period. Three-year period of data was decided considering major PM activities that scheduled yearly. The data were taken from the production records and discussions were conducted with the maintenance engineer of the POM. Considering all previous production records and failure history, the assistant manager of the mill ranked these losses based on the qualities and features that each of them has within the relevant manufacturing area. The easier avoidable losses were ranked before the harder avoidable ones. All the data was verified by POM manager. After screening the data, calculation of the OEE were performed according to the OEE formula developed as in the previous section. The calendar time was access to eliminate the days that the production did not running such as during public holidays. The calendar time deducted the scheduled PM, and planned shutdown. The time and date for these types of stoppage were already planned in advance. Downtime is an impromptu stoppage that happened when the machines broken down and waiting time. These events were recorded in the production systems. After deduct the downtime, then the value for net operating time is measured for calculation of availability rate. The performance rate denoted the difference between the ideal output and the actual output from the process. In this POM, the ideal output recorded 40 Mt of CPO per hour when the machines and equipment run in full capacity. The quality rate is calculated from the ideal OER and the actual OER. The summary of data and OEE measurement (Availability, performance, and quality rate) of the POM as shown in Table 2, Table 3, and Table 4 for the month of January till December from 2014,2015, and 2016 respectively.

Meanwhile, Figure 2 illustrates the OEE level comparing to the world class OEE for three years' period of study. From Figure 2, the OEE performance were mostly in between 65% and 85%, clustered as Level 2 benchmarking to the world class OEE. The highest OEE achieved in the POM for Level 1 were during November 2015, May 2016, July 2016, August 2016 and December 2016. However, there was a trend of lower OEE values were recorded for certain month in a year. It shown that between November until March for these three years' data, the OEE were set in Level 3. In order to investigate further on the real factors that affecting the OEE performance in the POM, Figure 3 presents the graph of OEE elements individually; availability, performance, and quality rate for three years. From Figure 3, the main OEE elements that affect the OEE performance in the Malaysian POM was availability rate. The availability rate of the POM shows the lowest value at 58.20%..

The availability rate depends to the net operating time and scheduled operating time. According to Table 2, Table 3, and Table 4, the waiting time is the highest contribution lower operating time between November until March, thus affect the OEE performance. Waiting time, considered as a type of waste, reflected as an indicator of uneven production. Waiting time comprised of parts waiting in queue for the next step in the operation, finish product waiting to be ship out, idle equipment, and waiting for material, equipment, or tools to perform operations. Waiting time in the POM happened when the equipment idling waiting for FFB. In Malaysia, FFB is produced throughout the year, but it is marked by a strong seasonality due to variations in reproductive growth, the yield is more in boreal fall compared to boreal spring. Because of the diversity in the climate and geographic conditions, the yields are locked to seasons, with a minimum in production around January to March and a peak in September to October (Oettli et al. 2018). Kamil and Omar (2016) also suggested that during raining season such as La Niña, CPO production will normally drop immediately. The drop is mainly attributable to disruptions in harvesting and FFB collection caused by floods. The supply shock arising from these events have a significant impact on the waiting time in the POM.

The lower OEE measure in the POM has been recognised in the study of Baluch (2012). However, the results presented by Baluch (2012) showed the average of OEE measure for different mills based on daily data collected. The daily data show huge gap of the OEE performance when the PM is scheduled on that day. The PM activities normally will halt the production line for 4 to 6 hours. Thus, the OEE performance on that day will be noticeably low. In this study, the maintenance activities are counted in the availability rate calculation. But, that the data is aggregated due to occasionally long non-productive time periods necessary for successful production. For instance, the downtime for PM was prerequisite for production, but was only carried out on certain day, which entails that the OEE value for this given day is unreasonably low Sophie and Hansen (2010). Furthermore, inclusion of the unscheduled downtime in the production time, the availability would be considerably lower, but the accurate availability rate would be shown. This is supported by Zuashkiani et al. (2011), suggested that the maintenance function affects all OEE constituting measures especially availability rate. All maintenance activities reduce equipment availability and, hence, affect the OEE performance level.

Performance rate in the POM also affected by maintenance activities as any unplanned shutdown and breakdown reduces performance. After each stoppage, a certain amount of time is wasted to bring the production rate back to its normal speed, again decreasing performance. Finally, with respect to quality, faulty equipment and breakdowns create deficiencies in the final product. This also cause work-in-process to be wasted, especially in process industries, again leading to reduced quality of the final product. The highest performance rate of the POM recorded within the three years was 98.51% and the lowest was 88.64%. In the POM, the performance rate of OEE associated with the speed loss. It happened when equipment speed decreases comparing to the ideal speed but not zero. It linked to malfunctioning, small technical imperfections, like stuck packaging or because of the start-up of the equipment related to a maintenance task, a setup or a stop for organisational reasons. The quality rate performance for POM was recognised in between 94.29% and 99.06%. Quality losses happened because of incorrect functioning of the equipment and process parameters were not tuned to the standard parameters during production.

