Impact of Total Productive Maintenance in Manufacturing on Overall Equipment Effectiveness

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Declaration of own work

I, **Tawandah Musengi** declare that this research report is my own unaided work. It is submitted in partial fulfilment of the requirements of the **M.Eng of Engineering Management** degree at the University of Johannesburg, Auckland Park, South Africa. This material has not been submitted before for any degree or examination at any other university or educational institution.

Abstract

In order for manufacturing organisations to preserve and enhance their organisational competitiveness, it is imperative that they maintain optimal levels of overall equipment effectiveness. Overall equipment effectiveness (OEE) is a widely and well accepted measure of manufacturing plant performance. Low OEE suggests high manufacturing costs and in-turn low organisational competitiveness. As such, manufacturing organisations have adopted numerous techniques such as lean manufacturing and six-sigma in order to continually enhance their OEE.

Nevertheless, total productive maintenance (TPM) is a business tool that is used in industry to improve organisational manufacturing capabilities. The techniques of TPM can hence be used to enhance the OEE of the organisation. It follows that the OEE of manufacturing companies is adversely affected when the principles of TPM are neglected in the manufacturing process.

This research investigates what the effects of TPM initiatives are on OEE and how such effects are brought about through the various pillars of TPM. The research activity is done by method of case study on a production line where TPM was introduced where production reports, archival data and interviews were employed with reference to the period between August 2017 and October 2018 over-which TPM was implemented. It was found that through the adoption of TPM techniques on the production line the OEE was increased as the various losses of OEE were reduced. Furthermore, the logic behind how the various pillars of TPM inhibit respective OEE losses was explored, analysed and outlined in this work.

Industry practitioners can use this work as a reference to promote the introduction of TPM initiatives in manufacturing organisations so as to preserve competitiveness and boost economic growth. The logic behind how the TPM pillars affect respective losses of OEE can be used by industry practitioners to target relevant specific losses in their organisations which may be causing economic loss. On the other hand, scholars and academics can employ this work as reference for future research and development.

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A	Availability
OEE	Overall equipment effectiveness
OEM	Original equipment manufacturer
PE	Performance efficiency
PLC	Programmable logic controller
PM	Preventive maintenance
QR	Quality rate
RCM	Reliability centred maintenance
TPM	Total productive maintenance

Chapter 1: Introduction

1.1 Background

In any manufacturing organization, it is of great importance that plant performance is kept at its optimal levels at all times (Krawczyk-Dembicka, 2016). It follows that the better the plant performs, the more competitive it is on the market environment and a measure that significantly affects this is overall equipment effectiveness (LionRed, 2006; Behzadirad & Stenfors, 2015). It has been remarked numerous times in literature that overall equipment effectiveness should be continually monitored and opportunities to raise it constantly pursued and exploited in a plea to enhance organizational performance (Singh, Shah, Gohil, & Shah, 2013).

Plant overall equipment effectiveness (OEE) has been defined as a comprehensive indicator of a manufacturing plant's condition which considers the operating time, quality and performance (Madanhire & Mbohwa, 2015b). OEE measures the resource utilization level by multiplying performance by quality by availability to assess efficiency of plant machinery and equipment (Kumar, 2016). It is apparent hence that in order to maximize OEE, plant performance together with availability and quality must be kept at the highest levels possible (Jaganure & Badiger, 2017). The enhancement of overall equipment effectiveness raises organizational competitiveness due to the fact that the unit cost of manufacturing is brought to a minimum allowing the organization to sell its products at relaxed costs in comparison to competitors (Singh, Shah, Gohil, & Shah, 2013).

Production in the modern world is heavily dependent on manufacturing technologies (Cornwall, 1977; Schonmann, Greitmann, & Reinhart, 2016). However, manufacturing organisations have been seen to be adversely affected economically due to decreased margins brought about by delays on the production line. Such delays arise from machine setup processes, malfunctioning machinery and to a greater extent machine breakdowns (Afefy, 2013; Palanisamy & Vino, 2013). It follows that this results in lowered asset use by the organisation and hence increased operational costs. It is noted that the effectiveness and efficiency of manufacturing organisations is heavily dependent on the effectiveness of the equipment and losses in operational time reduce such effectiveness (Fore & Zuze, 2010). Overall equipment effectiveness is thereby a tool that can be used to measure and monitor the performance of the organisation with relation to its design capacity during periods when it is scheduled to operate (Palanisamy & Vino, 2013).

Theory has pointed out that Total Productive Maintenance (TPM) is a program that brings plant maintenance into organisational strategy not as a non-profit exercise but as a vital part of the business (Madanhire & Mbohwa, 2015b). TPM was brought into light in Japan 1971 in response to plant maintenance issues that were being faced at the time (Nakajima, 1988). It has been defined as a maintenance system that that covers the whole lifespan of machinery and equipment taking into account all aspects of the asset's life including maintenance, planning and manufacturing (Madanhire & Mbohwa, 2015b). It brings to light the relationship between maintenance activities and the production exercise and then focuses on improvement of product quality, equipment efficiency and capacity as well as occupational safety (Iannone & Nenni, 2015). The primary goals of TPM are to reduce costs of manufacturing and retain superior quality standards while avoiding material and time wastages (Kumar, 2016). It can be seen that through the effective implementation of TPM the equipment effectiveness of the organisation can be enhanced. It is apparent that TPM can be employed as a tool to maintain and/or improve plant OEE.

1.2 Motivation

Due to continued technological advancement, manufacturing organisations have been driven to compete more over the past few years (Jaganure & Badiger, 2017). Cost of products as well as quality and supplier reliability have become the most significant factors affecting the competitiveness of manufacturing organisations (Kumar, 2016; Goldratt & Cox, 1986). The overall equipment effectiveness is a factor that is used by manufacturing organisations to monitor their operational performance (Vijayakumar & Gajendran, 2014). Lowered OEE signals poor performance and reduced profits for the manufacturing company (Jeong & Phillips, 2001). This thereby insinuates lowered organisational competiveness for the company. It is imperative hence that the OEE of the organisation is kept at optimal levels at all times.

As outlined earlier, the goals of Total Productive Maintenance include the maximisation of plant capacity, minimisation of rejects and promotion of equipment efficiency which is line with the enhancement of OEE. It follows that TPM is a tool that can be utilised by the manufacturing organisation to continually optimise OEE. However, the logic behind the implementation of TPM in the manufacturing concern in terms of whether or not and if so how it brings about OEE enhancement should be of great interest both at a theoretical and at an empirical level for manufacturing companies. Such companies should come to the realisation that in today's markets, plant maintenance should be considered an important aspect of operation which significantly affects business performance. As such, it should be considered in business strategy and maintenance techniques, knowledge and processes already implemented should be considered assets on the balance sheet. It is in the interest of manufacturing concerns that principles and best practices are outlined regarding how they can continuously enhance plant OEE.

Problem statement

It is clear that in order for the manufacturing organisation to realise superior levels of competitiveness it must strive to keep its overall equipment effectiveness at its optimal state at all times (Johannsen, 2013). It has been established that the maintenance of plant equipment and machinery has significant implications on the achievable equipment effectiveness and efficiency. Some organisations have been found to consider maintenance activities to be non-profitable operations necessary only for the manufacturing activity to go on (Madanhire & Mbohwa, 2015b). However, it is alluded that in order to enhance their OEE, manufacturing organisations must implement total productive maintenance programs as part of their business strategy at the operational level (Nallusamy & Majumdar, 2017).

It can be seen that it is important for the effects of implementing TPM in the manufacturing organisation to be investigated and outlined for the benefit of industry and academia. Furthermore, the application of total productive maintenance in manufacturing and how it then impacts OEE and in-turn business competitiveness should also be investigated and a framework of best principles drawn up to be at the disposal of industry practitioners as well as scholars.

Problem Statement*: Overall equipment effectiveness of manufacturing companies is adversely affected when the principles of total productive maintenance are neglected in the manufacturing process.*

1.3 Research questions

1. What is the effect of total productive maintenance incorporation on overall equipment effectiveness?
2. How does the implementation of total productive maintenance affect overall equipment effectiveness in manufacturing?

Research question 1 looks at what the implications are on OEE of incorporating TPM in the manufacturing organisation. On the other hand, research question 2 addresses the logic behind how said effects on OEE are brought about when TPM is implemented in the manufacturing concern. It follows that the first research question what the results of TPM implementation are in terms of OEE whereas the latter probes how the implementation of TPM causes such results in OEE.

1.4 Objectives

This research aims to outline for industry practitioners and scholars what the effects of implementing total productive maintenance are (if any) for the organisation in terms of its influence on overall equipment effectiveness and in-turn organisational competitiveness. Knowledge regarding said effects will be at the disposal of manufacturing companies and will provide encouragement or discouragement as the case may be for such organisations to adopt such principles for the enhancement of their competiveness.

To demonstrate where and how the relevant aspects of total productive maintenance can be employed to exploit opportunities to enhance the overall equipment effectiveness of production facilities and in so doing define a framework for manufacturing firms to employ for the sustenance and improvement of plant overall equipment effectiveness.

The definition of the benefits and best principles of total productive maintenance implementation for the enhancement of overall equipment effectiveness will be of benefit to manufacturers for the sustenance of their organisational competitiveness. This is so because such informed incorporation of TPM will promote the cost effective use of employees and process equipment and machinery thereby improving the organisation’s performance.

On the other hand, the identification of shortfalls and redundancies brought about by the implementation of TPM techniques in manufacturing with reference to OEE enhancement will also assist organisations when deciding on what techniques to invest in. Academia will also benefit from this work as literature will be available validated by empirical findings for future research and development.

1.5 Research design

The purpose of this research is to investigate and analyse how Total Productive Maintenance programs can be employed to continually improve the overall equipment effectiveness of a manufacturing plant. As such, literature relating to manufacturing aspects that influence the overall equipment effectiveness of manufacturing equipment and processes will be gathered from peer reviewed sources. TPM will then be defined and its applications in industry will be stated. Thereafter, the application of TPM in the manufacturing organisation will be explored and the effects of its application on OEE will be analysed.

