A STUDY ON OVERALL EQUIPMENT EFFECTIVENESS (OEE) FOR PERFORMANCE MEASUREMENT: CASE STUDY FOR SURFACE MOUNT TECHNOLOGY (SMT) DEPARTMENT

By

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May 2018

This dissertation is submitted to Universiti Sains Malaysia

As partial fulfilment of the requirement to graduate with honors degree in

BACHELOR OF ENGINEERING (MANUFACTURING ENGINEERING WITH MANAGEMENT)

School of Mechanical Engineering

Engineering Campus

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DECLARATION

Candidate's Declaration

I hereby declare that this work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree. This research is the result of my own investigations, except where otherwise stated. Other sources are acknowledged by giving explicit references.

Signature ……………………………………….........

Name ……………………………………….........

Date …………………………………………...

Supervisor's Declaration

This thesis has been submitted as partial fulfilment of the requirements for the final year project and I hereby declare that this thesis were supervised accordance with guidelines laid down by Universiti Sains Malaysia.

Signature ……………………………………….........

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ACKNOWLEDGEMENT

Praise is exclusively to Allah. The Lord of the Universe and Peace is upon the Master of the Messengers, his family and companions for allowing me to complete this dissertation.

Firstly, I would like to express deepest appreciations to my lovely parents Shamsudin Bin Haji Jaafar and Wan Rekiah Wan Mohamad, and my siblings for their prayers and continuous support throughout my life. I express my special thanks and gratitude to my supervisor Associate Prof. Datin Dr. Norizah Mohamad for her guidance, encouragement, patience, support and valuable information during my research. Not to forget the team from the case study company, General Manager Mr Wong, trainee staff Mr Khairil, Head of SMT Department Encik Wan Jasri and my field supervisor which is also Six Sigma Consultant of the company, Dr Lim for their supports and helps during this research.

I would also want to thank all people whom involves directly and indirectly in this project. I gratefully appreciate USM for providing me research study platform which help me a lot to improve my knowledge.

Siti Nor Atiqah Shamsudin

May 2018

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LIST OF ABBREVIATION

AOI	Automated Optical Inspection
C/O	Changeover
FPC	Flexible Printed Circuits
FPC	Flexible Printed Circuits Assembly
HMLV	High-Mix, Low-Volume
HOD	Head of Department
IPA	Isopropyl alcohol
LM	Lean Manufacturing
LMHV	Low-Mix, High-Volume
NVA	Non-Value Added
OEE	Overall Equipment Effectiveness
P1	Plant 1
P2	Plant 2
PCB	Printed Circuit Board
SMED	Single Minute Exchange Dies
SMT	Surface Mount Technology
SPI	Solder Paste Inspection
TPM	Total Predictive Maintenance
WIP	Work In Progress

ABSTRAK

Kecekapan dan keberkesanan adalah kata kunci dalam pasaran hari ini yang tidak menentu dan mempunyai persaingan yang amat tinggi. Semakin bertambah kecekapan dan keberkesanan, sesebuah organisasi akan menjadi semakin produktif. Kebanyakan organisasi terpaksa melaksanakan pelbagai program untuk meningkatkan produktiviti supaya terus mampu mengatasi persekitaran perniagaan hari ini yang bergolak dan kompetitif. Pengukuran prestasi adalah penting untuk menentukan di tahap mana kita berada dan dan yang lebih penting adalah arah tujuan pada masa hadapan. Terdapat bebrapa faktor yang mendorong syarikat untuk mengukur prestasi mereka. Dengan mengukur prestasi, sesebuah syarikat dapat meningkatkan tahap kawalan, kerana maklum balas adalah penting untuk setiap sistem. Tambahan pula, tanggungjawab dan objektif yang jelas dapat dilihat, kerana langkah-langkah prestasi yang baik menjelaskan individu yang bertanggungjawab untuk setiap keputusan atau masalah tertentu dan juga membantu dalam memahami proses perniagaan. Ini adalah kerana mengukur data memerlukan pemahaman tentang proses pembuatan. Overall Equipment Effectiveness (OEE) merupakan kayu ukur prestasi, yang menunjukkan status pengeluaran semasa. OEE adalah salah satu metrik yang digunakan untuk mengenal pasti kerugian, boleh menjadi kayu ukur/penanda aras, dan dapat digunakan untuk meningkatkan tahap produktiviti. Walau bagaimanapun, dengan mempunyai nilai OEE shaja tanpa menganalisis nilai tersebut tidak membantu untuk memperbaiki proses tersebut. Kajian ini dijalankan untuk mengkaji dan menganalisis bagaimana OEE digunakan untuk mengukur prestasi Surface Mount Technology (SMT). Enam kerugian besar telah dikenalpasti dan kaedah analisis Pareto telah digunakan dan didapati bahawa masa yang tidak dijadualkan dan aktiviti penukaran merupakan kerugian terbesar. Oleh itu, Single Minute Exchange Die (SMED) disyorkan untuk mengurangkan masa yang diambil untuk proses penukaran. Hasil kajian ini menunjukkan bahawa OEE merupakan kayu ukur yang baik yang boleh digunakan oleh sesebuah syarikat untuk mengukur prestasi mereka.

ABSTRACT

Efficiency and effectiveness are buzzwords in today's fluctuating and competitive market. The greater the efficiency and effectiveness, the more productive is the organization. Many organizations are forced to implement various productivity improvement programs in order to continue to cope with the complexities and survive in today's turbulent and competitive business environment. Performance measurement is the language of progress, and provides a sense of where we are and more importantly where we are going. There are many reasons for companies to measure performance. By measuring the performance, the company can improved control, since feedback is essential for any system. Furthermore, clear responsibilities and objectives can be seen, because good performance measures clarify who is responsible for specific results or problems and also helps in understanding business processes. This is because measuring data requires an understanding of the manufacturing process. Overall Equipment Effectiveness (OEE) is such a performance measure, which indicates current status of production. OEE is one of the metric used for identifying losses, benchmarking progress, and improving the productivity of manufacturing equipment. However, having the OEE matrices without proper understanding of the occurrence of losses will hinder improvement of the process. This research was conducted to study and analyse on how the OEE matrices are used to measure the performance at the Surface Mount Technology (SMT) Department. The six big losses mainly are identified and Pareto analysis method was used and it is found that non-scheduled time and changeover activity contribute to the greatest loss. Thus, single minute exchange dies (SMED) technique was recommended to reduce time taken for the changeover. This project indicate that OEE is a powerful yardstick that can be used by companies to measure their performance.

