Practical Framework: Implementing OEE Method in Manufacturing Process Environment

N. C. Maideen¹, S. Sahudin², N. H. Mohd Yahya¹ and A. O. Norliawati¹

¹Faculty of Mechanical Engineering, Universiti Teknologi MARA Pulau Pinang, 13500 Permatang Pauh, Pulau Pinang, Malaysia

²Faculty of Environmental Engineering, Universiti Malaysia Perlis, 02600, Arau, Perlis, Malaysia

E-mail: normariah@ppinang.uitm.edu.my

Abstract. Manufacturing process environment requires reliable machineries in order to be able to satisfy the market demand. Ideally, a reliable machine is expected to be operated and produce a quality product at its maximum designed capability. However, due to some reason, the machine usually unable to achieved the desired performance. Since the performance will affect the productivity of the system, a measurement technique should be applied. Overall Equipment Effectiveness (OEE) is a good method to measure the performance of the machine. The reliable result produced from OEE can then be used to propose a suitable corrective action. There are a lot of published paper mentioned about the purpose and benefit of OEE that covers what and why factors. However, the how factor not yet been revealed especially the implementation of OEE in manufacturing process environment. Thus, this paper presents a practical framework to implement OEE and a case study has been discussed to explain in detail each steps proposed. The proposed framework is beneficial to the engineer especially the beginner to start measure their machine performance and later improve the performance of the machine.

1. Introduction

Productivity is a measurement to the efficiency of the activity. In manufacturing process environment, productivity is a key measurement to reflect on the overall performance of the process capacity (i.e. man, machine, factory, system, etc). In machine factor point of view, the measurement of machine effectiveness is very important. Thus, Nakajima [1] has introduced six big losses that relates to the machine effectiveness. In extension of 6 big losses, Overall Equipment Effectiveness (OEE) was also introduced. OEE is a measurement tool to measure machine effectiveness based on three important parameters which are; Availability (A), Performance (P), and Quality (Q). Continuation from the method introduced by Nakajima, many research have also been produced. Bamber et al. [2] have
highlighted the significance of cross-functional team working in implementation of OEE in plant and machinery environment.

Modified OEE to be used in semiconductor industry has been introduced by Chakravarthy et al. [3] where two-dimensional methodology was proposed and is called as Overall Equipment Productivity (OEP). Another modified OEE have been introduced by Relkar and Nandurkar [4], Ahire and Relkar [5], and Samat et al [6]. Relkar and Nandurkar has introduced Design of Experiments (DOE) to be used in optimizing and analyzing OEE. The method proposed has good agreement with three parameters in OEE where when the level of OEE is higher, the measured parameter show it is significant. They also suggest that to improve OEE, more focus should be given to the factors that affect the performance (P) measurement (i.e. equipment breakdown, idle, etc). Ahire and Relkar has find the correlation between Failure Mode Effect Analysis (FMEA) and OEE. FMEA’s parameter used in finding correlation are; severity, occurrence, and detection. A total of 32 hypothesis have been tested and they found that FMEA result give a significant insight for OEE improvement. On the other hand, Samat et al have introduced an integration between OEE and reliability method. Reliability method involves Failure Rate and Failure Ratio. The integration is aim to improve maintenance performance level. From three reviewed publications, significantly they do some modification on original method to suit their application. It is good to be applied and testing. However, for the beginner, the guideline to apply those methods comprehensively is still missing. Therefore, this paper is produced to provide a starting guideline for the beginner to measure the effectiveness of the machine in manufacturing processes environment.

2. Framework

The proposed framework consists of three major phase which can be identified as; Phase I: Define, Phase 2: Design, and Phase 3: Implementation. Figure 1 shows the illustration of proposed framework followed by explanation on each phase.

![Diagram of Proposed OEE Framework](image-url)

**Figure 1. Proposed OEE framework**
2.1. Phase I: Define

2.1.1 As-Is Process Map
The process flow should be understood before any assessment can be conducted. The process flow should include input, output, and person in charge at that particular process. From the process flow, we should be able to identify potential factors that can lead to the losses in production operation. A brainstorming between respective person in-charge shall be conducted.

