



NEW OVERALL EQUIPMENT EFFECTIVENESS FRAMEWORK DEVELOPMENT WITH INTEGRATION OF MAYNARD OPERATION SEQUENCE TECHNIQUE

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ABSTRACT

Overall Equipment Effectiveness (OEE) is widely used in the industry to measure the current performance of the machine and indicate the potential area of improvement. However, OEE has the limitation in the visualization of the wastes. Although six big losses were proposed, OEE still failed to show the area of the improvement effectively. Therefore, a modification to the OEE calculation is required. In this study, Maynard Operation Sequence Technique (MOST) is integrated to the OEE calculation to develop a new modified OEE. This modified OEE calculation is introduced with two new factors, usability and human factor that distinguish setup losses into the frequency of the setup process and excessive work performed by workers. By using the modified OEE, the wastes are categorised in a better picture and visualization is shown. This modified OEE able to improve the visualization is shown. This modified OEE is able to improve the visualization and assist company to identify and monitor the area of improvement.

Keywords: overall equipment effectiveness, Maynard operation sequence technique, visualization.

INTRODUCTION

In the manufacturing sector, performance measurement is a critical element that contributes to performance able, profitable, waste-free production system. One of the well-known performance measurements is OEE. OEE is the product of three main factors, availability, performance and quality. It is widely used in the industry to allow user to monitor the performance of the machine or process, to understand the actual situation of the machine or process and identify the scope of improvement. By indicating OEE will not bring any effect unless the scope of improvement was found and improvement plan was executed based on the scope of improvement. As stated by authors [1], OEE has been just a display number once being evaluated and indication of current utilization of machine only. Therefore, indicating scope of improvement is important to utilize the usage of OEE.

To achieve this, classification of losses is relatively important. As proposed by Nakajima [2], six big losses were distributed into three major factors accordingly. Breakdown and setup losses fall in availability factor while minor stoppages and reduced speed categories in performance factor. For quality factor, it indicates yield losses and defects. Although six big losses are stated, it is not sufficient to indicate the scope of improvement especially in availability factor. There are two main factors indicated in the availability factor which is breakdowns and setup losses. Most of the study focuses on the breakdown losses because it brings greater impact to the OEE percentage. Then, the effect of setup losses is minimized by the long data collection periods and not concerned by the management level [3]. Therefore, setup losses tend to ignore or neglect, but it actually can contribute to the performance improvement of machine or process.

MOST is a predetermined motion time study that used to standardize working procedures and working time, utilize resources and reduce manufacturing cost through revealing value added and non-value added activities of manpower. In previous study, MOST is used to identify the hidden wastes in OEE, which motion losses, excessive working time and unnecessary working procedure [4]. However, frequency of setup process also contributes to the setup losses which are hidden in the OEE calculation.

Therefore, a new framework to integrate OEE and MOST is proposed to visualize losses in the machine or process. It contains four phases, data collection, modified OEE calculation, identification of scope of improvement and development of the improvement plan. A modified OEE model is proposed with two new factors, usability and human factor. Usability is used to indicate the frequency of the setup process in a given period while human factor indicates an excessive time that used by the workers to perform task. These two factors differentiate setup losses from the availability factor and availability factor is just indicating breakdown losses. This modification is resulting better visualization of losses and easier the user to indicate the scope of improvement. MOST is used to identify the ideal setup time and ideal setup time will be used in the usability and human factor.

LITERATURE REVIEW

Hidden Losses in Overall Equipment Effectiveness

As stated by Puvasnasvaran *et al.* [5], OEE cannot quantify all the losses available in the production. There are losses that invisible in the OEE calculation and OEE unable to quantify those wastes by itself. There might have unnecessary operating time that included in the OEE and underestimated effect of excessive transportation and setup time. The time to complete the setup time might be



extended due to the tool searching, material shortage and inadequate verification but it is not quantified in the OEE due to the allowances were given by the companies to the workers. In which this situation might causes the management level considered the OEE level is satisfied because these losses were invisible in the OEE and treated as standard operating time. Next, authors [6] mentioned that the running time of the machine is including the start-up period which increases when the number of changeover or setup increases. As mentioned by Zeller [7], start-up period is the period for a machine to reach its operating speed from static. In other word, the occurrence of the changeover or setup process is affecting the speed of the machine and also reduces the available operating time.