A case study will then be undertaken at XYZ manufacturing company wherein data relevant to plant overall equipment effectiveness of manufacturing machines over time will be collected together with rationale of how TPM has been employed or neglected in the manufacturing process. From this data, findings will then be generated for the case study presenting how the implementation of TPM or neglect thereof has affected the overall equipment effectiveness of the manufacturing plant and subsequently the organizational competitiveness.

The case study results will be compared to theoretical principles found in literature regarding how TPM can be employed to continually raise and upkeep overall equipment effectiveness in the manufacturing organization. Conclusions will then be drawn based on the analysis effecting whether or not TPM can be used to raise the overall equipment effectiveness of manufacturing concerns.

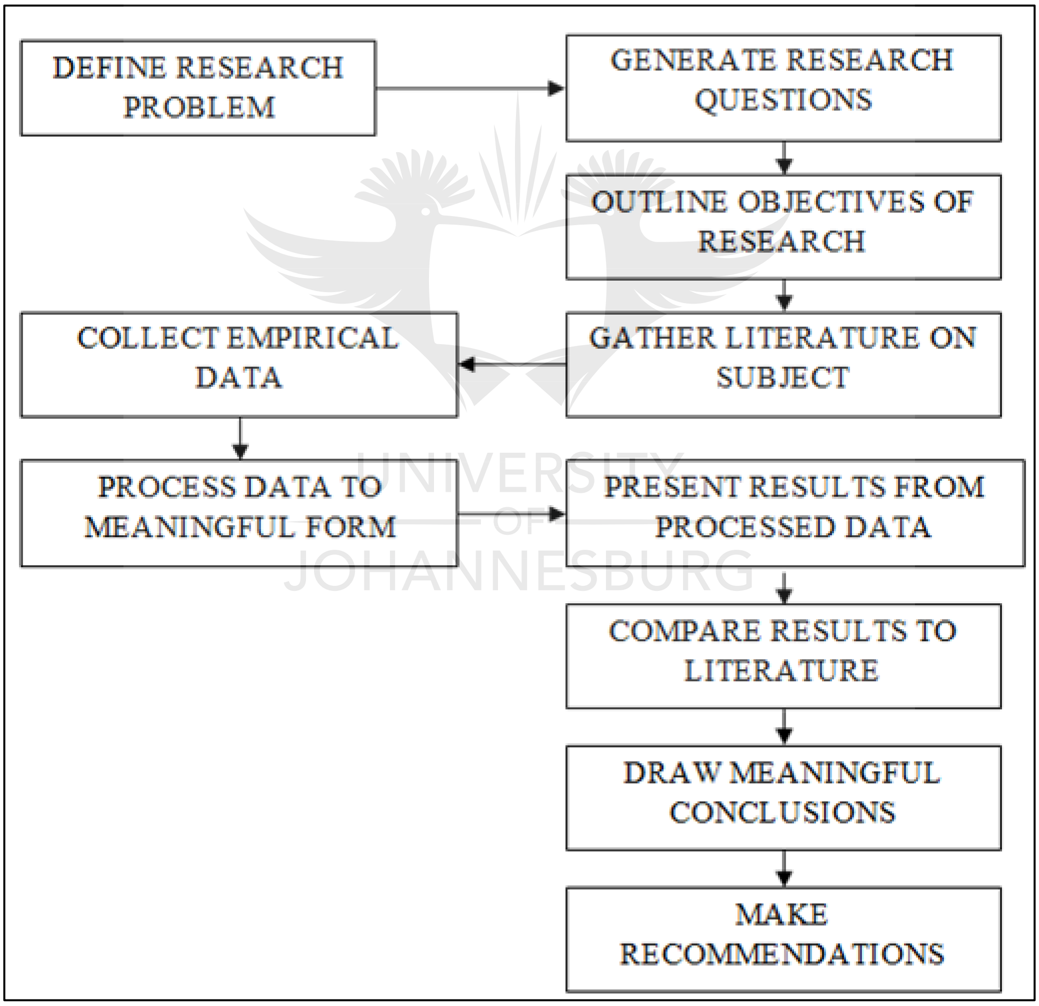


Figure 1: Research Design Flow Diagram (Harrison, et al., 2017;Yin Robert, 2009)

1.6 Document layout

The purpose of this research is to investigate how the implementation of Total Productive Maintenance affects Overall Equipment Effectiveness in a manufacturing organisation. As such it follows that this document is to be structured in a manner that addresses the matter at hand in a logical manner.

In Chapter 1, the background of the problem is outlined together with its relevance. The research focus and the structure of the research document are documented in this chapter. It can be alluded Chapter 1 gives an overview of the research activity undertaken.
Chapter 2 documents the relevant literature pertaining to the theory behind Overall Equipment Effectiveness. Further, the definition of Total Productive Maintenance together with the pillars of it thereof is outlined here. The logic behind how the implementation of Total Productive Maintenance affects the various factors of Overall Equipment Effectiveness is discussed. It is apparent that existing literature regarding terminology, facts and theories about what TPM and OEE are as well as how TPM affects OEE is presented in this section.

Chapter 3 outlines the research approach employed for the purpose of this activity. The methods used for the collection, cleaning and processing of data as well as relevant considerations made during the execution of case studies are also deliberated. Reasoning behind the adopted methodologies is stated and ethical considerations are pointed out.

Chapter 4 documents the observations made as well as the results computed from data collected as per Chapter 3. Graphs and tables illustrating observed trends and numerically depicting how the implementation of TPM affects the various factors of OEE as computed in Chapter 3 are presented. Further, the trends and observations seen in this section are discussed and contrasted against theoretical predictions and dictations so as to validate empirical findings with literature (Chapter 2) and/or evaluate disagreements where they exist.

Chapter 5 brings together the conclusions that can be made regarding how the implementation of TPM affects OEE in the manufacturing concern. In addition, recommendations for future research that could not be done in this work are given. It follows that in Chapter 5 the logic of how TPM influences OEE as per literature and case study is given.

1.7 Conclusion

Manufacturing companies must maintain optimal levels of OEE at all times in order to remain competitive. This is owing to the fact that poor OEE levels on the production line indicate high levels of inefficiency of the manufacturing process which adversely affects the competitiveness of the organisation. Poor organisational competitiveness proceeds to results in poor performance of the company in the market-place as competitors exploit such poor competitiveness in a plea to gain market-share. As such, the manufacturing concern must focus on the continual monitoring and optimisation of OEE so as to retain and increase its competitiveness and ultimately its market-share. The aim of this research is to investigate what strategies and techniques the manufacturing organisation can adopt in order to enhance its OEE as well as to analyse how such techniques influence the various aspects of OEE which lead up to its enhancement.

Chapter 2: Literature survey/review

Overall equipment effectiveness provides a quantitative metric for manufacturing organisations to measure the effectiveness performance of machinery on a production line (Madanhire & Mbohwa, 2015b). The purpose of such measurement is to monitor how effectively equipment is being utilised and where possible identify opportunities for improvement (Nallusamy & Majumdar, 2017). Factors determining OEE include quality, availability and performance of machinery and these need to be kept at maximum levels at all times in order to maintain high levels of OEE (Singh, Shah, Gohil, & Shah, 2013). In so doing, the organisation achieves the highest possible economic gain at the lowest possible input levels in terms of material, labour and other related costs ensuring that operational costs are kept at a minimum (Singh, et al., 2013; O'Brien, 2015).

It has been brought to light that the minimisation of operating costs in manufacturing companies gives the organisation a competitive edge over its competitors as it can then leverage product prices for market-share gain (Klocke, Bucholz, & Stauder, 2014). The minimisation of operational costs is in line with the maximisation of OEE hence it is imperative that the manufacturing organisation continually seeks means and methods to improve its OEE.

Total Productive maintenance has been found to be an effective method of continually improving OEE in manufacturing plants (Patel & Thakkar, 2014). It is primarily developed from the preventive maintenance concept meant for plant maintenance management (Singh, Shah, Gohil, & Shah, 2013). The implementation of TPM programs acts to eradicate certain losses on the production line which in-turn enhances the factors that affect OEE thereby positively impacting OEE at the same time (Patel & Thakkar, 2014). Appropriate TPM incorporation in manufacturing organisations has been directly linked to significant decline in equipment breakdowns and quality related product rejects (Patel & Thakkar, 2014). Theory extends to state that through the involvement of machine operators in the establishment and execution of preventive plant maintenance systems for production equipment, employee morale is raised and individuals take responsibility in taking preventive action against possible failures (Sahu, Meghraj, & Chandrakar, 2016).

It is of great importance that South African manufacturing organisations regardless of company size incorporate TPM as part of business strategy at the operational level to maximise OEE. This is owing to the fact that enhancement of overall equipment effectiveness will bring better business competitiveness for the organisation not only locally but on global markets as well. In this chapter, OEE and TPM will be defined in detail and the rationale behind how TPM affects OEE and subsequently business competitiveness shall be analysed.

2.1 Overall equipment effectiveness – overview

2.1.1 Why overall equipment effectiveness

The capacity of manufacturing equipment is seldom utilised to optimal or maximum possible levels (Linberg, Tan, Yan, & Starfelt, 2015). Causes of this stem from equipment breakdowns, change-overs on machinery, high reject rates and other unplanned delays during operation time (Singh, Shah, Gohil, & Shah, 2013). This directly results in lessened productivity as a result of low product quantity and poor quality which in-turn adversely affects the competitiveness of the organisation at large since the manufacturing cost per unit rises (Linberg, Tan, Yan, & Starfelt, 2015). In order to remedy this, organisations continually attempt to incorporate continuous improvement strategies in the production processes in a plea to raise the production counts and enhance product quality while keeping input costs at a minimum (Goldratt & Cox, 1986). As such, manufacturing concerns employ the overall equipment effectiveness to track the performance of their plant as a control for the upkeep and improvement of production standards (Schonmann, Greitmann, & Reinhart, 2016).