2.1.2 Machine Capacity and Machine Variation
Identify machine capacity and machine variation of the process. Especially for job shop manufacturing environment, usually the machine are varies. They performed the same process but the capacity and handling may differ. The example of variations such as machine model and/or brand, manual operated, semi-automated, or fully automated that later will affect the cycle time per output, output per hour, set-up time and time taken to repair when the machine is breakdown. All the information will later useful in setting the target of maximum output that process can gain from. Also, function as a benchmark when OEE results appear.

2.1.3 Machine Layout
Mapping the machine layout is the step to gather the information regarding the location for each machine. This is important in planning for data collection. What machine at which location. It is also indicate the movement of raw material from store or other department to be shipped to the assigned workstation. The distance between this will affect the transfer time required to ship the raw material, that later may sometimes issuing idle time of workstation that waiting for the raw material.

2.2. Phase II: Design

2.2.1 On-Site Observation and Analysis
On-site observation is the step to deeply investigate the activity in the process. During observation, criteria that can be focused are; type and cause of machine breakdown, smoothness of material loading to the machine, availability of the operator, skill of the operator, quality of product produced and reject part produced. Then, analysis should be conducted to get a clear picture of cause and effect from the process.

2.2.2 Mapping of Identified Losses with 6 Big Losses
From the analysis of the observation, it can be classified as observed losses. Then observed losses have to be mapped to 6 big losses. As identified by Nakajima [1], 6 big loses are; breakdowns, setup and adjustments, small stops, reduced speed, startup rejects, and production rejects. The definition of the 6 loses is tabulated in Table 1. The mapping is significant to be used in next step to effectively identify the quantitative measurement for the identified loses and mapping to the performance measure of OEE.
Table 1. Definition of 6 big losses.

| Losses                        | Definition                                                                 |
|-------------------------------|---------------------------------------------------------------------------|
| Equipment failures/breakdown  | The time losses and quantity losses caused by defective products          |
| Set-up and adjustment         | Time losses resulting from downtime and defective products that occur when production of one item ends and the equipment is adjusted to meet the requirements of another item |
| Idling and minor stop         | Production is interrupted by a temporary malfunction or when a machine is idling |
| Reduced speed                 | Difference between equipment design speed and actual operating speed       |
| Reduced yield                 | Occur during the early stages of production from machine start up to stabilisation |
| Quality defects and reworks   | Quality caused by malfunctioning of production equipment. Occur during the early stages of production from machine start up to stabilisation |

2.2.3 Mapping of Losses to Performance Measure of OEE (Availability, Performance, and Quality) and Identify Quantitative Measurable Parameter

The identified losses can be measured in terms of OEE, which is a function of Availability (A), Performance Rate (P), and Quality Rate (Q) (Equation 1) [2]. Thus, the identified losses should be mapped to the OEE measure. Then, from the identified OEE measure, derive the quantitative measurable parameter for particular losses.

\[ OEE = \text{Availability (\%)} \times \text{Performance rate (\%)} \times \text{Quality rate (\%)} \] (1)

From literature, the definitions for A, P and Q might have some versions. In this work, the definition used as below:

\[ \text{Availability}, A = \left( \frac{\text{Planned Production Time− Unplanned downtime}}{\text{Planned Production Time}} \right) \times 100 \] (2)

Where:
- Planned Production Time = Observation time − Planned downtime
- Planned Downtime = Machine set up time / scheduled maintenance time
- Unplanned Downtime = Idle time + Minor stop + Machine breakdown

\[ \text{Performance}, P = \left( \frac{\text{Actual Production Output}}{\text{Expected Production Output}} \right) \times 100 \] (3)

\[ \text{Quality}, Q = \left( \frac{\text{Actual Production Input}}{\text{Actual Production Output}} \right) \times 100 \] (4)
2.2.4 Design of OEE data collection sheet
Once the required losses to be measured are identified, a data collection sheet should be designed. Important information in the data collection sheet can be listed as: type of process, shift, person in-charge (operator/QC/auditor), and selection of parameters to be recorded. The data sheet should be as simple as possible but precise. It should be simple to minimize confusion and error during data collection.