Low *et al.* [3] opined that the effect of wastes like excessive setup time can be minimized by the long data collection. OEE as a universal performance measurement also cannot get rid of this trouble which tends to minimize the effect of the losses if it does not bring great impact. This is supported by Hedman, Sundkvist and Almstrom [8] with their statement, there are hidden improvement potential which is not captured by using only equipment oriented measures such as OEE. Moreover, Garza-Reyes [9] argued that OEE is not ignored some losses that available in the production. The quality factor quantified reworks and defect products as losses but the overfilling or overweight is ignored in the calculation. The overfilling or overweight will lead to high manufacturing cost which is one of the losses that should be streamlined but it is not quantify in the OEE calculation. Then, the number of operators in the assembly line is not affecting the OEE percentage as long as the productivity is still same.

Modification on Overall Equipment Effectiveness Calculation

As discussed by Wudhikarn [10], some of the studies are tried to overcome the limitation of the OEE through some modification. The classification of these studies is generally consists of two groups, scope expansion and calculation modification. Scope expansion is about the changes or expand the area that covered by the OEE philosophy while calculation modification is modified the calculation method of OEE to achieve other requirements. The examples of scope extension are overall process effectiveness (OPE) and total effective plant performance (TEPP). OPE is introduced by Al-Najjar in year 1997 to measure the losses in term of the entire process while TEPP is introduced by Ivancic in year 1998 to quantify aforementioned capacity utilization in the key performance index (KPI) calculation. Wojakowski used the OPE and TEPP to measure the plant performance [1]. Next, Scott and Pisa [12] proposed overall factory effectiveness to measure the effectiveness of the industry that has many machines and operations involved in the production line and it is applicable to both parallel and serial manufacturing systems. Then, another performance measurement called overall fab effectiveness that covered entire industry is developed by Oechsner and his teammates. The scope of OEE is expanded by including

equipment operation and its relationship to other equipment [13].

Nachiappan and Anantharam [14] have improved the OEE by propose another performance measure, overall line effectiveness (OLE) to evaluate the overall effectiveness of a continuous-line manufacturing system. This is due to the limitation of the OEE in measuring the effectiveness of a manufacturing line that consists of several machines in series although OEE is an effective tool to measure the individual equipment in a manufacturing plant or factory. On the other hand, Muthiah and Huang [15] supported the overall throughput effectiveness (OTE) by claimed that OEE is insufficient when indicate at factory level. They also stated the OTE able to diagnose the factory level performance to detect bottleneck and identify hidden capacity. Braglia *et al.* [16] proposed another metric that modified based on the general OEE to apply in an automated line for engine basements production. This performance measurement called as overall equipment effectiveness of a manufacturing line (OEEML). It is used to detect the critical points in the line and able to visualize buffers without underestimate the efficiency of the system.

In the modification of the OEE, Raouf [17] proposed a modified OEE by giving weight to each of the elements of the OEE. He spotted the elements of the OEE equally weighted but the weight of the elements should be different due to the important level of the specific losses to be indicated. Kwon and Lee [18] also modified the calculation method of the traditional OEE approach by quantify production losses in monetary units. Through this new OEE approach, the cost reduction from an increasing percentage of OEE is demonstrated. Next, De Ron and Rooda [19] argued that OEE is lacked of a proper framework and replace it with equipment effectiveness (E). This performance measurement measures stand-alone machine and isolate it from the environment. The base of the measurement is the available effective time but not total time. They also claimed that E is able to indicate the influence of downtime and rework, where OEE is lack of.