CHAPTER 1

INTRODUCTION

1.0 Overview

The first chapter discussed about the introduction of this project and structured in six sections. Firstly, the background of the research followed is described, followed by the problem statement. Third and fourth section emphasize more on objectives and scope of this research. To highlight the contribution of this research, research significant is discussed in the fifth section. The outline of this thesis is presented in the final section.

1.1 Research Background

What has not been measured, cannot be improved (Dal, Tugwell and Greatbanks, 2000). In this highly competitive business environment, well run organizations continually strive to enhance their capabilities to create excellent value for the customers by improving the cost effectiveness of the operations. This is why proper performance measurement is necessary in industry. Nakajima (1988) stated that, OEE measurement is a powerful way of analysing the efficiency of machines. Evaluation of manufacturing equipment performance has been very important in production-related functions such as planning, scheduling, and maintenance. Nevertheless, low accuracy of performance measurements can mislead decision makers (Sonmez, Testik and Testik, 2017).

In this research, Overall Equipment Effectiveness (OEE) is considered as a performance indicator in a manufacturing company. OEE is the standard for measuring manufacturing productivity. It identifies the percentage of manufacturing time that is truly productive and evaluate how effectively a manufacturing operation is utilized. OEE breaks the performance of a manufacturing unit into three separate but measurable components which indicate the availability, performance, and quality. New (2014) stated that an OEE score of 100% means the company are manufacturing only good parts, as fast as possible with no stop time.

Hence, OEE is a tool for evaluating the future performance of manufacturing resources and comparing them with the initial situation by considering alternative operational scenarios (Rita *et al.*, 2017). This context is of particular interest for the development of Industry 4.0 principles and for supporting the implementation in real life production environment. OEE measurement is also commonly used as a Key Performance Indicator (KPI) in conjunction with lean manufacturing efforts to provide an indicator of success. Measuring OEE is a manufacturing best practice. By measuring OEE and the underlying losses, we are able to gain important insights on how to systematically improve manufacturing process.

1.2 Problem Statement

Performance of machine is regarded as one of the important topics when discussing about process improvement. To carry out day to day business without knowing the actual performance is one of the worst thing to be practiced in industry. Most of company are unable to detect the losses encountered by machines that yield the poor line performance hence failing to improve the line performance. The performance of machines used is very important and have high potential to increase productivity of the company. The goal was to reveal the meaning behind the OEE values and helps the production personnel recognize the area of problems to focus on improvement process.

1.3 Research Objectives

The objectives of this research are:

1. To investigate the OEE value to evaluate how effectively a manufacturing operation is utilized by identify all the six big losses.
2. To determine what is contributing to the greatest loss and what areas should be targeted to improve the performance.
3. To recommend on how to improve OEE.

1.4 Scope of Research Work

This study mainly focuses on evaluating the OEE in Surface Mount Technology (SMT) Department. The prosecution of this study only covers on Line 1 from total of three lines in the department. Secondary data of OEE were obtained. The OEE data that was taken for three months period from the company day to day operation is an initial key point, further analysed to identify the equipment losses and propose an improvement to reduce them. On a particular process it will be scope down to lowest percentage of element. Recommendation was done on elements with lowest percentage, the other two OEE elements are not in the scope of this study.

1.5 Research Significant

The findings of this study will clarify the benefit of measuring OEE as one of the performance measure in a company. The secondary data for OEE calculation is valuable to be further analyse and becomes a yardstick in measuring the performance of the company. The main idea is that numbers will reveal the performance of the production. Thus, further action can be made by the company to overcome the problems that they have. This thesis will become a guidelines to the management of the company on how to analyse the OEE value to improve their performance.

1.6 Thesis Organization

The paper is structured in five chapters. After this introduction, chapter two discussed and compared about the topics of the research based on the related published papers. Chapter three illustrates the methodology of this research, the source of data both primary and secondary data which focus is on the use of OEE as performance measure for SMT department. Thereafter chapter four gives a short overview of case study company background and also describes the results and analyses that been carried out. Finally chapter five provides a conclusion and suggestion for future work.

CHAPTER 2

LITERATURE REVIEW

2.0 Overview

This second chapter is structured to provide the general idea of lean manufacturing, Single Minute Exchange Dies (SMED) as one of the lean manufacturing tools followed by the seven type of wastes in manufacturing and benefits of lean manufacturing. This chapter then discuss about Overall Equipment Effectiveness (OEE) and further explore the OEE relevant research made recently.

2.1 Lean Manufacturing

Organization whether service oriented or manufacturing need to systematically and continuously respond to the rapid changes of business environment. In this context, lean manufacturing (LM) is a useful tools that can be practiced by the organizations to maintain and improve their competitive advantage and becoming a core competency for any type of organizations to sustain.

According to Sundar *et al.,* (2014), Modi and Thakkar (2014) and Yang *et al.,* (2011), the concept of LM was developed for maximizing the resource utilization through minimization of waste. LM is also a philosophy to provide better quality of products with lower cost and on time with lesser efforts. D'Antonio *et al.,* (2017) agreed that LM relies on the elimination of wastes and non-productive processes, in order to focus on value added operations and produce high-quality products, at the customers demand pace, with ideally no waste.

As stated by Melton (2005), lean thinking helps us to understand the principle of lean which is the identification of value, the elimination of waste and the generation of value to the customer. Elimination of wastes can be achieved through the successful implementation of lean elements (Sundar, Balaji and Satheesh Kumar, 2014).