Table 2: Overall Equipment Effectiveness from POM for 2014

Equipment Effectiveness Variables	Jan	Feb	March	April	May	June	July	August	Sept	Oct	Nov	Dec
Calendar Time (hrs)	496.0	448.0	496.0	480.0	496.0	480.0	496.0	496.0	480.0	496.0	480.0	496.0
Scheduled PM, PM_T (hrs)	80.0	64.0	64.0	64.0	80.0	64.0	64.0	80.0	64.0	80.0	64.0	64.0
Planned Shutdown, PS_T (hrs)	32.0	16.0	0.0	0.0	32.0	16.0	48.0	16.0	16.0	32.0	32.0	16.0
Scheduled Operating Time, ScO_T	384.0	368.0	432.0	416.0	384.0	400.0	384.0	400.0	400.0	384.0	384.0	416.0
Downtime, DW_T:												
Unscheduled breakdown (hrs)	31.0	20.5	33.8	28.7	37.8	50.0	38.5	39.0	71.8	19.0	15.3	58.5
Waiting time (hrs)	117.1	88.7	63.7	4.4	4.1	4.3	4.1	4.3	4.3	4.1	4.1	33.4
Net Operating Time, OP_T	236.0	258.8	334.4	382.9	342.1	345.8	341.5	356.7	324.0	360.9	364.6	324.1
Ideal CPO output per hour, OUT_S	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
Actual CPO output per hour, OUT_A	36.06	35.46	35.82	35.56	35.3	35.74	35.67	37.11	36.37	36.22	37.6	35.12
Total FFB received (Mt)	9438	10351	13377	16584	18355	20583	22167	22777	22910	22086	15830	12957
FFB reject (Mt)	178	91	107	364	185	213	197	207	240	216	220	197
CPO recovered (Mt)	1988	2184	2747	3374	3816	4339	4702	4853	4885	4724	3247	2766
Actual OER, OER_A (%)	21.47	21.28	20.70	20.80	21.00	21.30	21.40	21.50	21.55	21.60	20.80	21.68
Ideal OER, OER_I (%)	21.94	21.94	21.94	21.94	21.94	21.94	21.94	21.94	21.94	21.94	21.94	21.94
Availability Rate (%)	61.445	70.32	77.41	92.05	89.10	86.44	88.92	89.18	81.00	93.98	94.96	77.91
Performance Rate (%)	90.15	88.64	89.55	88.91	88.24	89.35	89.17	92.78	90.93	90.55	93.99	87.80
Quality Rate (%)	97.87	97.00	94.35	94.80	95.72	97.08	97.54	97.99	98.22	98.45	94.80	98.80
OEE (%)	54.21	60.46	65.41	77.59	75.25	74.98	77.34	81.08	72.34	83.78	84.62	67.59

Table 3: Overall Equipment Effectiveness from POM for 2015

Equipment Effectiveness Variables	Jan	Feb	March	April	May	June	July	August	Sept	Oct	Nov	Dec
Calendar Time (hrs)	496.0	448.0	496.0	480.0	496.0	480.0	496.0	496.0	480.0	496.0	480.0	496.0
Scheduled PM, PM_T (hrs)	80.0	64.0	64.0	64.0	80.0	64.0	80.0	64.0	64.0	80.0	64.0	64.0
Planned Shutdown, PS_T (hrs)	16.0	32.0	0.0	0.0	16.0	16.0	48.0	16.0	48.0	16.0	32.0	32.0
Scheduled Operating Time, ScO_T	400.0	352.0	432.0	416.0	400.0	400.0	368.0	416.0	368.0	400.0	384.0	400.0
Downtime, DW_T:												
Unscheduled breakdown (hrs)	28.8	14.0	54.8	21.0	63.7	39.8	51.0	44.7	42.6	52.0	32.8	67.1
Waiting time (hrs)	118.9	103.4	125.8	4.4	4.3	20.5	3.9	4.4	3.9	4.3	4.1	4.3
Net Operating Time, OP_T	252.4	234.7	251.4	390.5	332.0	339.7	313.1	366.9	321.5	343.8	347.1	328.7
Ideal CPO output per hour, OUT_S	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
Actual CPO output per hour, OUT_A	39.28	35.98	38.75	36.35	36.78	37.78	37.95	37.08	36.86	37.73	38.83	37.62
Total FFB received (Mt)	10047	6636	8700	17378	22928	14502	18149	22212	21840	23121	18849	15502
FFB reject (Mt)	227	209	321	286	183	165	225	183	252	405	300	130
CPO recovered (Mt)	2003	1359	1797	3680	4911	3092	3802	4792	4571	4917	4031	3334
Actual OER, OER_A (%)	20.40	21.14	21.45	21.53	21.59	21.57	21.21	21.75	21.17	21.65	21.73	21.69
Ideal OER, OER_I (%)	21.94	21.94	21.94	21.94	21.94	21.94	21.94	21.94	21.94	21.94	21.94	21.94
Availability Rate (%)	63.10	66.66	58.20	93.88	83.01	84.93	85.09	88.20	87.37	85.95	90.39	82.17
Performance Rate (%)	98.19	89.94	96.88	90.87	91.94	94.44	94.87	92.71	92.15	94.33	97.07	94.04
Quality Rate (%)	92.98	96.35	97.77	98.13	98.40	98.31	96.67	99.14	96.50	98.66	99.06	98.85
OEE (%)	57.61	55.75	54.33	83.40	74.89	78.93	79.37	79.05	79.82	78.24	86.57	76.54