OEE is a scale used to measure the efficiency and effectiveness of the machine or process and the percentage of the OEE also initiate company to improve the production. However, OEE does not account all the losses but only focus on the losses within loading time [20]. Therefore, they modify the traditional OEE with the inclusion of market time into OEE calculation. The modified OEE called as OEE-MB. This allows the OEE to reflect internal and external market changes and measure the effectiveness of the machine or process based on a wider capability to meet all market demands. Furthermore, Puvanasvaran, Teoh and Tay [1] also claimed that one of the limitations of the OEE is lack of planning direction. In this study, planning factor is added into the OEE calculation to promote the concept of On Time in Full (OTIF). Prabhu, Karthick and Kumar [21] calculated availability factor of OEE through ratio of mean time between failure to total of mean time between failure and mean time to repair. The intention of using this formula is



to focus on the breakdown losses that occurred in the production.

Integration of Overall Equipment Effectiveness with Other Tools

As argued by the Palanisamy and Vino [22], OEE cannot solve all the problem and simple measuring the OEE percentage of the machine or process is useless. OEE percentage is just a displayed value after the evaluation and its only function is indication of the current utilization rate of the machine or process [1]. Then, Marcello, Marco and Francesco [23] also claimed that problems in the manufacturing line cannot be easily identified by measuring OEE only. The OEE measurement is useless when it is stand-alone without any other tools to assist and identify the root causes.

Therefore, OEE needs to integrate with other tools and techniques to improve the performance of the machine or process continuously. OEE acts like a performances measure that monitors the performance of the machine and the impact of the improvement has been made to the machine or process. Mulla and Ramesh [24] found that losses might be caused by the non-standardization of procedures and non-availability of tools at required time. To improve OEE, Total Preventive Maintenance (TPM) was used along with 5S to improve OEE. The environment was maintained through training provided to workers. The OEE is assists in monitoring the effectiveness of the improvement and reveal the area of problems that should be tackling. Mano *et al.* [25] used times study to improve the OEE of the automatic fettling machine. The process steps are categories as value added or non-value added activities which can further improved through problem solving technique. Then, Puvanasvaran, Mei and Alagendran [26] also integrated time study with OEE to improve the performance of the machine in autoclave machine. Direct time study is used to identify the current working procedure and time performed by the operator. MOST is used to quantify the value-added and non-value added activities, and create ideal working procedure and time. The improvement is identified through comparison between current OEE and future OEE.

In a printing company, the implementation of TPM is evaluated by the OEE. Kumar, Shetty and Rodrigues [27] claimed that OEE able to identify the impact of the improvement action to the performance of the printing machine. Furthermore, Saleem *et al.* [28] integrated OEE and FMEA in the tyre curing press process to improve the industrial performance by rectifying the repetitive failures. The repetitive failures caused the low OEE performance of the machine, and increase the downtime and maintenance cost. On the other hand, Sinhal and Kulshreshtha [29] also faced the problem where high non-value adding activities available in the production line. They used pareto chart to identify the wastes to be focused and reduce the wastes through implementation of Kaizen and Single Minute Exchange Die (SMED). OEE is acts as a monitoring tool to identify the improvement after the implementation of the tools. Mihir, Vivek and

Ramchandra [30] also integrated OEE with the SMED to reduce the setup time of the bending machine. The setup time for one setup is 129 minutes and it is reduced to 105 minutes after the implementation of SMED. After the reduction of setup time, the OEE level fo the bending machine is increased 5.79 percent.

Moreover, Benjamin, Marathamuthu and Murugaiah [6] highlighted the speed loss in a manufacturing firm by integration of OEE and 5-WHYs analysis. They claimed that manufacturers are not or less focus on speed loss due to the process complexity. They also stated that workers are getting used to their working nature which can be quantified as excessive motion or unnecessary working steps. The 5-WHYs analysis is used to identify the root causes of the high speed loss and OEE is used to monitor the improvement made. The solutions are given based on the root causes to eliminate the speed loss. It is found that the integration of OEE and 5-WHYs analysis is effective in tackle the speed loss.

METHODOLOGY

In this study, MOST technique is essential due to the contribution to the development of the new modified OEE. The two new equations, usability and human factor are constructed through the involvement of the MOST technique. Table-1 shows the three types of sequence model of the basic MOST.

Table-1. Basic MOST sequence model.