2.2 Single Minute Exchange Dies

Single Minute Exchange of Die (SMED) is one of the lean tool created by Shigeo Shingo to allow waste reduction in productive processes, making it more efficient and flexible. This approach proposes waste elimination through the reduction of non-production time in each machine, more precisely, the reduction of the time needed for tool change in a machine (or setup time) (Simões and Tenera, 2010). 'Changeover' is defined as the period between the last good products from previous production order leaving the machine and the first good product coming out from the following production order (Ferradás and Salonitis, 2013).

2.2.1 Principles of SMED

There are five principles for doing quick changeovers and listed as follows (Jebaraj Benjamin, Murugaiah and Srikamaladevi Marathamuthu, 2013):

(1) Differentiate internal setup elements from external setup elements. The total time required for carrying out setup and changeover activities are measured in this step. Internal setup refers to setup and changeover activities that are performed while a machine is stopped while external setup relates to activities that can be conducted while a machine is in operation (Moxham and Greatbanks, 2001). Getting tools from the changeover tool cart prior to machine completing the last piece of the batch, for example, is an external element because production does not need to stop. It is not easy, however, to attach a new die while producing products. The actual attachment or removal of dies would be classified as an internal element. This step of the SMED technique requires a detail view of the production floor and videotaping of the entire setup and changeover.

(2) Separate the internal elements from the external elements. In this step the set operations are divided into internal and external setups.

(3) Convert as many internal elements as possible to external elements. In the third step, technical modifications are made to convert some of the internal elements to external elements.

(4) Streamline the remaining internal elements. This step of the SMED technique requires exploration of alternate ways to reduce the time of the remaining internal

elements so that the setup and changeover consumes less time. Examples of measures to streamline internal elements are to utilize quick release tools to reduce part exchange, implement positive stops to reduce positioning, design standard parts to eliminate part exchange and to relocate parts and materials to reduce walking, searching and gathering time.

(5) Streamline the external elements. The external activities are streamlined to make them faster and more efficient. Reducing the time taken to perform external activities does not directly reduce the downtime or improve OEE but free operators for other activities.

2.2.2 The Conceptual Stages

Figure 2.1 shows SMED conceptual stages and it is related with the five principles for doing quick changeovers as discussed in Section 2.2.1.

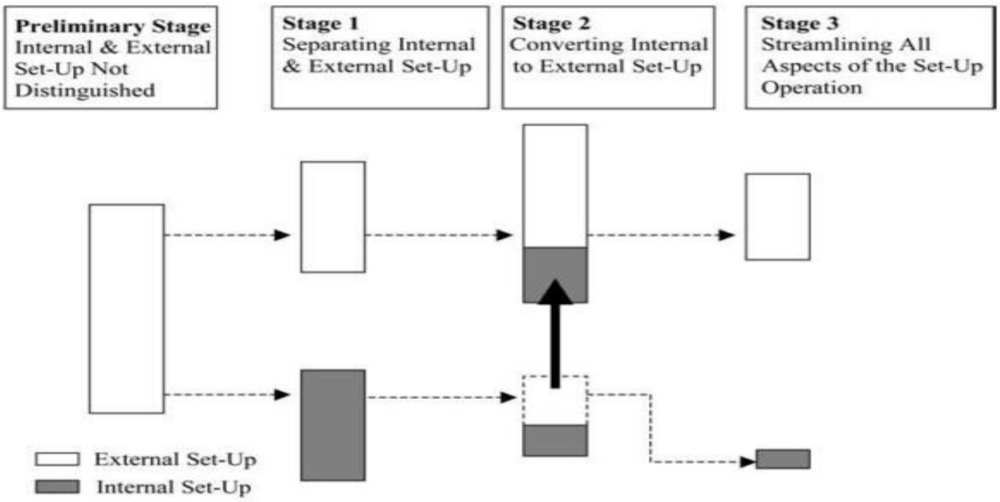

Figure 2.1 SMED conceptual stages. *Source: (Moxham and Greatbanks, 2001)*

2.3 Major waste in Lean Manufacturing

Modi and Thakkar (2014) agreed that lean manufacturing aims for identification and elimination of waste in all aspects of a business and there by enriching value from the customer perspective. Figure 2.2 shows the classification of the seven types of waste known as Taiichi Ohno's 7 waste introduced by Taiichi Ohno, a Toyota executive to denote all the activities that require resources but do not add value to the process or to the product. D’Antonio *et al*, (2017) in his study revealed that wastes do not add value to the product, customers are not willing to pay for them, and manufacturers must be less wasteful to increase profit and improve competitiveness. Thus, a systematic method to eliminate waste is Lean Manufacturing.

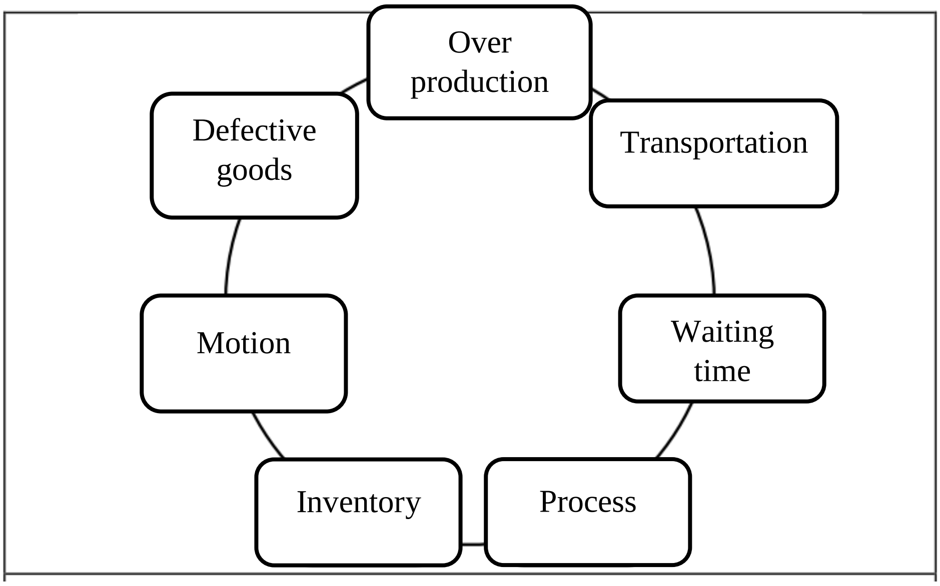

Figure 2.2 Taiichi Ohno 7 waste. *Source: (Sundar, Balaji and Satheesh Kumar, 2014)*

Defective goods, over production, unnecessary transportation, motion, waiting time, inventory, over processing is all wastes that need to be eliminated because it is considered as non-value added (NVA) activity to the production. Table 2.1 reveals the seven type of waste that been analysed by (Melton, 2005).