2.1.2 Overall equipment effectiveness defined

Overall equipment effectiveness has been defined as a comprehensive indicator of a manufacturing plant's condition which considers the operating time, quality and performance (Klocke, Bucholz, & Stauder, 2014). It is a measure of machine efficiency with reference to product quality related losses, machine performance losses and machine availability losses and is a tool through which the manufacturing organisation improves its processes when employed appropriately (Stamitis, 2010). Theory goes on to lament that the overall equipment effectiveness as a quantitative metric tool came as a result of total productive maintenance and is not limited to the analysis of the efficiency of a single machine but also for entire integrated manufacturing systems (Garza-Reyes, Eldrdge, Barber, & Soriano-Meier, 2010). Overall equipment effectiveness is dependent on how well equipment and processes perform hence it is of great importance that plant effectiveness is duly considered in the management of technology exercise (Gunawardana, 2006).

In order to compute the equipment effectiveness, losses that are related to external factors are removed and those arise from machine breakdowns or malfunctions as well as those that can be altered through manipulation of the manufacturing process are considered (Stamatis, 2010). Such losses include downtime losses, speed losses and quality losses (Iannone & Nenni, 2015). Quality losses occur as a result of the production of products that do not meet the quality requirements as a result of a faulty machine or start-up phase throughput instability (Iannone & Nenni, 2015). On the other hand, downtime losses are a result of machine stand stills during operating time which may be due to breakdown maintenance activities or malfunctioning equipment (Iannone & Nenni, 2015). Lastly, of relevance to the OEE are speed losses which occur when machinery is not run to its maximum design capacity due to faulty components or malfunctions which slow down the machine (Iannone & Nenni, 2015). Nakajima proposes the six big losses that affect OEE in manufacturing and these are discussed in the subsections that follow.

It follows that in the computation of OEE three factors are defined and these are as documented in the table that follows:

Table 1: Factors affecting overall equipment effectiveness of manufacturing firm

Parameter	Description
Equipment performance (Performance efficiency)	The ratio of machine operating speed to the design performance of the machine (Singh, Shah, Gohil, & Shah, 2013)
Plant availability	The fraction of available operating time when the operation of plant machinery and equipment is not affected breakdowns or malfunctions (Madanhire & Mbohwa, 2015a)
Product quality (Quality rate)	The degree to which a particular product meets the customer's expectations (Nakura & Ohashi, 2013). The rate of quality affecting the OEE is the ratio of defective to actual processed parts (Singh, Shah, Gohil, & Shah, 2013) hence rejects must be kept at a minimum so as to maximise profits (LionRed, 2006)

Where;

$$Availability\ (A) = \frac{Operating\ time}{Loading\ time} \quad [1]$$

(Singh, Shah, Gohil, & Shah, 2013)

Where $Operating\ time$ is the total shift time less all actual downtime and stop time, and $Loading\ time$ is total shift time less planned downtime.

$$Quality\ rate(QR) = \frac{Valuable\ operating\ time}{Net\ operating\ time} = \frac{(total\ number\ of\ parts) - (number\ of\ defective\ parts)}{total\ number\ of\ parts} \quad [2]$$

(Singh, Shah, Gohil, & Shah, 2013)

Where $total\ number\ of\ parts$ is the count of both rejected and accepted product and $number\ of\ defective\ parts$ is the count of rejected products.

$$Performance\ efficiency\ (PE) = (operating\ speed\ rate) \times (net\ operating\ rate) \quad [3]$$

(Singh, Shah, Gohil, & Shah, 2013)

Where $operating\ speed\ rate$ is the ratio of theoretical to actual cycle time and $net\ operating\ rate$ net operating rate is the ratio of actual processing time to overall operating time(Singh, Shah, Gohil, & Shah, 2013).

Overall equipment effectiveness is computed as the product of availability, performance and quality rate. i.e.:

$$OEE = availability(A) \times quality\ rate(QR) \times performance\ efficiency(PE)$$

$$OEE = A \times QR \times PE \quad [4]$$

(Singh, Shah, Gohil, & Shah, 2013)

It can be seen hence that OEE gives the organisation a systematic approach to the establishment of targets in the production schedule while taking into consideration practical management techniques that provide a level view of influential process parameters (Singh, Shah, Gohil, & Shah, 2013). World class OEE standards for manufacturing organisations are as shown in the table that follows:

Table 2: World class OEE (O'Brien, 2015; Sahu, et al., 2015)

Factor	**World class standard**
Availability	90,0%
Quality Rate	99,9%
Performance Efficiency	95,0%

OEE	85,0%

The sub-section that follows discusses the key factors affecting the overall equipment effectiveness of manufacturing companies.

2.2 Aspects affecting overall equipment effectiveness in manufacturing

2.2.1 Equipment performance

Literature defines equipment performance as the ratio of the ideal cycle time to manufacture a product to the actual throughput divided by the magnitude of operating time (Gomaa, 2003). Furthermore, performance efficiency of equipment in the calculation of overall equipment effectiveness is as calculated in equation [3] above where:

$$net\ operating\ rate = \frac{actual\ processing\ time}{operating\ time} \quad [5a]$$

(Singh, Shah, Gohil, & Shah, 2013),

Where $actual\ processing\ time$ is the time during which tangible work that is part of the manufacturing process is being done and $operating\ time$ is the time when equipment and/or machinery is in operation.

$$operating\ speed\ rate = \frac{theoretical\ cycle\ time}{actual\ cycle\ time} \quad [5b]$$

(Singh, Shah, Gohil, & Shah, 2013)

Where $theoretical\ cycle\ time$ is the ideal/theoretical state time required to complete a product and $actual\ cycle\ time$ is the real life time it takes to complete a product. It follows that in order for the manufacturing process to be cost effective, its efficiency must be kept at optimal levels. Delays on the production line as well as poor machine condition and incorrect machine settings are some sources of lowered performance efficiency (Gomaa, 2003) which the manufacturing concern must keep at a minimum. It is apparent that in order to enhance organisational OEE, performance efficiency should be monitored continuously and programs to improve it put in place.

2.2.2 Plant availability

It has been pointed out that availability of plant influences the overall equipment effectiveness (OEE) of manufacturing organisations as per the focus of this research. Plant availability is defined as the fraction of available operating time when the operation of plant machinery and equipment is not affected by machine set-up, change-overs, breakdowns or malfunctions (Klocke, Bucholz, & Stauder, 2014). Downtime refers to periods when machinery is not functioning during designated operating time due to losses originating from unplanned maintenance tasks or otherwise being undertaken on a machine while it is supposed to be operating (Madanhire & Mbohwa, 2015a). The term availability can be employed to refer to a single machine or an entire facility (Madanhire & Mbohwa, 2015a). Availability is calculated as:

$$Availability\ (A) = \frac{(Shift\ time) - (Downtime\ and\ stop\ time)}{Total\ loading\ time} \qquad [6]$$

(Afefy, 2013)

which is in agreement with equation [1] above where $Total\ loading\ time$ is shift time less planned downtime.

Plant availability can be detrimental to the overall success of the manufacturing organisation as it influences facility OEE and hence productivity. Low availability will minimise plant capacity and in-turn adversely impact organisational gross margins (Schonmann, Greitmann, & Reinhart, 2016). Therefore, it is of great significance that the organisation puts in place technology that is capable of achieving acceptable standards of equipment availability in line with organisational strategy (Ikegami, Shimura, & Koike, 2001).

It has been pointed out that availability is negatively affected by unplanned maintenance activities on the production line (breakdown maintenance) (Garza-Reyes, Eldrdge, Barber, & Soriano-Meier, 2010). It follows that in order to enhance plant availability and ultimately overall equipment effectiveness, plant maintenance needs to be executed effectively in line with Total Productive Maintenance and strategies to improve manufacturing processes (Garza-Reyes, Eldrdge, Barber, & Soriano-Meier, 2010). Plant maintenance has been referred to as the systemic upkeep of equipment, machines, processes and other assets as part of the production management activity (Madanhire & Mbohwa, 2015a). Furthermore, plant maintainability is the systematic assessment of the maintenance strategies employed to maximise availability of the manufacturing plant (Madanhire & Mbohwa, 2015a). The upkeep of production technologies as well as the discarding of such technologies whose reliability has declined is a pivotal aspect of production management and in-turn OEE (Porter, 1985).

2.2.3 Product quality

Product quality is defined as the degree to which a particular product meets the customer's expectations (Nakura & Ohashi, 2013). The quality rate that is employed in the computation of OEE is further defined as the ratio of defective parts to total number of processed parts in a given period (Nakajima, 1988)**.** It follows that the greater the number of defective products, the lower the OEE. As such, product quality is a critical element contributing to the success of the manufacturing organisation as it directly affects the business competitiveness of the company (Nakura & Ohashi, 2013). Manufacturing organisations constantly work to maintain and where possible improve their quality standards so as to enhance their OEE. Production aspects that may cause products to not meet quality requirements include faulty or malfunctioning machinery as well as instability in consistence in the early stages of machine start-up (Iannone & Nenni, 2015). The rate of quality is then computed for the purpose of OEE as follows:

$$Quality\ (Q) = \frac{(Total\ number\ of\ units) - (Total\ number\ of\ defective\ units)}{(Total\ number\ of\ units)} \qquad [7]$$

(Jeong & Phillips, 2001) where the parameters are as defined in equation [2] above which is in agreement with (Singh, Shah, Gohil, & Shah, 2013).

It is documented that many manufacturing organisations around the globe tarnish their reputation due to compromised quality standards which in-turn results in lowered OEE and market share losses (Singh, et al., 2013; Nakura & Ohashi, 2013). It is noted however, that in order for the manufacturing concern to achieve superior quality standards, it must possess superior technology (i.e. machines, equipment, processes, technological literacy) (Zimon, 2015).