Activity	Sequence Model	Sub-Activities
General Move	ABG-ABP-A	A= Action distance
		B= Body motion
		G= Gain control
		P= Placement
Controlled Move	ABG-MXI-A	M= Move control
		X= Process time
		I= Alignment
Tool Use	ABG-ABP-X-ABP-A	F= Fasten
		L= Loose
		C= Cut
		S= Surface treat
		M= Measure
		R= Record
		T= Think

As shown in Table-1, three categories of the activity are General Move, Controlled Mover and Tool Use. General Move indicates the free movement that related to space for object through the air while Control Move is a sequence that describes the movement of object when it remains in contact with a surface or when it is



attached to another object during the movement. For Tool Use, it is a sequence used to indicate the use of common hand tools such as writing, fastening, loosening, cleaning and gauging. Moreover, the time unit used by MOST is the time measurement unit (TMU). 1 TMU is equal to 0.036 second, 0.0006 minute or 0.00001 hour.

Moreover, the sequence model for each of the activities is shown and the sequence model consists of sub-activities. An index number will be given to the sub-activities based on the description of the movement. The common scale index can be 0, 1, 3, 6, 10, 16, 24, 32, 42 and 54. The total sum of the index number will multiply by 10 to get the TMU value and can be further converted to time unit of second, minute and hour.

Next, two new equations are added into the modified OEE to quantify wastes in the better way. Tables 2 and 3 show the different between the general OEE and modified OEE in term of the equations and also the classification of losses.

Table-2. General OEE.

	General OEE
Availability	$\frac{\text{Operating time}}{\text{Planned production time}}$
Performance	$\frac{\text{Total} \frac{\text{pieces}}{\text{Operating}} \text{time}}{\text{Ideal run rate}}$
Quality	$\frac{\text{Total good pieces}}{\text{Total pieces produced}}$

As shown in Table-2, general OEE consists of three main factors, availability, performance and quality rate. OEE is the multiplicity of these three factors and used to indicate the effectiveness of the machine or process. For availability factor, operating time is the time available in planned production time after eliminating the unplanned downtimes like machine breakdown and setup process. Planned production time is the periods of total calendar time that not involving planned downtimes like planned maintenance and lunch break. For performance factor, ideal cycle time is the minimum cycle time that process can be achieved in optimal condition. It also called as design or theoretical cycle time. Since run rate is the reciprocal of cycle time, performance can be calculated in another way [21]. The third factor is quality rate and the

total good pieces are the total product that can be sold or sent to the next process without rework.

Table-3. New modified OEE.

	General OEE
Availability	$\frac{\text{Actual operating time}}{\text{Planned production time}}$
Usability	$\frac{\text{Theoretical running time}}{\text{Actual operating time}}$
Human factor	$\frac{\text{Actual running time}}{\text{Theoretical running time}}$
Performance	$\frac{\text{Total output} \times \text{Ideal cycle time}}{\text{Actual run rate}}$
Quality	$\frac{\text{Total good products}}{\text{Total output}}$

As shown in the Table-3, actual operating time is the available time after the exclusion of breakdown losses from the planned operating time. Planned operating time is the time without inclusion of the planned downtimes, lunch break and planned maintenance. Usability is a new formula that used in the new modified OEE to quantify the wastes created due to the frequency of the setup and changeover time. The frequency of the setup and changeover time is referring to the number of the setup and changeover process available in the daily production. Changeover process is the process used to change tools, materials, parts, or equipment and it is held in between the last products of previous batch and the first good product of the new batch. Theoretical running time is the deduction of the multiplication of frequency of setup time with the ideal setup time from the actual operating time. The ideal setup time is developed through MOST. The ideal setup time is included setup process and changeover process. Through usability, the frequency of the ideal setup time can be indicated. The excessive working time is indicated in another factor to prevent the overlap occurs. Human factor is used to indicate the excessive working time. The actual running time is calculated by exclusion of the excessive setup time from the theoretical running time. Human factor shows the effect of the excessive working time to the production, which not quantified in the traditional OEE calculation.