Table 2.1 The seven types of waste

No.	Type of waste	Description
1	Over production	Development of a product, a process or a manufacturing facility for no additional value. Product made for no specific customer.
2	Waiting	When people, equipment or product waits to be processed it is not adding any value to the customer and considered as waste.

3	Transport	Moving the product to several locations. Whilst the product is in motion it is not being processed and therefore not adding value to the customer.
4	Inventory	Inventory is a hidden costs. Storage of products, intermediates, raw materials all costs money.
5	Over processing	When a particular process step does not add value to the product. It is the duplication of any steps related to the process.
6	Motion	The excessive movement of the people who operate the manufacturing facility is wasteful. Whilst they are in motion they cannot support the processing of the product. Excessive movement of data, decisions and information also categorized as motion waste.
7	Defects	Errors during the process which is either requiring rework, additional work or scrap.

2.4 Benefits of Lean Manufacturing

By implementing LM techniques, the organization can gain tremendous benefits. The benefits that can be obtained are reduction in cost, lead time, cycle time, and waste. The focus of the approach is on cost reduction by eliminating NVA activities (Abdulmalek and Rajgopal, 2007). Improvement in productivity and quality and also helps in space and equipment utilization via reduction in work in process (WIP) Inventory (Modi and Thakkar, 2014). Melton (2005) also agreed that successful implementation of LM can decrease lead times for customers, reduce inventories for manufacturers and improved knowledge management. Lean manufacturing practices enhance manufacturing productivity by reducing setup times and work in process inventory improving throughput times, and thus improve market performance (Yang, Hong and Modi, 2011).

2.5 Overall equipment effectiveness (OEE)

Overall Equipment Effectiveness (OEE) is a quantitative metric used for measuring productivity of machine in a factory. The OEE has born as the backbone of Total Productive Maintenance (TPM) concept that been launched by Nakajima (1988) in 1980's.

OEE considers that effective production requires three elements. First is the equipment to be running during the planned production time, second, the equipment to produce the parts in the optimal speed and the third one is the parts to be produced according to specification (Jauregui Becker, Borst and van der Veen, 2015). In OEE each of these are important aspects in manufacturing namely availability, performance and quality rate. This supports the improvement of equipment effectiveness and thereby its productivity (Muchiri and Pintelon, 2008).

There are few common issues faced by manufacturing company which is waste of time, energy, money and overworked staff. OEE is a novel technique to measure the effectiveness of a machine and it can reduces complex production problems into simple and intuitive presentation of information and also tells us whether the equipment is in under-utilization or over-utilization (Singh, Shah, *et al.*, 2013). Fattah *et al.,* (2017) also agreed that OEE is a way to monitor and improve the efficiency of the manufacturing process. It helps in systematically analysing the process and identifying the potential problem areas affecting the utilization of the machines and OEE is not only a metric, but it also provides a framework to improve the process.

The goal of OEE is to minimize or reduce the causes of inefficiency in the manufacturing environment. There are many factors that can affect OEE. OEE calculation aims to point out each aspect of the process that can be ranked for improvement. According to Nakajima (1988) the most effective application of OEE is by process teams in conjunction with the application of the basic quality control tools such as Pareto and cause and effect charting. Such applications can be important complement to the existing factory performance measurement system. Within this context OEE must therefore be considered an operational measure rather than strategic.

OEE is also defined as the ratio between the times spent on producing goods of approved quality to the scheduled production time (loading time). One of the main reasons for the widespread application of OEE, among both researchers and practitioners, is that it is a simple, yet comprehensive, measure of internal efficiency and the measure is incorporated as an important driver in order to do any improvements on the production (Hedman, Subramaniyan and Almström, 2016).

2.6 OEE Evaluation Method

In general, there are two motivations to use OEE. It is used as an identification and elimination of losses for process improvement and benchmarking within or between production facilities (Sonmez, Testik and Testik, 2017). Commonly companies specify a target OEE level or use a benchmark level for monitoring or improving their processes.

Singh *et al.*, (2013) and Dal, Tugwell, *et al.*, (2000) proposed that the OEE measure can be applied at several different levels within a manufacturing environment;

- Firstly, OEE can be used as a benchmark for measuring the initial performance of a manufacturing plant in its entirely. In this manner the initial OEE measure can be compared with future OEE values, thus quantifying the level of improvement made.
- Secondly, an OEE value is calculated for one manufacturing line and can be used to compare line performance across the factory, thereby highlighting any poor line performance.
- The last one if the machines process work individually, an OEE measure can identify which machine performance is worst, and therefore indicate where to focus improvement and TPM.

Most of the research involving the OEE measure related to maintenance but there is also several research which focussed on areas such as performance measurement and productivity improvements (Hedman, Subramaniyan and Almström, 2016).

2.7 OEE Losses Classification

The understanding about disturbances is very important to the manufacturing process. According to Jonsson *et al.,* (1999) disturbances can be classified into two types which is chronic and sporadic according to their frequency of occurrence. Both of disturbances have different negative impacts on the manufacturing process since they consume resources without adding any value to the final product

Small, hidden and complicated disturbances that occur from the result of several concurrent causes is namely chronic disturbances. Meanwhile, sporadic disturbances are more obvious since they occur quickly and as large deviations from the normal state. Sporadic disturbances occur irregularly and their dramatic effects are often considered to lead to serious problems. However, research evidence suggests that since chronic disturbances occur repeatedly it will result in the low utilisation of equipment and larger costs. Chronic disturbances are more difficult to identify since they can often be accepted as the normal state of the process. Identification of chronic disturbances is only possible through comparison of performance with the theoretical capacity of the equipment (Dal, Tugwell and Greatbanks, 2000).