2.2.4 OEE calculation procedure

In order to calculate the factors of OEE in the manufacturing organisation, theory prescribes the collection of various parameters that are necessary for this exercise. These parameters are as documented and described in the table that follows:

Table 3: OEE parameters (Singh, et al., 2013)

Parameter	Definition
$total\ shift\ time$	total amount of time designated for plant operation per unit time

planned down time	predetermined time set aside for operations other than production e.g. planned maintenance
actual downtime and stop time	sum of all the time when the line is not running
theoretical cycle time	ideal/theoretical state time required to complete a product
actual cycle time	real life time it takes to complete a product
actual processing time	time during which tangible work that is part of the manufacturing process is being done
operating time	time when equipment and/or machinery is in operation
total number of parts	count of both rejected and accepted product
number of defective parts	count of rejected products

Once the production data required is available, it can be processed further to determine the variables that affect the three factors of OEE. The table that follows illustrates how these variables are calculated:

Table 4: Variables of OEE factors (Singh, et al., 2013)

$operating\ time = total\ shift\ time - (actual\ downtime\ and\ stop\ time)$	[8]
$operating\ speed\ rate = \frac{theoretical\ cycle\ time}{actual\ cycle\ time}$	[9]
$net\ operating\ rate = \frac{actual\ processing\ time}{operating\ time}$	[10]
$loading\ time = total\ shift\ time - planned\ down\ time$	[11]

With the variables of the OEE factors determined as shown in equations [8] to [11], the factors of OEE can then be determined using equations [1], [2] and [3] above.

2.3 Losses of overall equipment effectiveness

Theory has defined losses as exercises that utilise and consume resources without generating any value (Iannone & Nenni, 2015). As such, losses are meant to be kept at minimal levels in manufacturing operations (Iannone & Nenni, 2015). Nakajima has described six different types of losses that affect OEE and these have come to be known as the Six Big Losses (Nakajima, 1988). Losses have been classified further to either being chronic or sporadic (Jonsson & Lesshammer, 1999). Sporadic losses are those that are quick to propagate and cause significant deviations from normal performance while chronic losses are minute, complex and not simple to detect (Jonsson & Lesshammer, 1999). It is important that losses incurred on the production line are classified in this manner so that they can be ranked according to their frequency and severity so as to prioritise the eradication of those that have the most severe impact on the organisation (Jonsson & Lesshammer, 1999).

The losses that adversely affect the organisations are categorised by cause of the respective loss into three groups namely process, external and machine malfunction (Iannone & Nenni, 2015). External losses are those that cannot be improved by either the maintenance or the production team and these may include unavailability of raw material or personnel shortages (Ikegami, Shimura, & Koike, 2001). External losses must not be taken into account when determining the overall equipment effectiveness (Iannone & Nenni, 2015). On the other hand, process losses are related to the manner in which machines and equipment are utilised in the manufacturing process (Iannone & Nenni, 2015). Furthermore, machine malfunctioning losses are those that come from equipment that does not operate in the manner in which it is supposed. Both the process and machine malfunctioning losses are considered in the determination of OEE as these can be manipulated by the daily organisation at the operational level of the organisation (Iannone & Nenni, 2015).

Machine malfunctioning and process losses can be further broken down to quality losses, speed losses and downtime losses (Stamitis, 2010). It can be seen that these are the aspects directly related to the OEE of plant. Quality losses which contribute to the quality rate that is used in the computation of OEE are synonymous to parts rejected owing to the fact that manufacturing equipment produces parts that do not comply with quality requirements (Stamatis, 2010). Speed losses occur when machinery does not operate at the maximum rated performance capacity and hence such losses adversely affect the performance efficiency that is employed in the calculation of OEE and in-turn negatively affecting OEE (Stamitis, 2010). Causes of speed losses may range to improperly set machines to other operational anomalies such as raw material clogging (Madanhire & Mbohwa, 2015a). Lastly, downtime losses originate mostly from unplanned maintenance tasks being undertaken on a machine while it is supposed to be operating (Madanhire & Mbohwa, 2015; Jaganure & Badiger, 2017). Such tasks are necessitated by machine breakdowns which bring equipment and related processes to a standstill (Madanhire & Mbohwa, 2015a). The table that follows depicts the six big losses proposed by Nakajima:

Table 5: The traditional six big losses of OEE (Nakajima, 1988; O'Brien, 2015)

Category	**Big losses**

Speed	• Idling/Minor stoppages • Reduced speed
Downtime	• Breakdowns • Setup and adjustments
Quality	• Lowered throughput • Quality losses

The six big losses documented above can be further broken down into specific losses potentially experienced on the manufacturing line. The table below documents the possible wastes and losses under the six big losses that adversely affect OEE in manufacturing organisations alongside the corresponding elements of Nakajima's six big losses.

Table 6: OEE waste and losses (McIntosh, et al., 2001)

OEE Factor	Nakajima's six big losses	OEE losses	Potential waste or loss
Availability	Set-up and adjustments	Downtime	Change-overs
			Machine set-up and warm-up
			Material shortage
			Absent operators
			Delays
	Breakdowns	Downtime	Reactive/Unplanned maintenance
			Machine breakdowns
			Tool failures
Quality	Start-up and production rejects	Quality loss	Defective parts
			Rework losses
			Incorrect assembly
			In-process damage
			In-process expiry
Performance	Minor stoppages	Speed loss	Mis-feeds
			Cleaning and lubrication
			Waiting for parts/tools
			Machine/Equipment jams
			Obstructed supply chain
			Blocked sensor
	Reduced speed	Speed loss	Rejects
			Inefficient operators

			Wear and tear of machinery and equipment
			Below design specification capacity
			Machine mal-function

It is noted that the losses documented in the table above have further underlying causes which bring them about. These are illustrated by (Yamamoto & Bellgran, 2010) in the figure that follows:

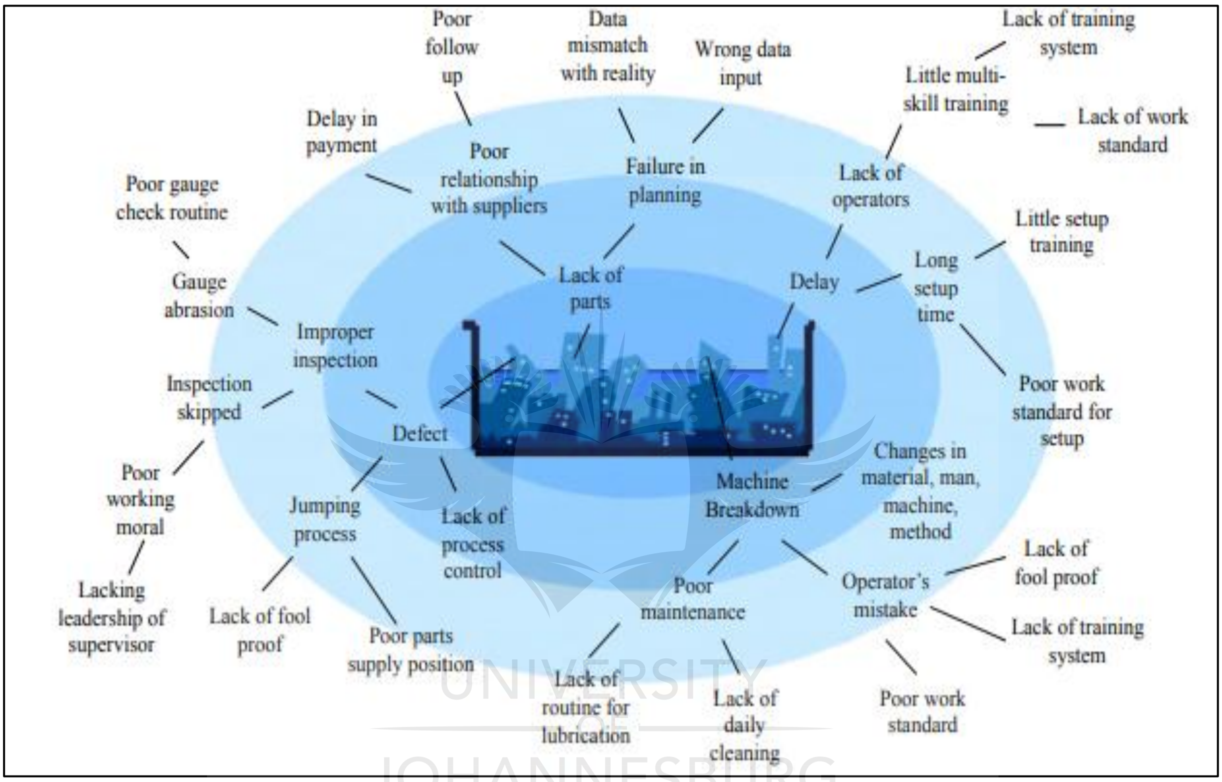


Figure 2: Causes of OEE losses (Yamamoto & Bellgran, 2010)

It can be seen in the figure that the losses that affect OEE on the production line arise from various underlying causes most of which are process related. Poor machine and equipment maintenance as well as lack of training of machine operators are the primary causes of machine breakdowns (Yamamoto & Bellgran, 2010; Gupta & Garg, 2012). On the other hand, product defects and rejects are brought about by poor work-flow structures and poor operating standards and equipment which in-turn decrease production quality rates (O'Brien, 2015). Furthermore, as depicted in the figure above, lack of good administration and planning in the manufacturing organisation results in lowered OEE as this results in process disorganisation and in-turn unwanted delays (Yamamoto & Bellgran, 2010).

It is hence apparent that in order to sustain and enhance organisational OEE, such causes of OEE losses must be eliminated.

2.4 OEE and TPM

Up to this point, OEE has been defined and its importance for the performance of the manufacturing organisation established. However, the purpose of this paper is to investigate and analyse the effects of the implementation of TPM on OEE of the manufacturing plant as well as to outline how such effects are brought about. TPM is a company-wide, team based theme that aims to improve the quality of plant machinery and enhance plant productivity through the elimination of delays arising from equipment failure (O'Brien, 2015). It is based on a framework that employs eight key strategies (Pillars of TPM) that focus on continuous improvement, measurement of plant performance, and improvement of maintenance planning as well as occupational safety (O'Brien, 2015).