**Table-4.**Classification of Losses.

	Traditional OEE	Modified OEE
Availability	Machine breakdown, setup and changeover losses	Machine breakdown
Usability	-	Frequency of ideal setup process (setup, changeover)
Human factor	-	Excessive setup and changeover time, lack of material and manpower
Performance	Minor stoppage, reduced speed	Reduced speed, minor stoppage
Quality	Yield losses, defects	Yield losses, defects

Table 4 depicts the difference between traditional OEE and modified OEE in term of classification of losses in each category. The changes are made mostly at the availability which setup and changeover losses are differentiate from the availability factor. Previously, the lack of material and manpower that cause machine operating without producing any products are categorized in the performance factor. The performance factor is comparing the speed of the actual machine with an ideal machine that run at its designed speed. However, lack of material and manpower should not be included in the performance factor because it is caused by the human such as handle other issues, lunch time and others. Therefore, these losses are categorized in the human factor.

Moreover, the setup and changeover losses are separated from the availability and these losses were categorized in frequency of ideal setup and changeover process, and excessive setup and changeover time. The reason to separate the setup and changeover losses is to get the attention of the production team to the losses and utilize the resources of the company to reduce the setup and changeover losses. Most of the people are focusing on

the reduction of setup and changeover time by optimizing the working efficiency of the operator when performing setup and changeover time. However, the utilization of the setup and changeover process by reduction of setup and changeover time is not enough because the orientation of the setup and changeover process will affect to the production time too. Most of the time, the companies are not aware of the effect of the frequency of the setup and changeover process. The frequencies of the setup and changeover process allocate some portion of the production time and reduce the flexibility of the production time.

RESULT AND DISCUSSIONS

In this study, the modified OEE is implemented in a real case for five weeks on a wire bond machine in a semiconductor industry. The setup and changeover process of the wire bond machine are wedge tool changing, wire spool changing, lot changing and conversion setup. Table-4 showed the data collected during the five weeks and it is used to develop the modified OEE level of the machine.

**Table-5.** Collected data.

	1	2	3	4	5
Breakdown	32335	12764	25819	84042	12142
Setup and changeover	67426	72729	91661	63632	95091
Lack of material	39480	10995	6975	5778	6914
Waiting for setup	4342	3234	5	0	3
Waiting for technician	27577	36886	47584	45338	19837
Adjustment	8794	4770	79	59	7
Frequency of wedge tool changeover	57	53	58	51	42
Ideal wedge tool changeover time	70.2	70.2	70.2	70.2	70.2
Frequency of wire spool changeover	2	5	2	4	3
Ideal wire spool changeover time	30.96	30.96	30.96	30.96	30.96
Frequency of lot changeover	1	4	1	2	2
Ideal lot changeover time	518.544	518.544	518.544	518.544	518.544
Frequency of conversion setup	2	3	7	3	7
Ideal conversion setup time	612.144	612.144	612.144	612.144	612.144
Planned downtime	0	1737	9444	8437	11973
Total time available	604800	604800	604800	604800	604800
Total output	331830.2676	360977.8692	330570.4177	310482.3325	310575.2786
Ideal cycle time	1.28	1.28	1.28	1.28	1.28
Total good units	331510	360799	330372	310210	310537

Table-5 outlines all the relevant data. The ideal time of each setup and changeover process is the result of the MOST analysis and the frequency of each setup and changeover process is the number of the process that available in the whole week. The ideal time is the minimum required time to finish the setup and changeover process without any involvement of the unnecessary motion, excessive working time and lack of material or manpower.

From these data, the modified OEE can be computed in the following sequence of steps.

$$\text{Availability} = [(604800 - 0 - 32335) / 604800] \times 100\% = 94.65\%$$

$$\text{Usability} = \{[572465 - (57 \times 70.2) - (2 \times 30.96) - (1 \times 518.544)] - (2 \times 612.144) / 572465\} \times 100\% = 98.99\%$$

$$\text{Human factor} = [(566658.848 - 61619.848 - 39480 - 4342 - 27577 - 8794) / 566658.848] \times 100\% = 74.97\%$$

$$\text{Performance} = [(331830.2676 \times 1.28) / 424846] \times 100\% = 99.98\%$$