The OEE tool is designed to identify losses that reduce the equipment effectiveness (Muchiri and Pintelon, 2008). Nakajima, (1988) defines these six big losses as follows:

The first two type of losses known as downtime losses that will help to calculate availability of a machine.

(1) Equipment failure or breakdown losses are categorised as time losses when productivity is reduced, and quantity losses caused by defective products.
(2) Set-up or adjustment time losses result 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.

Speed losses that determine the performance efficiency of a machine is classified under third and fourth losses. This losses will helps in calculation of performance rate.

(3) Idling and minor stop losses occur when the production is interrupted by a temporary malfunction or when a machine is idling.

(4) Difference between equipment design speed and actual operating speed identified as reduced speed losses.

Losses due to defects will be determined by the fifth and sixth losses. This losses will helps in calculation of quality rate.

(5) Reduced yield occurs during the early stages of production from machine start up to stabilisation.
(6) Losses in quality are quality defects and rework which is caused by malfunctioning production equipment.

The OEE is measured in terms of these six big losses, which are essentially a function of the availability, performance rate and quality rate which is the focus of OEE application. The classification OEE measurement tool and six big losses is simplified in Figure 2.3.

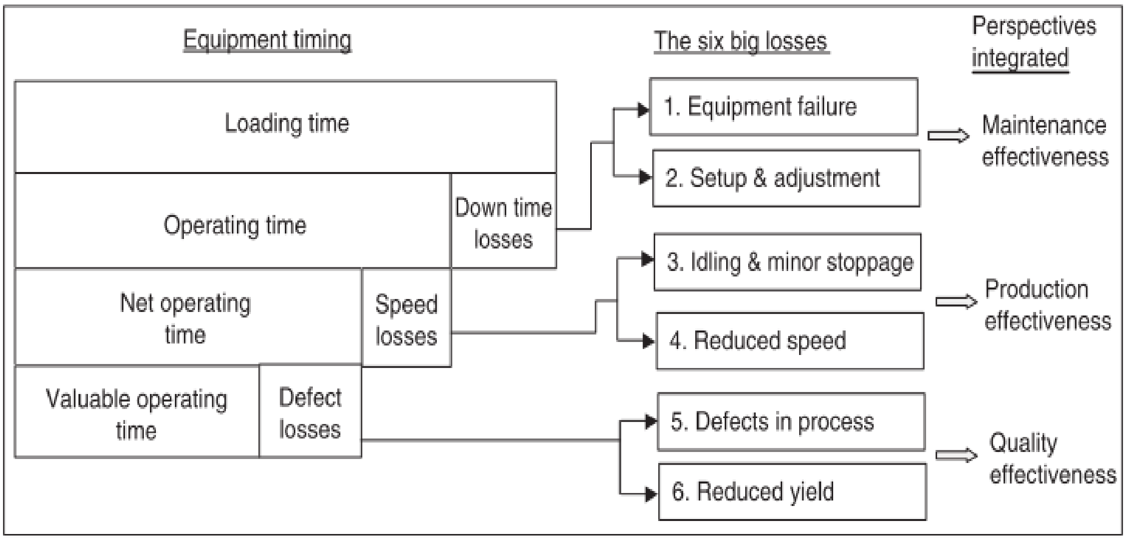

Figure 2.3 Classification of OEE measurement tool and six big losses. *Source: (Muchiri and Pintelon, 2008)*

Hedman *et al*, (2016) in his study stated that the downtime losses are used to calculate the availability factor, the speed losses determine the performance efficiency of the equipment, and the quality losses are incorporated to calculate the quality rate. Fattah *et al*, (2017) also came out with list of losses according to the category as shown in Figure 2.4. The OEE elements been classified accordingly and the data were obtained. From the list of loss category for example equipment failures, unplanned maintenance, rework and other loss be categorized into specific loss category according to the OEE metric to calculate overall OEE.

Major Loss Event	OEE Metric	Loss Category	Example of Loss Category
Machine Breakdowns	Availability	Down Time	Equipment Failures, Tooling Damage, Unplanned Maintenance
Machine Ajustements/Setups	Availability	Down Time	Process Warm Up, Machine Changeovers, Material Shortage
MachineStops	Performance	Speed	Product Misfeeds, Component Jams, Product Flow Stoppage
Machine Reduced Speeds	Performance	Speed	Level of Machine Operator Training, Equipment Age, Tooling Wear
Machine Startup Bad Parts	Quality	Quality	Tolerance Adjustments, Warm Up Process, Damage
Machine Production Bad Parts	Quality	Quality	Assembled Incorrectly, Rejects, Rework

Figure 2.4 Major losses events classifications. *Source: (Fattah, Ezzine and Lachhab, 2017)*

2.8 OEE Calculation

In order to establish an accurate OEE figure the six big losses must be measured accurately. OEE was given by availability index, productivity index and quality rate. As contested by Nakajima (1988) the most important objective of OEE is not to get an optimum measure but to get a simpler measure that indicates the areas for improvement. Furthermore, Sonmez *et al,.* (2017) also agreed that calculation of OEE requires production speed and stoppage measurements of equipment. Nevertheless, the author of this research emphasizes that there will be uncertainties in these measurements and it is common in practice whether with manual or semi-automated data collection systems where operators record the data.

The uncertainties are often due to unreported losses such as minor stoppages or minor speed losses, errors due to human factor, limitations of measurement instruments, and flaws in the data collection processes.