2.5 Total productive maintenance (TPM)

2.5.1 TPM defined

Total productive maintenance is a productive maintenance system whereby employees undertake small group exercises to upkeep the condition of manufacturing equipment (Madanhire & Mbohwa, 2015b). TPM has been found to benefit companies owing to the fact that it relies on employee training and team empowerment rather than traditional engineering techniques (Madanhire & Mbohwa, 2015b; O'Brien, 2015). TPM focuses on the promotion of equipment maintainability through the enhancement of technology literacy amongst personnel who work with the manufacturing equipment and machinery (Johannsen, 2013).

Literature dictates that TPM aims to increase the efficiency of plant equipment and material yield through the implementation of best practices for continuous production processes (Madanhire & Mbohwa, 2015b) and in the long run leads to improved OEE which in-turn brings about enhanced competitiveness and productivity (Chen, Lu, Wang, Jang, & Dahlgaard, 2015). It follows that one of the primary goals of TPM is the maximisation of OEE in the manufacturing organisation through the elimination of equipment failures and decrease in production defect count (Madanhire & Mbohwa, 2015b). This is achieved through the implementation of various machine maintenance systems that not only retain machine performance but also empower machine operators and other practitioners encouraging them to take initiative over the maintenance activity (Johannsen, 2013).

2.5.2 Types of maintenance

Maintenance has been defined as an exercise that is undertaken in plea to retain and/or upkeep plant machine performance (Gomaa, 2003). It is the process of undertaking activities that ensures that physical assets deliver results that they are meant for (Moubray, 1997).On the other hand, maintenance has also been referred to as routine and recurring exercise of preserving a piece of equipment in its optimal operating condition so as to ensure that it renders the function meant for it at performance rates in line with its design specifications (Tsang, Kolodny, & Jardine, 1999).

The implementation of appropriate and structured maintenance systems in manufacturing plants has been found to effectively decrease the frequency and severity of machine breakdowns while enhancing the rate of quality (Afefy, 2013). There are various types of maintenance that are identified and these may be planned or reactive to machine failure as shown in the figure that follows:

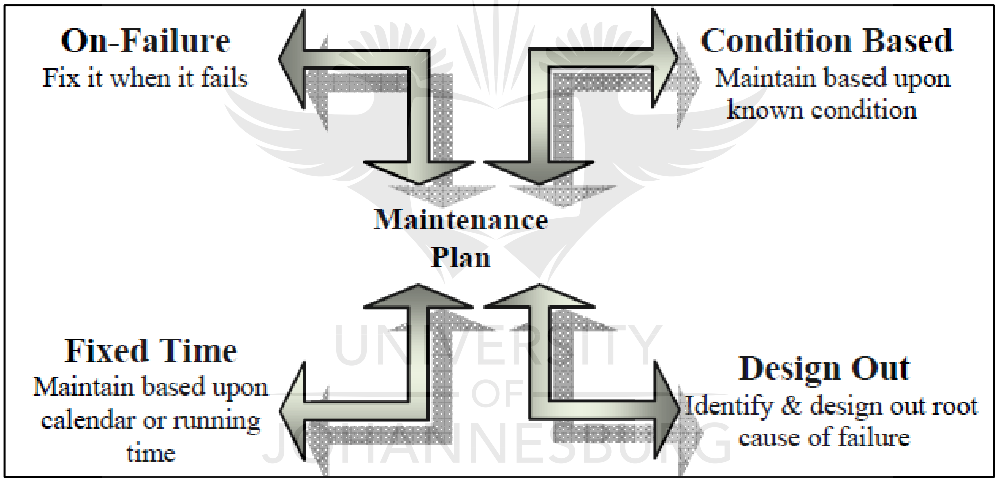


Figure 3: Maintenance categories (Fore & Zuze, 2010)

The table that follows documents the types of maintenance that are considered as part of the Total Productive Maintenance programme in the manufacturing environment.

Table 7: Types of maintenance

Maintenance category	Description
Preventive maintenance (PM)	This is time based maintenance (periodic of predictive) that aims to avoid failure through the

	prevention of component or equipment deterioration (Madanhire & Mbohwa, 2015a). Condition monitoring and machine inspections together with associated activities e.g. machine lubrication constitute part of preventive maintenance and are referred to as autonomous maintenance activities (Tsang, Kolodny, & Jardine, 1999). Predictive maintenance is a category of preventive maintenance (Fore & Zuze, 2010).
Breakdown maintenance	Occurs when equipment fail while they are in operation where such failure is unforeseen (Madanhire & Mbohwa, 2015a). The figure that follows illustrates the classification of breakdown maintenance according to duration (Denso, 2006).
Corrective maintenance	Involves the improvement of machine components which are prone to repetitive failure to avoid such failure in future and promote the effectiveness of preventive maintenance (Fore & Zuze, 2010). This may constitute the complete re-design of machine components which resemble weaknesses that cause the machine to be prone to failure.
Predictive maintenance	A category of preventive maintenance which involves the predetermination of the service life of critical machine components and as well as their reliability (hence RCM - reliability centred maintenance) in a plea to predict their maximum service life (Fore & Zuze, 2010). It follows that predictive maintenance is also condition based e.g. condition monitoring of electric motors
Maintenance prevention	Maintenance prevention effects the educated design of new equipment in such a manner that will avoid the need for certain maintenance activities (Fore & Zuze, 2010). Information about the design flaws of current equipment in terms of maintainability is employed to improve future equipment designs (Tsang, Kolodny, & Jardine, 1999).

The maintenance of old machinery is an expensive and cumbersome affair. Time based overhauls and replacement of broken components of machinery have been found to be in-effective one too many times (Madanhire & Mbohwa, 2015a). This comes as it has been shown on a number of occasions that such overhauls may be unnecessary which actively causes production down-time and raises organisational expenditure without notably making plant more reliable (Porter, 1985).

The primary function of plant maintenance as a part of strategic management is to put in place equipment maintenance policies that manage plant in line with organisational goals such as the minimisation of expenditure and downtime (Ikegami, Shimura, & Koike, 2001). It is apparent that minimizing maintenance costs and lengthening plant life through maintenance contribute to the afore-stated vision. Condition based maintenance is employed in the manufacturing industry in a plea to leverage the service life of machinery as economically as possible (Madanhire & Mbohwa, 2015a). It assesses the wear and tear of plant before any maintenance activities are recommended (Madanhire & Mbohwa, 2015a). In order to effectively practice it, condition monitoring technologies are employed (Ikegami, Shimura, & Koike, 2001). An example in industry would be vibration analysis technology for condition monitoring of electric motors.

Through total productive maintenance the maintenance of production machinery and equipment is done by operators and practitioners as well as maintenance personnel in a structured manner that is line with business strategy (Madanhire & Mbohwa, 2015a). This is so as in this type of maintenance strategy, the maintenance team undertakes the scheduling, planning, administration and valuation of the maintenance that is carried out by operators (Madanhire & Mbohwa, 2015a). TPM activities involve the strategic maintenance programs that fall under the various categories of plant maintenance defined above whose aim is primarily to minimise down-time and maximise material yield.

2.5.3 TPM and the 5S

The foundation of Total Productive Maintenance is the 5S program. The 5S program is a systematic process of workplace housekeeping by all employees in order to create a placid working environment (Gupta & Garg, 2012). The logic is that problems and opportunities for improvement cannot be easily identified in a disorganised working environment. The organisation of the working environment thereby gives room for the identification of problems which in-turn gives way for improvement opportunities (Gupta & Garg, 2012). Literature provides an advancement of the 5S to 6S which has the extra aspect of safety as shown in the figure below:

Figure 4: 6S program (O'Brien, 2015)

The 5S program is comprised of five steps all leading to a clean and efficient working environment. These steps are also referred to as the pillars of 5S and are documented in the table that follows:

Table 8: The 5S program

5S step	Description
Sort	Focuses on the removal of all items that are of no use in the workplace and the identification of those that are frequently used (Gupta & Garg, 2012; O'Brien, 2015; Sahu, et al., 2015)
Set in order	Ensures that all relevant items in the workplace are organised in such a manner that they are easily and conveniently accessible for the undertaking of work (Sahu, Patidar, & Soni-Kumar, 2015). It follows that such organisation takes into account how work will be done so as to streamline the process. (Gupta & Garg, 2012)
Shine	The shine pillar emphasizes the cleaning of the workplace by all employees in terms of eliminating all debris, dust, oil e.t.c from the working environment (Gupta & Garg, 2012)
Standardise	Refers to the establishment of a consistent manner in which tasks and activities are done such as procedures and schedules for particular employees (Sahu, et al.,

	2015; Gupta & Garg, 2012)
Sustain	Once procedures and schedules are put in place and the work place has been sorted and set in order, it is imperative that this is maintained and improved when and where possible (Gupta & Garg, 2012).
Safety	When the production line is being organised, the location of various items, equipment and machinery must consider the safety risks first so as to avoid potential occupational hazards (O'Brien, 2015)

2.5.4 Pillars of TPM

Theory dictates that in order to for the manufacturing company to realise the benefits of implementing TPM, the TPM pillars framework must be employed (Sahu, Meghraj, & Chandrakar, 2016). The eight pillars of TPM are as shown in the figure that follows:

Figure 5: Pillars of TPM (O'Brien, 2015)

The table that follows documents the description of the eight pillars of TPM.