Table 4: Overall Equipment Effectiveness from POM for 2016

quipment Effectiveness Variables	Jan	Feb	March	April	May	June	July	August	Sept	Oct	Nov	Dec
Calendar Time (hrs)	496.0	464.0	496.0	480.0	496.0	480.0	496.0	496.0	480.0	496.0	480.0	496.0
Scheduled PM, PM_T (hrs)	80.0	64.0	64.0	80.0	64.0	64.0	80.0	64.0	80.0	64.0	64.0	80.0
Planned Shutdown, PS_T (hrs)	16.0	32.0	0.0	0.0	16.0	32.0	32.0	16.0	48.0	32.0	16.0	32.0
Scheduled Operating Time, ScO_T	400.0	368.0	432.0	400.0	416.0	384.0	384.0	416.0	352.0	400.0	400.0	384.0
Downtime, DW_T:												
Unscheduled breakdown (hrs)	23.6	39.6	39.7	43.3	13.6	32.6	38.4	22.3	60.2	60.1	42.0	22.6
Waiting time (hrs)	124.6	98.7	4.6	4.3	4.4	4.1	4.1	4.4	3.7	4.3	4.3	6.1
Net Operating Time, OP_T	251.7	229.8	387.7	352.5	398.0	347.3	341.5	389.3	288.1	335.6	353.8	355.3
Ideal CPO output per hour, OUT_S	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
Actual CPO output per hour, OUT_A	37.90	38.43	35.79	36.57	39.06	37.93	39.40	38.82	38.28	38.92	36.73	38.35
Total FFB received (Mt)	10760	10681	18277	19763	19506	21673	21075	23122	23262	22389	18085	13561
FFB reject (Mt)	322	330	316	175	229	370	266	345	352	303	289	279
CPO recovered (Mt)	2222	2141	3798	4138	4064	4535	4459	4840	4832	4775	3814	2852
Actual OER, OER_A (%)	21.29	20.69	21.14	21.13	21.08	21.29	21.43	21.25	21.09	21.62	21.43	21.47
Ideal OER, OER_I (%)	21.94	21.94	21.94	21.94	21.94	21.94	21.94	21.94	21.94	21.94	21.94	21.94
Availability Rate (%)	62.93	62.43	89.75	88.12	95.67	90.45	88.94	93.58	81.83	83.90	88.44	92.52
Performance Rate (%)	94.76	96.08	89.48	91.43	97.66	94.82	98.51	97.06	95.71	97.31	91.82	95.88
Quality Rate (%)	97.03	94.29	96.37	96.29	96.10	97.03	97.67	96.85	96.14	98.55	97.67	97.87
OEE (%)	57.86	56.57	77.40	77.58	89.78	83.22	85.57	87.96	75.30	80.46	79.32	86.82

Figure 2: Overall Equipment Effectiveness Performance of POM Compared to the World Class OEE