Iannone and Elena (2013) indicated that the basic definition of OEE is;

$$\text{OEE} = \frac{\text{Valuable operating time}}{\text{Loading time}} \quad (2.1)$$

Where valuable operating time is the net time during which the equipment actually produces an acceptable product and loading time is the actual number of hours that the equipment is expected to work in a specific period (year, month, week, or day). Basically OEE is a metric accumulated from multiplication of availability, performance rate, and quality rate and the formula used for calculation of OEE is defined as follows (Dal, Tugwell and Greatbanks, 2000);

$$\text{OEE (\%)} = \text{Availability (\%)} \times \text{Performance (\%)} \times \text{Quality rate (\%)} \qquad (2.2)$$

2.8.1 Availability

The first element is availability. The time calculation is in minutes and formula used for calculating availability is as follow;

$$\text{Availability (\%)} = \frac{\text{Actual operating time (mins)}}{\text{Planned operating time (mins)}} \times 100\% \qquad (2.3)$$

$$\text{Planned operating time (mins)} = \text{Total shift time} - \text{Planned maintenance} \qquad (2.4)$$

$$\text{Actual operating time (mins)} = \text{Planned operating time} - \text{Unplanned maintenance} - \text{Minor stoppages} - \text{Set-up changeover} \qquad (2.5)$$

An important factor within the availability element is loading time. Loading time can be defined as the total length of the shift after any deductions for planned downtime. Planned downtime can typically include the waiting due to completion of current orders, no labour available due to operator breaks, machine cleaning and general operator maintenance, operator undergo training, planned maintenance activities and equipment trials and process improvement activities.

2.8.2 Performance

The second element of the OEE calculation is performance rate. This is the ratio of the actual speed of the equipment to the ideal speed. Performance rate calculation according to Nakajima (1988) method is he measures a fixed amount of output, and in his definition performance indicates the actual deviation in production in time from ideal cycle time. Performance efficiency is the product of the operating speed rate and net operating rate.

$$\text{Performance efficiency (\%)} = (\text{Net operating rate} \times \text{Operating speed rate}) \times 100 \qquad (2.6)$$

The net operating rate measures the achievement of a stable processing speed over a given period of time, for example a production shift of 12 hours, rather than whether the actual speed is faster or slower than the design standard speed. This calculates losses resulting from minor recorded stoppages, as well as those that go unrecorded on daily logs, such as small problems and adjustment losses.

$$\text{Net operating rate} = \frac{\text{No produced} \times \text{Actual cycle time}}{\text{operation time}} \qquad (2.7)$$

The operating speed rate of equipment refers to the discrepancy between the ideal speed and its actual operating speed.

$$\text{Operating speed rate} = \frac{\text{Theoretical cycle time}}{\text{Actual cycle time}} \qquad (2.8)$$

New (2014) also stated that the rule of ideal run rate is to use the best output rate known to be produced on the machine, regardless of whether that is above or below design speed. Then if a machine consistently outperforms its design spec, the performance rate will exceed 100% and potentially mask availability problems. On the other hand, if the machine has never been able to achieve its design spec, it's usually not helpful to use that as the standard.

2.8.3 Quality rate

The third element of the OEE calculation is the quality rate and is used to indicate the proportion of defective production to the total production volume. The quality rate involves defects that occur only within OEE measurement scope production. Mathur *et al.*, (2011) in is study stated that quality loss is time for which equipment is operating on below-quality products.

$$\textbf{Quality rate (\%)} = \frac{\text{Total no.produced} - \text{No.scrapped}}{\text{Total no.produced}} \times 100\% \qquad (2.9)$$

2.9 World Class OEE

World class OEE is often used by company as a benchmark to compare their OEE performance. Nakajima suggested that the ideal values for OEE set to be 85% (Dal, Tugwell and Greatbanks, 2000). The percentages are dubbed the World Class Performance level with different percentage of each OEE elements as depicts in Table 2.2. The world class OEE indicates to be a good benchmark for manufacturers. However, Ljungberg (1998) estimated OEE average to be only 55%. The different percentage are not really critical because it depends on the data collection for OEE calculation because different company have different style of data collection and calculation. The important thing to address is that the each measurement process should mirror previous process so that any comparison and data analysis done is valid. If the measurement process is not standardized, then the results is not reliable to be further analysed for any process improvement.

Table 2.2 World Class OEE Standard

OEE elements	OEE World Class Value (%)
Availability	90.0
Performance	95.0
Quality	99.0

2.10 Summary of the Chapter

This chapter bring forward discussion of lean manufacturing, SMED and introduction of OEE followed by method to calculate the OEE index, six big losses to analyse the losses that are available in the literature. With the understanding that OEE can be a useful yardstick to the performance measurement, then it is important to understand and analyse the OEE value so that we know meaning of the OEE calculations and how does it mirror the actual production performance. Further discussion concerning the development of research model is further discussed in research methodology chapter three.

CHAPTER 3

METHODOLOGY

3.0 Overview

In this chapter all the theories in chapter two was applied to develop the method that had been used for this research study. There are five subsections in this chapter. The first section discussed about the flow of the research, followed by site description of the case study company. Third section discuss about the research design followed by data collection method. The subsequent section contain the data analysis method. The conclusion of this research approach discussed in the final section of this chapter.