2.3. Phase III: Implementation

2.3.1 Collect Data, Data Calculation, Analysis, and Draw Conclusion
Before data can be collected, the person in charge should be trained and explained on how the work should be conducted. The best data collector should be operators that work on the process. However, they tend to be biased to get better results to show their process is productive. Thus, it is suggested to assign another person such as QC or auditor to record the data. When the system is established, an automatic data collection system can be an option. From the data collected, OEE calculation shall be conducted as well as analysis on the results. Then, reflective conclusions can be drawn.

3. Framework Implementation
The framework was implemented in a production process company located in North Malaysia. Almost 85% of the sub-assembly parts are built-in the company. They have seven (7) main departments and the process has been done in a job-shop layout. In this work, the framework has been implemented in a pad printing department.

3.1. Phase I: Define

3.1.1 As-Is Process Map
The as-is process map for the pad printing process is shown in Figure 2. The shift starts with a production output target planned by the planner. The planner will get a feedback from assembly and packaging department on the model required to be produced ahead. From the quantity of scheduled output, the supervisor and line leader will sit together and plan for production.

The planning will involve the input from models to be produced, quantity for each model, machines available, skilled and semi-skilled operators, and raw material available to be used. The determined model to be produced will affect the selection of suitable machines to be used. Once the machines are finalized, the technician will set up the machine according to the model to be produced. For every different model, the technician needs to re-setup the machine where the time taken to setup depends on the number of prints required for that particular model. Time taken to setup may range from 10 minutes to 1.5 hours. Thus, during planning, they will try to minimize the machine changes and setup by finishing the volume required (lot) at one machine. For some models, they may require more than one machine to complete the printing on the product. In this case, the subsequent machine will be allocated near the previous machine to minimize the transfer or handling time and effort. Also, a skilled operator will be allocated to conduct this process to minimize the risk of reject part during the process. However, before run by the operator, a person from QC department will by-off the machine where the criteria are: (1) correct model has been setup between sheet order and pad print used, (2) correct color code for the print, (3) the alignment and number of prints required are
correct, and (4) all the prints are in good quality similar to the blueprint model. At the same time during QC by-off, runner will supply the model near to the machine. If by-off result is good, the operator can start producing the parts. However, if the result is bad, technician need to re-setup the machine to comply the quality requirement. The output monitoring will be closely monitored by line leader. Every two hours, the output is recorded and before the shift ends, supervisor will give a feedback on the output achieved. During the work study, the output always less than expected output at least by 20%. From the as-is process map, the losses may came from the effectiveness of machine usage and the effectiveness of the machine setup by technician. However, it is still in the early stage to decide. Thus, a study on machine effectiveness should be conducted to confirm the assumption.

3.1.2 Machine Capacity and Machine Variation

In printing department, there are 104 machines available with 4 variations. All the machines are semi-automated where loading and unloading of the model is conducted manually. The specification of all machines is shown in Table 2.

| Machine type | Num. of side per print | Set-up time range (minute) |
|--------------|------------------------|----------------------------|
| A            | 4                      | 60-90                      |
| B            | 1                      | 10-30                      |
| C            | 2                      | 30-60                      |
| D            | 2                      | 30-60                      |
Figure 2. As-Is Process Map
3.1.3 Machine Layout

Machine layout is shown in Figure 3. From the layout, it is known that most of the same machine type has been placed together. However, a few are scattered.

![Figure 3](image-url)

**Figure 3.** Pad printing machine layout
3.2. Phase II: Design

3.2.1 On-Site Observation and Analysis
From the observation, analysis has been conducted using fish-bone diagram and the result is shown in Figure 4.

![Fish-bone diagram](image)

Figure 4. Fish-bone diagram

3.2.2 Mapping of Identified Losses with 6 Big Losses
Table 3 show a summary of mapping. From the figure, the man factor cannot be mapped to any losses in 6 big losses. Thus, later only factor of machine, material, and method will be assessed further.