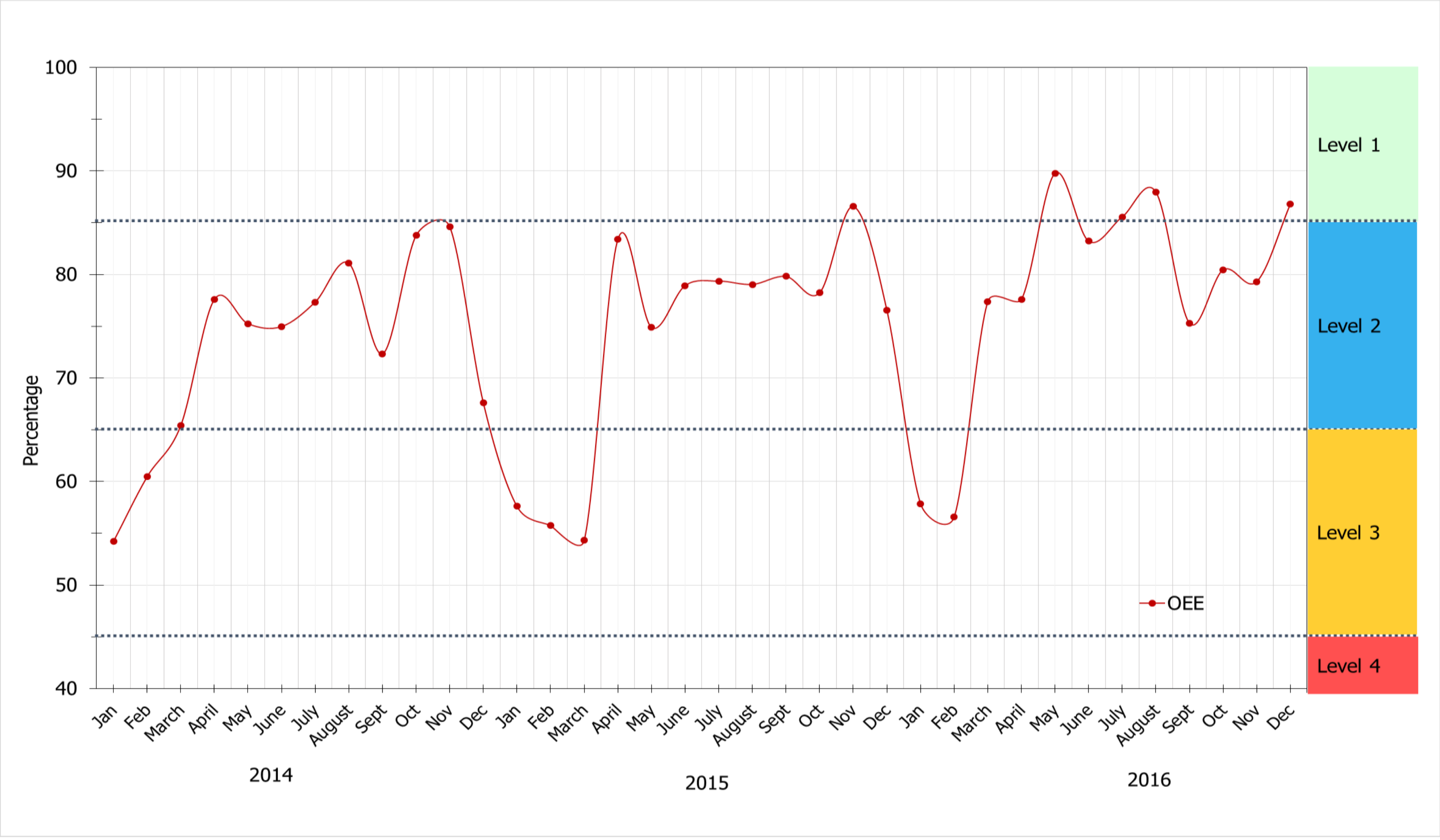
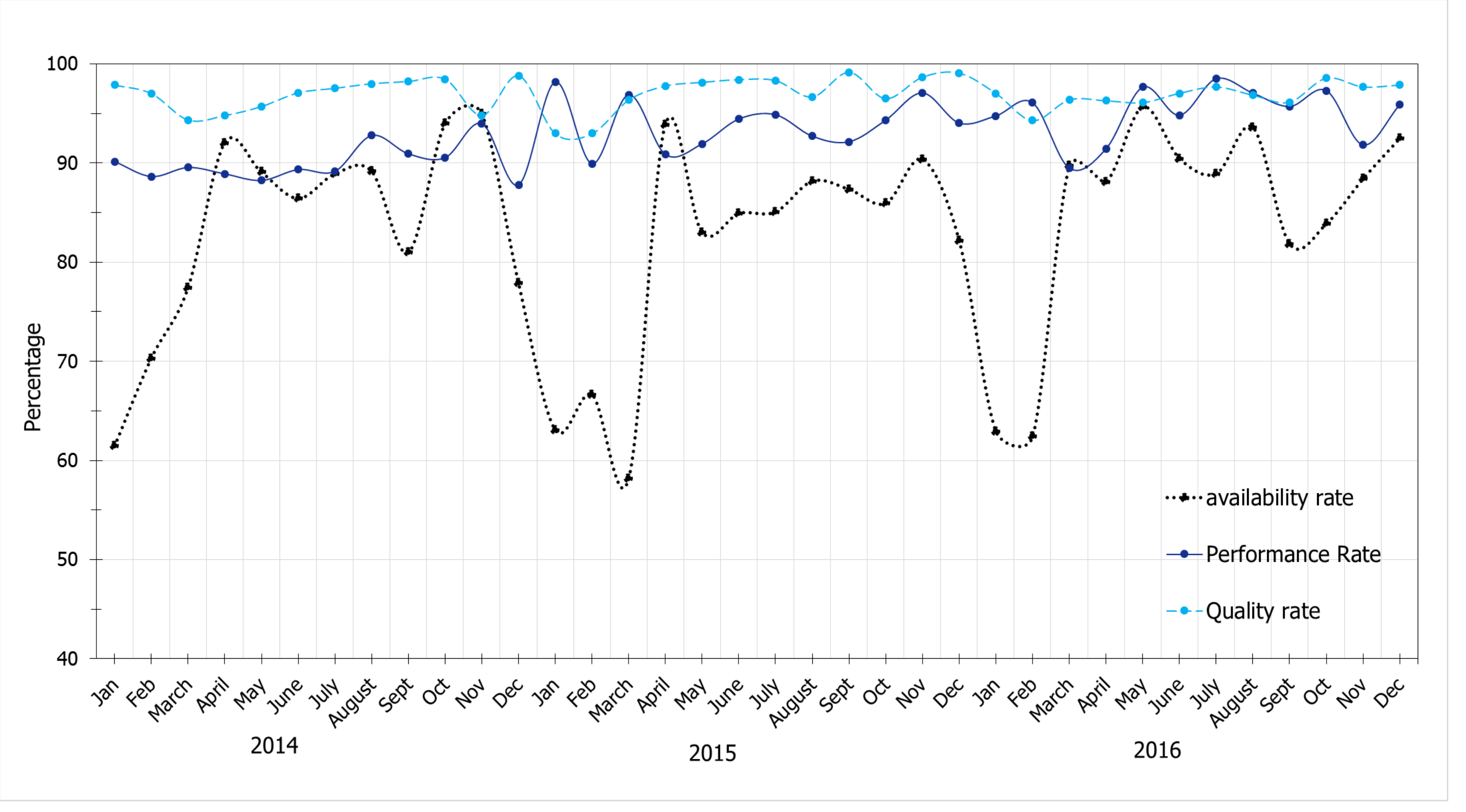