3.1 Research Flowchart

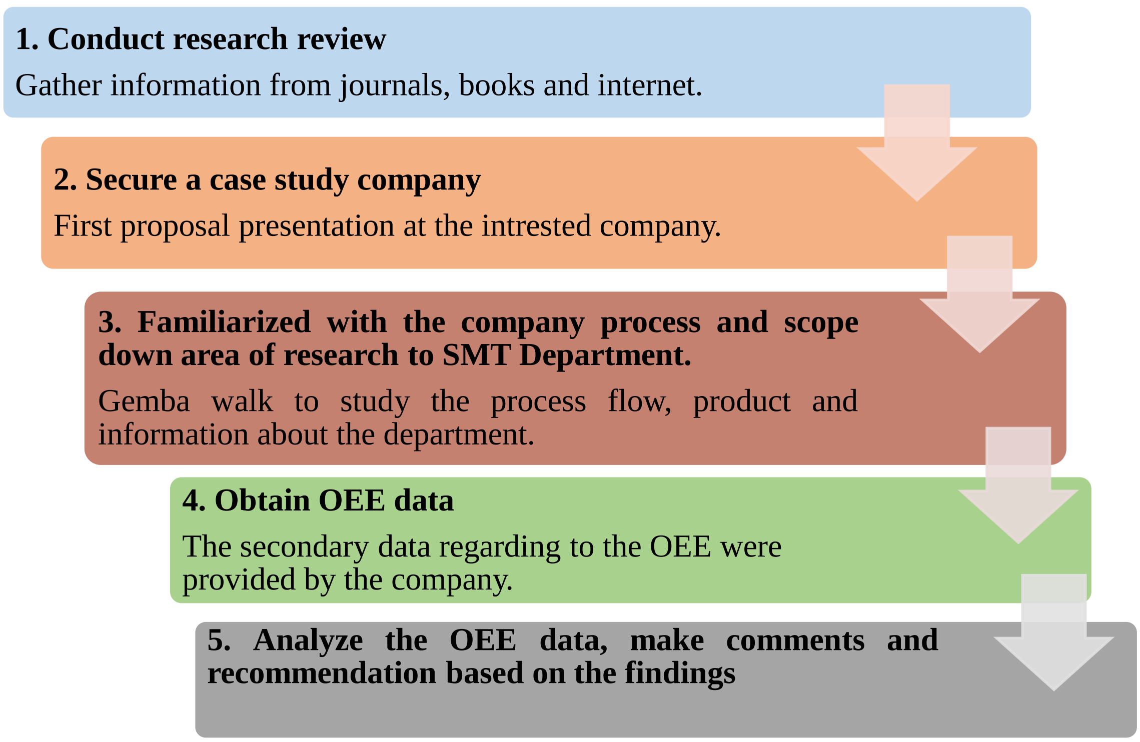

Figure 3.1 Research flowchart

3.2 Site Description

This study was carried out in one of the department in a semiconductor manufacturing company located in Penang. At the area of study, the researcher brainstorm and have one to one discussion with the team involved in the department where the study was carried out and collect secondary data of the OEE.

3.3 Research Design

Research design refers to the methods employed to conduct the research. There are two types of research design which is qualitative and quantitative design. Qualitative research is empirical research where the data are not in the form of numbers, useful for studies at individual level and explore the ways in which people think or feel while quantitative research design gathers data in a numerical form and data are reported through statistical analysis (McLeod, 2008). This research is a quantitative because involves gathers data which is the OEE data for three months which can be put into categories and in rank order. This data then used to construct graphs and tables of raw data and can be interpreted with statistical analysis, and since statistics are based on the principles of mathematics, the quantitative approach is viewed as scientifically objective, and rational (Denscombe, 2010)

3.4 Data collection methods

Both primary data and secondary data collection methods has been used to gather the data in this research. This case study used the secondary data which was undertaken over a three-month period. Secondary data which is the OEE data collection was obtained from production floor. Primary data were gathered through multiple methods and this study utilised a number of collection techniques including observations, Gemba walk, discussions and brainstorming. Gemba walk able to promote a deep and thorough understanding of real-world manufacturing issues by first-hand observation and by talking with plant floor employees in the case study area.

3.4.1 Primary data

Primary data is obtained by execution of discussions and brainstorming. The discussion were done with three level of group which is top management, middle class (engineers and technicians) and the operators. This is done as information digging about SMT Department and to familiarize with the process flow. Observation also done during the production running to understand the operation, flow of process and how operators collect raw data from the production floor was conducted in the early stage of the research. Background of the company, products, machine and information regarding the production floor was also obtained from Gemba walk in the SMT Department.

3.4.2 Secondary data

The secondary data obtained was the collection OEE data for three months period starting from November 2017 to January 2018. Secondary data analysis used because this approach can save time that would otherwise be spent collecting data and, particularly in this case, the OEE data is a quantitative data and need to be collected throughout the production for every working hours and production runs. By using this method, it actually can provide larger and higher-quality databases that would be unfeasible for any individual researcher to collect on their own (Denscombe, 2010).

3.5 Research framework

A research framework is developed based on the literature review and this research follows the research framework as shown in Figure 3.2. The secondary data were provided by the company regarding to the OEE which then further broken down into six big losses. The six big losses were classified under the three big losses which is downtime losses, speed losses and quality losses.