Table 9: Pillars of TPM

TPM pillar	Description
Autonomous maintenance	Operators are involved in day to day maintenance of machines and equipment including small task maintenance activities and routine inspections (Sahu, Meghraj, & Chandrakar, 2016). Operator active participation in the maintenance of equipment reduces asset deterioration and ensures machinery is kept in its new condition (Sahu, Meghraj, & Chandrakar, 2016).
Planned maintenance	The aim of planned maintenance is to increase plant availability through better machine reliability and maintainability (O'Brien, 2015). This is achieved by budgeting for maintenance activities as well as spares in advance so as to avoid possible future breakdowns and failures (Sahu, Meghraj, & Chandrakar, 2016).
Equipment and process improvement/Focused maintenance	Involves the continual monitoring and observation of plant machines and processes and the identification of opportunities for the betterment of equipment in terms of the six big losses of manufacturing (O'Brien, 2015). Maintenance activities undertaken are an effort to prevent future breakdowns. Small improvements on equipment are continuously done so as to enhance machine performance (Sahu, Meghraj, & Chandrakar, 2016).
Early management of new equipment	The aim is to reduce the time needed to get machinery running at optimal levels once it has been procured through the elimination of start-up issues (O'Brien, 2015). It involves the planning of project strategies to ensure that all factors affecting success are dealt with.
Quality maintenance	Targets to assure zero product defect condition by means of maintaining plant equipment in optimal operating condition so as to enhance product quality (Sahu, Meghraj, & Chandrakar, 2016). With a set standard, the condition is continuously checked against the standard to ensure that no defects exist (Chen, Lu, Wang, Jang, & Dahlgaard, 2015).
Office TPM	Looks at the elimination of waste in administration and support processes in the organisation in a plea to enhance the efficiency of the production process (O'Brien, 2015). Tasks such a issuing of material and releasing of production orders to production are examples of administrative processes that are in question here.

Education and training	The skilling of personnel promotes a multi-skilled workforce for the organisation which allows for efficient and versatile teams that can work more efficiently. Operators are developed so that they can effectively maintain production equipment (O'Brien, 2015). Training and skilling has been found to also increase the morale of workers which makes them take responsibility to take proactive action to avoid breakdowns (Sahu, Meghraj, & Chandrakar, 2016).
Safety and environmental management	The goal is to maintain a working environment that is hazard and risk free by getting rid of defective machinery which may pose occupational hazards. Machine guards as well as PPE are put in place to reduce likelihood of injury to operators (O'Brien, 2015).

2.6 Total productive maintenance and overall equipment effectiveness

In order for production based organisations to maintain their competitiveness on local and global markets, it is imperative that they minimise the costs that they incur in the manufacturing process (Voss, 1989). Wastage and loss in manufacturing has been attributed to various factors such as non-availability of plant machinery, lack of sufficient manpower or expertise and malfunctioning equipment (Nallusamy & Majumdar, 2017). Such losses have been found to have detrimental effects for manufacturing companies as they adversely affect the cost of time and ultimately the economies of scale which organisations traditionally leverage product price on (Nallusamy & Majumdar, 2017). It is of optimal importance hence that the performance of manufacturing lines to be continuously monitored so that control measures can be implemented.

Overall Equipment Effectiveness has been defined as a fundamental way to continually measure and monitor the performance of production machinery and processes (Jaganure & Badiger, 2017). It is affected by manufacturing factors namely plant availability, performance efficiency and production quality rate. Higher rates of performance, availability and quality translate to higher OEE (Jaganure & Badiger, 2017). The causes of waste and losses related to the three aforementioned factors that adversely affect the OEE are shown in the previous figure. It follows that in order to raise OEE, such causes of losses must be reduced or eliminated where possible so that the manufacturing costs incurred by the organisation can be brought to a minimum.

Total Productive Maintenance is a plant maintenance regime that has been found to effectively enhance the OEE of manufacturing plants (Fore & Zuze, 2010). This is owing to the fact that through the implementation of TPM, the utilisation of machine tools and manpower is increased (Nallusamy & Majumdar, 2017). TPM reduces losses on the production line by introducing a systematic workflow in the work environment which streamlines processes that are related to the manufacturing activity (O'Brien, 2015). This comes as the result of the incorporation of the 5S program which comes with TPM and focuses on the premeditated organisation of the work environment in such a manner that that promotes organised employee behaviour thereby increasing manpower utilisation.

In addition, the implementation of maintenance management systems that comes as part of the TPM program ensures that plant availability is increased (Madanhire & Mbohwa, 2015a). This is due to the fact that critical machine components can be replaced before failure occurs which avoids unwanted downtime related to breakdown maintenance activities (Madanhire & Mbohwa, 2015a). Further, spares for such critical components are kept in stock which also prevents production time losses while waiting for parts (Sahu, Meghraj, & Chandrakar, 2016). Other machine maintenance strategies related to TPM such as condition monitoring anticipate component failure in advance and such failure can then be mitigated without the incurrence of machine downtime (Madanhire & Mbohwa, 2015b).

The adoption of autonomous maintenance in the manufacturing space has been found to encourage plant operators to be proactive in maintaining machinery in its prime state of operation (Iannone & Nenni, 2015). Daily inspections by operators ensure that machine operation and performance is continually monitored which in-turn avoids situations whereby abrupt breakdowns occur during operation time (Singh, Shah, Gohil, & Shah, 2013). It is also noted that plant operators take responsibility for the state of the machinery that work with when they understand the relationship between maintenance and productivity which is also an aspect that comes with TPM (Sahu, Meghraj, & Chandrakar, 2016).

Another pillar of TPM that enhances OEE is quality maintenance (Sahu, Meghraj, & Chandrakar, 2016). The minimisation of production rejects is achieved through the upkeep of production machinery in its prime state of operation such that it does not malfunction in a manner that may result in defective product (Gupta & Garg, 2012). On the other hand, the constant monitoring and enhancement of product quality ensures that machinery does not gradually deteriorate in terms of its quality capability which in-turn provides a control over reject rate (Gupta & Garg, 2012).it follows that the enhancement of quality rate directly improves OEE as well.

Focused maintenance brings continuous process and machine improvement to the manufacturing organisation (Sahu, Meghraj, & Chandrakar, 2016). Problems in the manufacturing process are constantly identified and solutions rendered. This may be areas of concern regarding product quality, process streamlining or machine performance. The active identification of opportunities for improvement under the aspects that affect OEE and the actual incorporation of such improvements in the production process aids in continual improvement of OEE (Madanhire & Mbohwa, 2015b). It is apparent that by adopting focused maintenance and process improvement, all the relevant aspects of OEE can be improved (O'Brien, 2015).

Effective training and education of machine operators and other personnel involved in the manufacturing process results in a multi-skilled and cross functional organisation (Afefy, 2013). Time losses related to machine start-up as well as start-up rejects are reduced when operators of the machinery have sufficient expertise on the machine operation (Jonsson & Lesshammer, 1999). In addition, operators can perform maintenance tasks better when they have been trained to do so which helps them keep respective machinery in desired operating condition thereby reducing downtime and rejects while increasing machine performance efficiency (Sahu, Meghraj, & Chandrakar, 2016). Theory also goes on to state that employee morale is raised when training activities are provided (Fore & Zuze, 2010).

Office TPM works to minimise losses in the administrative processes that may delay production activities (Denso, 2006). An example is the ordering of raw materials required for the production exercise. If such raw materials are not available in time for the production order, the OEE and ultimately the productivity of the company is adversely affected (Sahu, Meghraj, & Chandrakar, 2016). TPM streamlines administrative processes related to manufacturing and relegates activities that are not necessary which increases the efficiency of the manufacturing process (Nallusamy & Majumdar, 2017).

The table below illustrates in summary the effects of each TPM pillar on the factors of OEE:

Table 10: Effects of TPM pillars on OEE

	Availability	Performance efficiency	Quality rate
Autonomous maintenance	More corrective maintenance, less breakdowns, better availability (Fore & Zuze, 2010)	Enhanced machine condition, increased efficiency (Kumar, 2016)	Less rejects when machine condition is optimal (Kumar, 2016)
Equipment &	Permanent	Optimisation of	Continual

process improvement	solutions put in place for time consuming activities e.g. changeovers, breakdowns (Nallusamy & Majumdar, 2017)	manufacturing process bringing lowered cycle times and higher efficiency (Madanhire & Mbohwa, 2015a)	enhancement of quality management systems (Nallusamy & Majumdar, 2017)
Planned maintenance	Preventive and predictive maintenance activities avoid breakdowns which lower availability (Madanhire & Mbohwa, 2015b)	Machinery is kept I at optimal levels of operation avoiding poor condition of components which lowers performance (Jaganure & Badiger, 2017)	Machinery that is kept at optimal operating state (no worn parts) will have low defect frequency (Jaganure & Badiger, 2017)
Early management of new equipment	Promotes the ease of operating and maintaining equipment reducing setup times and increasing reliability hence better availability (Madanhire & Mbohwa, 2015b)	Improves machine stabilisation times thereby heightening machine efficiency (O'Brien, 2015)	Lowered stabilisation and commissioning times reduce reject rates (O'Brien, 2015) (Jaganure & Badiger, 2017)
Quality management	-	-	Error proofing mechanisms and systems that avoid mistakes from occurring enhance the quality rate, causes of issues are eliminated (O'Brien, 2015)
Office TPM	Streamlined process of administration	Efficiency of the production process is enhanced when	Information regarding quality management

	tasks related to activities such as breakdown maintenance will reduce downtime (O'Brien, 2015),	issues related to delay causing elements (e.g. raw material issuing) are reduced (Denso, 2006)	system's progress over time must be monitored to improve and maintain standards (Chen, Lu, Wang, Jang, & Dahlgaard, 2015)
Education and training	Operators trained to maintain machinery on a daily basis to ensure machine condition is up-kept, maintenance personnel can focus on process improvement (O'Brien, 2015)	Delays on the line can be reduced when operators are trained to resolve minor machine operation issues while in operation, better trained operators are more efficient (O'Brien, 2015)	Operators trained to undertake root cause analyses on where quality issues originate so that permanent fixes can be implemented (O'Brien, 2015)
5S program	Maintenance systems require organised procedures of spares issuing and job expedition (O'Brien, 2015), through 5S spares are strategically stored and the production line is set-up in such a way that allows for the ease of maintenance activities thereby minimising the time required for such activities (Gupta & Garg, 2012)	Streamlining of the production process increases efficiency as all equipment and machinery are organised in such a manner that work flows without delays (Afefy, 2013), unnecessary tools and obstructions are rid of to avoid obstruction (Gupta & Garg, 2012)	The production line is set in perfect working order where raw materials and finished products are stored strategically to avoid in-process and in-storage damage hence reducing rejects (Gupta & Garg, 2012)

The table that follows summarises how the implementation of TPM reduces the stated wastes and losses affecting OEE in the manufacturing organisation.