Figure 3: Availability Rate, Performance Rate and Quality Rate of POM



CONCLUSION

This paper has evaluated the OEE performance in one of Malaysian POM using a case study method. According to the accessed data from POM's records of three years' period, the determination of OEE was performed with calculation of availability, performance, and quality rate. Benchmarking to the world class OEE, the results indicated that the OEE performance of the selected PM were commonly in Level 2, ranging from 60% to 85%. It was acknowledged that the main factor affecting the OEE performance was availability rate. Among three elements of OEE, the availability rate of the POM shows the lowest value, 58.20%, that contributed to the lower OEE level. The decrease of OEE performance to level 3 is observed during the period between the months of November until March for these three years. The key factor that affect the availability rate contributes to the lower OEE performance, especially during these periods is long waiting time. Besides, unscheduled maintenance activities also affected the availability rate thus reduce the OEE performance of the POM. Malaysian POM could be benefited from this study as the practical OEE evaluation approach presented will serve as a useful guide to the engineers and managers in recognising and measuring the crucial losses in the production line. Further improvement on the specific area where the losses found would be explicit and directed. Furthermore, the analysis provides practitioners overview in decision making process for continuous improvement of productivity and quality.

There are still some gaps in this line of research that need to be covered. First, factors affecting equipment effectiveness of the production system might be varying from one sector to another. For future research, there is a clear need to study more industry cases with its corresponding inter-industry comparative analysis, which may then provide insights into the differences between various industry sectors. This current study serves as a basis for further research on the subject. Second, investigation on how equipment effectiveness benefited manufacturing organisation towards achieving manufacturing sustainability is still open to explore. So, further study could address these issues and develop a framework for performance measures and metrics for sustainability that will support the managers in making decisions regarding strategies, tactics and operational policies to achieve higher productivity and sustainability goals.

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