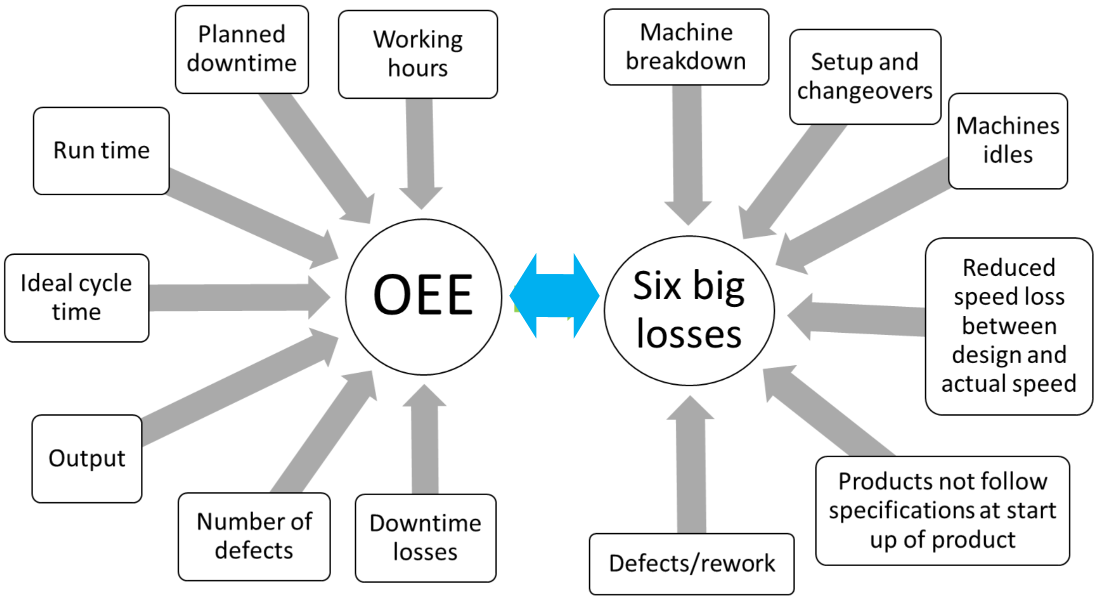

Figure 3.2 Research framework

3.6 Data Analysis Method

The OEE data collected had been analysed by classified the losses according to six big losses. By doing this, the losses were classified according to three different major losses which is downtime losses, speed losses and quality losses. From the three losses, the major type of losses are further selected using Pareto Analysis principle. As all the losses frequencies, percentages and cumulated percentages are calculated, Pareto chart is used to visualize the information. This will ease the identification of losses within the major losses. Figure 3.3 shows example of Pareto chart used for data analysis.

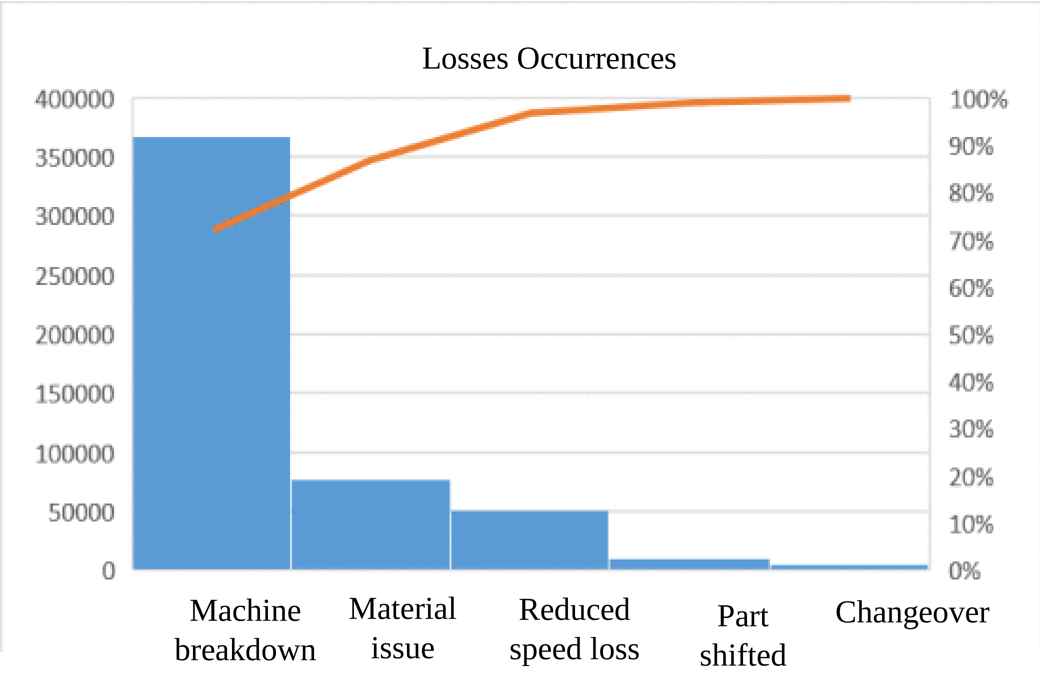

Figure 3.3 Example of Pareto chart

3.7 Summary of the Chapter

This chapter emphasize how this research were conducted. The sources of data and how the data will be analyse by using formula and tools involved in order to study the OEE as a tool that can be used to measure factory performance.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.0 Overview

This chapter discusses on the findings based on the method used in the previous chapter. Introduction of the case study company, their products, process flow and machines were presented in first section of this chapter. Data analysis were conducted in section two while section three discuss about the recommendation to improve the losses. To end the chapter, a brief summary is made.

4.1 Introduction of Case Study Company

4.1.1 Company Background

This research had been conducted in one of the expanding semiconductor company located in Pulau Pinang, Malaysia. It is a pioneer manufacturer of Flexible Printed Circuits (FPC) in Malaysia. It has been establish to provide a comprehensive FPC solution, covering circuit design, prototype fabrication, mass production and Surface Mount Technology (SMT) assembly. Being a vendor to telecommunications, automotive, consumer electronics, military and aerospace customers in more than 20 countries including the United States, Germany and Japan promising further expansion of the company.

The company provide one-stop FPC solutions from product conceptualization to delivery as they provide three major service which is Design, Manufacturing and Assembly. In design, they help customers with the design and transferring circuit schematic into routing design. They able to manufacture high quality products and have in-house SMT lines which is another value-added service from the company to their customers. This company is certified with ISO9001 (Quality Management System), ISO/TS16949 (Automotive Quality Management System), ISO14001 (Environmental Management System), Sony Green Partnership and Canon Green Procurement.

During the first two months of the research, most of the time were utilized to understand the process flow and production layout in the company. The company operation is divided into two main building which is Plant 1 (P1) and Plant 2 (P2) with approximately 1 kilometre distance from each other. P1 is for the production process and also houses of the administrative while P2 is specifically for assembly process, Surface Mount Technology (SMT) department. Part delivery and pickup from P1 and P2 was done every 4 hours. SMT department have two shifts from 7 a.m. to 7 p.m. named shift A and shift B with one hour rest from 11 a.m. to 11.30 a.m. and 3p.m. to 3.30 p.m. This department is divided into two section. Ground floor for the mechanical process such as punching, and first floor is the SMT line process (mounting components).

Figure 4.1 shows the overall layout of the SMT Department. The department have 3 main lines named Line 1, Line 2 and Line 3. This research had been conducted on Line 1 only. This is because Line 1 is prioritized and the production plan is scheduled to Line 1 first and only then followed by the other 2 lines. The production running is the most stable and frequenly run.