$$\text{Quality} = (331510 / 331830.2676) \times 100\% = 99.90\%$$

The modified OEE level is the multiplication of all the five factors and the percentage is 70.18% and the general OEE showed the same OEE percentage. As mentioned earlier, the difference between the modified OEE and the general OEE is the addition of two new equations, usability and human factor to quantify wastes in better picture. Figure-1 shows the level of three main factors and the OEE percentage over five weeks. The lowest OEE percentage is 66.60% during week 4. Based on the level of each factor, the availability factor with 75.23% contributes most to the low OEE percentage. However, availability factor is influenced by two big losses which are breakdown and setup losses. The area of improvement unable to visualize through OEE but further investigation is required to know the real cause. The setup losses can be caused by excessive human work or even the poor scheduling to the setup and changeover process. Therefore, investigation is required to know the real cause and tackle on the correct problem.

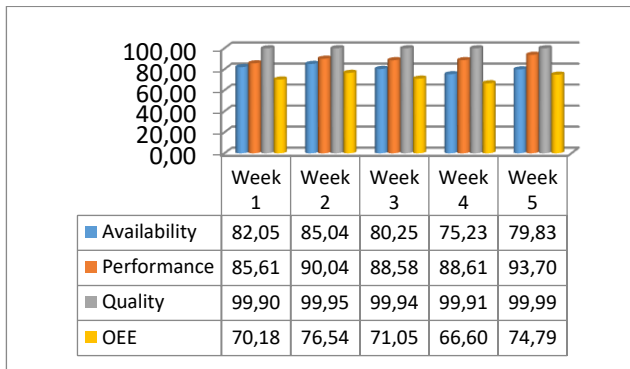


Figure-1. General OEE over five weeks.

Modified OEE consists of five main factors and bar chart is constructed by using the same set of data for over five weeks. It showed better visualization than the general OEE because user able to identify the area of improvement in the first sight. Then, the correct problem can be tackle.

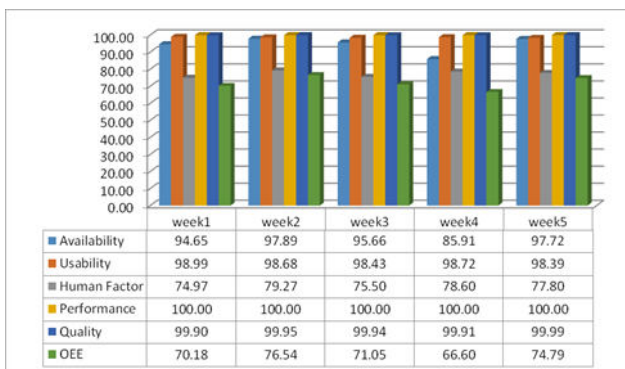


Figure-2. Modified OEE over five weeks.

In Figure-2, the modified OEE percentage and level of five main factors were shown. The OEE percentage of general and modified OEE is identical. This is because the modified OEE is focusing on the visualization of the losses that was included in the general OEE calculation but not visible to the user. In modified OEE, the OEE percentage at week 4 is still 66.60% but the human factor is 78.60% which contribute most to the low OEE on that week. Furthermore, the availability factor also has the lowest percentage among five weeks. This has showed the visualization of the modified OEE in identify the area of improvement and monitor the actual situation of the machine.

CONCLUSIONS

The new modified OEE calculation has integrated the MOST analysis into the calculation to have better visualization in quantifying wastes. The implementation of the OEE in the production is to identify the potential improvement that can be made and also monitor the current situation of the machine from time to time. However, the poor visualization in quantifying wastes will results in incorrect improvement plan and waste time and

money in improvement. As a part of the continuous improvement element, OEE should show the correct direction to the user to improve the performance of the machine continuously and achieve its optimum level. On the other hand, OEE is used to indicate the performance of the machine but most of the machine still required the involvement of the manpower especially in setup and changeover process. The number of the setup and changeover process can be varying due to different circumstance and it might mislead the user where they thought the low availability is due to the high breakdown or excessive working time performed by the worker. Therefore, it is necessary to improve the visualization of the general OEE. As the result, modified OEE possess better visualization than general OEE and the calculation still simple and easy to use. Then, it also highlights the important of the frequency of the setup and changeover process and also the impact of the high excessive working time performed by the workers.

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