Table 3. Summary of mapping

| Factor                  | Observed losses                  | 6 big losses                                |
|-------------------------|----------------------------------|---------------------------------------------|
| Man (Operator & technician) | Attendance, Skill, Break         | Set-up and adjustment                       |
| Machine                 | MC set-up, MC misalignment, Pad damage, Unsuitable pad, Ink pad dirty, Speed loss | Equipment failure/breakdown, Idling and minor stop, Reduced speed, Reduced yield, Quality defects and reworks |
| Material                | Printing color, Reject from previous process, Material waiting | Idling and minor stop, Quality defects and reworks, Reduced yield |
| Method                  | MC allocation: for part require more than 1 machine, waiting WIP | Idling and minor stop |
3.3.3 Mapping of Losses to Performance Measure of OEE (Availability, Performance, and Quality) and Identify Quantitative Measurable Parameter

Table 4 shows a complete mapping of losses to the performance measure of OEE and its unit of measurement.

| Factor        | Observed losses                  | 6 big losses                   | OEE measure   | Unit of measurement |
|---------------|----------------------------------|-------------------------------|---------------|---------------------|
| Machine       | - MC set-up                       | Set-up and adjustment         | Availability  | Time                |
|               | - MC misalignment                 | Equipment                      | Availability  | Time                |
|               | - Pad damage                      | failure/breakdown             | Availability  | Time                |
|               | - Unsuitable pad                  | Idling and minor stop         | Availability  | Time                |
|               | - Ink pad dirty                   | Reduced speed                  | Availability  | Time                |
|               | - Speed loss                      | Reduced yield                  | Performance   | Quantity            |
|               |                                   | Quality defects and reworks   | Quality       | Quantity            |
| Material      | - Printing color                  | Idling and minor stop         | Availability  | Time                |
|               | - Reject from previous process    | Quality defects and reworks   | Quality       | Quantity            |
|               | - Material waiting                | Reduced yield                  | Performance   | Quantity            |
| Method        | - MC allocation: for part require more than 1 machine, waiting WIP | Idling and minor stop         | Performance   | Quantity            |

3.1.4 Design of OEE data collection sheet

An example of designed data collection sheet is shown in Figure 5.
3.3. Phase III: Implementation

3.3.1 Collect Data, Analysis, and Draw Conclusion

Figure 6 show example of spreadsheet for OEE calculation. From the calculated OEE, the data shall be presented in a form of trend for machine variation, trend of shift, trend of weekly or monthly performance. Then, a relevant action can be planned.

4 Conclusions

In this paper, a structured framework has been proposed. With a practical example in actual manufacturing processes environment, the framework has been discussed. This framework is beneficial to the engineer especially the beginner to start measure their machine performance and later improve the performance of the machine.

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6 References

[1] Nakajima S., Introduction to Total Productive Maintenance (TPM), Cambridge: Productivity Press. 1988.

[2] Bamber C.J, Catska P, Sharp J.M, Motara Y. Cross-functional team working for overall equipment effectiveness (OEE). Journal of Quality in Maintenance Engineering. 2003;9:223-238.

[3] Chakravarthy G.R, Keller P.N, Wheeler B.R, Oss S.V. A methodology for measuring, reporting, navigating, and analyzing Overall Equipment Productivity (OEP). IEEE/SEMI Advanced Semiconductor Manufacturing Conference. 2007; 306-312.

[4] Relkar A.S. and Nandurkar K.N. Optimizing and analyzing Overall Equipment Effectiveness (OEE) through Design of Experiments (DOE), Procedia Engineering. 2012;38:2973-2980.

[5] Ahire C.P. and Rekar A.S. Correlating Failure Mode Effect Analysis (FMEA) and Overall Equipment Effectiveness (OEE). Procedia Engineering. 2012;38:3482-3486.

[6] Samat H.A, Kamaruddin S, Azid I.A. Intergration of Overall Equipment Effectiveness (OEE) and reliability method for measuring machine effectiveness. South African Journal of Industrial Engineering. 2012;23.