Table 11: How TPM reduces OEE losses

Potential waste or loss	**How TPM reduces respective loss**
Change-overs and machine set-up and warm-up	Through the 5S regime, set-up procedures are standardised which makes the work-flow efficient hence reducing changeover and set-up times (Gupta & Garg, 2012). Sufficient set-up and tool change training as per the education and training pillar of TPM is also essential in promoting a more streamlined and labour cost effective process of setting up and changing over (Fore & Zuze, 2010).
Machine malfunction	Autonomous maintenance ensures that all components are checked on a daily basis and condition monitoring carried out ensures the replacement of worn or faulty components (Madanhire & Mbohwa, 2015b). Training and education avoids incorrect machine settings or confusion that may result in machine malfunction (Fore & Zuze, 2010)
Material shortage	Through the 5S program material is organised in such a manner that is stored ergonomically so as to allow for easy access and channelling to production line (O'Brien, 2015). Office TPM then allows for effective tracking and issuing of material ensuring that material is ordered on time and in the right volumes corresponding to required product quantities
Absent operators	Education and training of employees promotes a multi-skilled and cross-functional workforce which allows for the substitution of on operator with another should they be absent allowing for critical processes to continue (Afefy, 2013)
Machine breakdowns	Machine breakdowns are reduced as a result of autonomous maintenance strategies which allow for condition monitoring (Madanhire & Mbohwa, 2015a). Further, corrective and predictive maintenance activities also bring about a decrease in machine component failure (Kumar, 2016)
Reactive/Unplanned	Due to reduced frequency of machine breakdowns, less

maintenance	unplanned maintenance activities are required (Madanhire & Mbohwa, 2015a)
Tool failures	TPM emphasises corrective over reactive maintenance which reduces failures (Gomaa, 2003). Autonomous maintenance comes with constant condition monitoring ensuring that components are replaced before failure (Singh, Shah, Gohil, & Shah, 2013).
Defective parts & Rework losses	Through quality maintenance and better kept machinery that is in good operating condition, less machine malfunctions occur hence reducing the frequency of defects caused by this aspect (O'Brien, 2015). Training of operators minimises the time and material required for start-up and adjustments in turn reducing number of defects associated hence less rejects (Fore & Zuze, 2010)
Incorrect assembly	Training and education of employees promotes a more effective and efficient workforce that is less likely to make mistakes (O'Brien, 2015)
In-process damage & In-process expiry	Through the 5S program work is organised in such a manner that products are stored in such a manner that they do not disrupt processes which minimises the risk of damage on the line (Gupta & Garg, 2012). In addition, through office TPM and the 5S products are tracked and set in order to ensure the first in go first out (Madanhire & Mbohwa, 2015b)
Mis-feeds	TPM (through training and 5S) promotes better skilled machine operators better equipped to avoid and/or rectify situations that may cause material and time wastage due to incorrect machine operation (Fore & Zuze, 2010)
Cleaning and lubrication	Autonomous maintenance ensures that operators clean and lubricate their equipment on a daily basis before machine operation hence limiting this activity during operation (Afefy, 2013)
Waiting for parts/tools	Autonomous maintenance coupled with preventive and corrective maintenance ensure that faulty or worn components are replaced before they fail. At the same time critical components are kept in stock as part of the 5S and planned maintenance regime to ensure availability should failure occur (Kumar, 2016)
Machine/Equipment jams	Better maintained equipment is less likely to jam as cavities and pathways are cleaned regularly avoiding unwanted

	entanglement of interference (O'Brien, 2015)
Obstructed supply chain	Through the 5S program that comes with TPM, the flow of work on the production line is streamlined at all times (Gupta & Garg, 2012)
Blocked sensor	Routine inspections of equipment and machinery ascertain that such anomalies are identified and rectified in a timely manner (O'Brien, 2015)
Inefficient operators	TPM training and education promotes operator skills and work efficiency (Jaganure & Badiger, 2017). Further, autonomous maintenance encourages plant operators to be proactive in maintaining machinery and to take responsibility for its performance (Jaganure & Badiger, 2017).
Wear and tear of machinery and equipment	Autonomous maintenance keeps machinery in its optimal state or condition since operators undertake routine inspections whereby worn components are identified and replaced hence causing machinery to not operate whilst components are worn (Jaganure & Badiger, 2017).

The table above demonstrates how the various pillars of TPM can be employed to reduce and/or eliminate the various causes of OEE losses. It follows that manufacturing organisations must employ the techniques of TPM in order to improve and sustain their OEE and in so doing enhance organisational competitiveness (Swapnil, Jadhav, & Kewate, 2016).

2.7 Conclusion

OEE measures the performance of manufacturing plant and processes and it is the product of machine availability, quality rate and performance efficiency. These factors must be kept in their optimal state so as to maintain good OEE levels. It has been established that manufacturing organisations need to maximise their OEE in order to ensure that they remain competitive and the implementation of TPM is widely recommended for the achievement of this goal. TPM is a maintenance program that is comprised of pillars or strategies which enforce team oriented maintenance techniques through the empowerment of machine operators for small task maintenance activities. It also promotes the streamlining of manufacturing activities while focusing on the elimination of manufacturing losses which adversely affect OEE. It follows that an understanding of TPM and how it can be employed for the enhancement of OEE in manufacturing is necessary for industry practitioners as well as scholars for application in industry and academic reference respectively.

Chapter 3: Research methodology

The aim of this chapter is to outline the manner in which this research activity was executed including data collection techniques and data analysis methodology. The research method selection rationale is discussed here. Further, the assumptions made as well as restrictions in terms of available data and scope of the project are stated. The procedure followed to address the research questions is explained and so is the rationale behind the selection of this research method.

3.1 Company background

3.1.1 Overview

XYZ manufacturing company manufactures windows for bus, rail and pick-up trucks and are a leading sliding window manufacturer in Southern Africa. Having customers in the fast moving and quality conscious automotive industry, it is of great importance that XYZ manufacturing company keeps up with required product volumes as well as quality standards while offering competitive product prices. It can be deduced hence that it is imperative for the organisation to maintain optimal levels of OEE. At the beginning of the year 2018, the TPM implementation project was commenced as part of organisational strategy to reduce manufacturing costs in the OEM (original equipment manufacturer) manufacturing lines and this will be used as the empirical basis of this work.

3.1.2 Production line set-up

The line where this study produces aluminium framed sliding windows for an automotive company. The windows comprise of up to eighteen components, eleven of which are manufactured on various separate lines and the rest are bought out. Six machines are on the line performing different operations on the various components from high speed assembly, robotic bond application, temperature and humidity controlled bond curing, high pressure leak testing of the product and dimensional checking for quality purposes. This study focuses on this section of the line where the machines six are arranged as shown in the figure below:

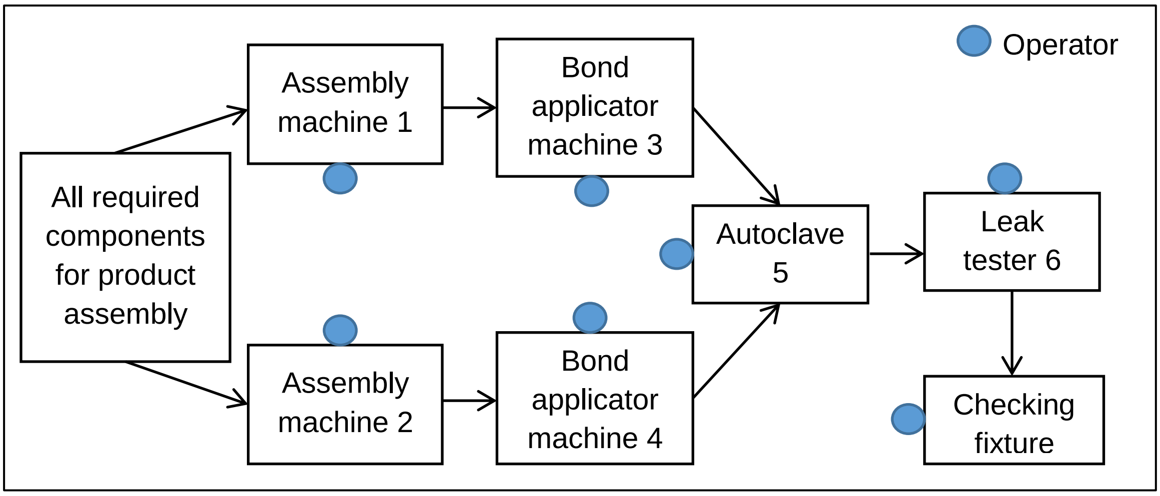


Figure 6: OEM line layout (XYZ manufacturing, 2017)

Seven components of the assembly are issued directly from the store and are booked out on a production order whereas eleven are pre-processed on other lines of the production plant. Further, at least seven operators work on this line for each respective station shown in the figure above. It is noted that disturbances at any one of the stations result in lowered production rates and/or quality issues which adversely affects organisational performance.

With reference to Figure 6 above, the components and parts required for the assembly of the products are received at assembly machines 1 and two where they are brought together in the required orientation as per the product requirements. All mechanical fasteners are implemented at this point as well as temporary fasteners which are removed after the curing of the bonding agent. With the assemblies held together by temporary fixes and mechanical fasteners, the assembly machines deliver the assemblies to the bond applicator machines 3 and 4. At the bond applicator machines sealant and bonding agents are squirted into the relevant areas through the use of robotic arms and automated dispensers. Thereafter the assemblies are manually loaded onto a conveyor belt which ferries the product into autoclave machine 5 for the sealant and bonding agents to cure. At the leak tester the product is checked for leaks by using high pressure water jets that are sprayed at regulated pressure and positions on incidence. If the product passes a dimensional check is done at the checking fixture before the product is packed away for dispatch.

3.1.3 Production line systems and components

Disturbances of the production process occur as a result of operator behaviour and/or machine component performance irregularities outlined in section 2.3 of

Chapter 2. It is noted that the machines shown above employ modern technology to facilitate high speed automation of the production process and as such, numerous technological systems, sub-systems and components are present. It follows that the operating condition of each component of the system may have detrimental effects to the performance of the entire line and must therefore be up-kept. The table that follows documents the common components of the six machines on the line which have the potential of affecting the performance of the machine and that of the production line at large:

Table 12: Machine components affecting performance (XYZ manufacturing, 2017)

	Assembly machine 1 & 2	Bond applicator machine 1 & 2	Autoclave	Leak tester
Sensors	X	X	X	X
Motors	X	X	X	X
Bearings	X	X	X	X
Programmable logic controllers (PLCs)	X	X	X	X
Gear boxes	X	X	X	X
Pumps		X	X	X
Power packs	X	X		X
Dies & tools	X			
Heat exchangers		X	X	
Chillers		X	X	
Gauges		X	X	X
Nozzles		X	X	X
Compressors		X	X	
Drives	X	X		X

It can be seen from the table above that there are numerous machine components that could potentially cause machine performance issues. The data collected on this line in terms of the parameters affecting the factors of OEE from July 2017 to October 2018 is to be employed for the case study of this research.

3.2 Research design

In order to address the research questions effectively, it is a matter of imperative that the research activity is planned and designed strategically. It follows that the research design should be structured in such a manner that suites the research questions (Yin, 2009).

3.2.1 Research methods

It can be exclaimed hence that the type of research questions posed by the researcher influence the research method selected (Odoh & Ihedigbo, 2014). Furthermore, theory states that the amount of control over behavioural occurrences that the researcher has as well as the focus on current as opposed to past events are also factors that determine the applicable research method (Yin, 2009). The table that follows depicts the different research methods with reference to the influencing factors discussed earlier:

Table 13: Various research methods for applicable conditions (Yin, 2009)

Research method	**Research question type**	**Requires control of behavioural events?**	**Focuses on current events**
Case Study	How, Why	No	Yes
Survey	Who, How many, Why, Where, What, How much	No	Yes
Experiment	How, Why	Yes	Yes
Archival Analysis	Who, How many, Why, Where, What, How much	No	Yes/No
History	How, Why	No	No

The research questions of this work are as follows:

1. What is the effect of Total Productive Maintenance incorporation on Overall Equipment Effectiveness?
2. How does the implementation of Total Productive Maintenance affect Overall Equipment Effectiveness in manufacturing?

With reference to the research questions and the preceding table, it can be concluded that the case study research method is most applicable. This is due to the fact this research activity aims to investigate the effects of the incorporation of TPM on OEE in manufacturing, elaborating how such effects are brought about and why specific stimuli result in said effects. As such, the control of behavioural events is rendered redundant for the purpose of this research but the contemporary situation in terms of the manufacturing process equipment and personnel would be of relevance in determining how TPM implementation affects OEE on an on-going basis.

This research activity is descriptive in nature and is designed to be deductive as conclusions were to be drawn from observed trends on an empirical basis as well as from literature (Creswell, 2009). Furthermore, secondary data was employed alongside interviews where documentation such as production data collected over time within the organisation was employed to investigate how the aspects that influence OEE were affected and continue to be affected by the implementation of TPM (Odoh & Ihedigbo, 2014; Yin, 2009).

Research bias

It is of great importance that the results of this research activity are not influenced by researcher bias. In order to ensure that no bias sways the results of this work, interviews were to be carried out by the researcher in line with the case study that was to be undertaken. However, in order to generate reliable information from the interviews, a structured questionnaire design process would be undertaken and this is discussed further in the sections that follow.

3.2.2 Scope of the research project

The aim of this research is to demonstrate where and how the relevant aspects of total productive maintenance can be employed to exploit opportunities to enhance the overall equipment effectiveness of production facilities and in so doing define a framework for manufacturing firms to employ for the sustenance and improvement of plant overall equipment effectiveness. As such, in order to justifiably answer the research questions, peer-reviewed literature was gathered in a plea to ascertain how TPM affects OEE in the manufacturing industry.

However, in order to validate theoretical findings, it is necessary that an empirical study (by method of case study) on how TPM has affected OEE in an actual manufacturing environment is done. As such, production data over 16 months (July 2017 to October 2018) was collected at XYZ manufacturing company for a production section where TPM was implemented. It follows that the period prior to the implementation of TPM (July 2017 to January 2018) will be contrasted against the period after TPM implementation (February 2018 to October 2018). The timeline shown in the figure that follows depicts the period under study in this work, citing when TPM implementation took place:

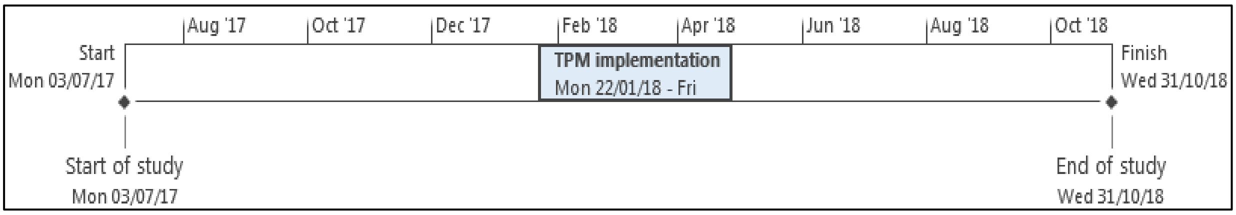


Figure 7: Study duration timeline

3.2.3 Sources of evidence

Data collection instruments employed for the purpose of the work are as follows:

- Documentation – production reports from July 2017 to October 2018 for the manufacturing line where the case study is to be conducted were put into consideration as crucial elements influencing the results of the study could possibly be picked up from them. Data that was employed from the production reports included the following:
    1. Absenteeism rates
    2. Idling time
    3. Changeover time
    4. Delays
    5. Stop time
    6. Rework time
- Archival records – secondary data related to the factors affecting OEE in the manufacturing company was collected (downtime figures, production count, reject rates, breakdowns, planned downtime). The table that follows documents the available data for the evaluation of OEE before and after the implementation of TPM on the OEM line as prescribed by literature in subsection 2.2.4 of Chapter 2. It is noted that this data was collected in the organisation for the purposes of tracking and monitoring plant performance and shall be used for the evaluation of OEE in this work.

Table 14: Data records for OEE (XYZ manufacturing, 2017)

Production count/total number of products
Reject count
Planned downtime
Actual downtime
Machine set-up time
Tool change-over time & frequency
Actual operating time

Machine processing time
Cycle time
Number of breakdowns
Breakdown repair time
Time between failures

It is noted that the required data as listed in the table above were collected before and after TPM implementation and these would be processed to attain OEE before and after TPM was put in place on the respective production line. It follows that in order to gauge the impact of TPM implementation on the OEE of the production line in question the behavioural trends of the factors of OEE before TPM implementation will be compared to those after TPM implementation thereby addressing the first research question. Once OEE has been computed and trends thereof drawn, this will be compared to theoretical predictions regarding the implications on OEE of the implementation of TPM in the manufacturing company. From this comparison, the research questions can be addressed where theory agrees with the results and inconsistencies between the two can be analysed thereof.

- Interviews – in order to eliminate bias and provide a more neutral assessment of the impact of TPM implementation on the OEE of the OEM manufacturing line in question, interviews will also be conducted with relevant personnel operating on this line. It is noted that the decisions on who to interview and what questions to ask them could have detrimental effects on the success, reliability and value of the exercise to the research being undertaken (Louis, Pruitt, & Rugeley, 2005). As such, it is imperative that the interview questionnaire is managed delicately all through the process.

  Theory suggests the structured design of the interview process for the purpose effective research strategy and this follows a series of steps as listed below (Louis, Pruitt, & Rugeley, 2005):

  1. Define the goals of the interview exercise
  2. Define the interviewees
  3. Choose methods of reaching interviewees
  4. Establish content of the interview
  5. Carry out the interview and collect relevant data
  6. Pilot and validate the interviews
  7. Conduct the interview and capture data
  8. Analyse data

Section 3.4 discusses in detail how the structured design of the interview process would be undertaken.

3.3 Case study OEE factors evaluation

This section discusses how the data from production reports and records of the required data for OEE computation as presented in Table 14 above will be processed into results usable for this research activity. It is noted that the strategy used here is to determine OEE factors before and after TPM implementation and compare plant performance for the two aforementioned periods based on the factors of OEE computed, OEE losses and ultimately OEE behaviour over the study period.

3.3.1 Available data

Performance indicators monitored at XYZ manufacturing company include quality rate, machine efficiency and downtime and these are in line with the theory presented in Table 1 which documents the factors of OEE. It follows that data relevant to the determination of the three parameters of OEE is recorded on an on-going basis for monitoring, control and continuous improvement purposes i.e. the data presented in Table 14 is recorded on a daily basis at the OEM line so as to monitor the performance of the line.

Table 4 in Chapter 2 defines the various aspects that lead to OEE losses as well as under which OEE factor they fall. It follows that data that is selected for the purpose of this research activity falls under at-least one aspect of OEE losses presented in Table 4. This research is focused on the OEM (original equipment manufacturer) production line section of XYZ manufacturing company where-by data presented in Table 14 above is available for the period of sixteen months during which TPM was introduced. The data that was collected at XYZ manufacturing company that is in line with theory in Table 4 of the literature as shown in Table 14 was employed to compute the OEE parameters documented in the table that follows as they are defined in Table 3 of the literature:

Table 15: OEM line available data (XYZ manufacturing, 2017)

$total\ shift\ time$
$planned\ down\ time$
$actual\ downtime\ and\ stop\ time$
$theoretical\ cycle\ time$
$actual\ cycle\ time$

$actual\ processing\ time$
$operating\ time$
$total\ number\ of\ parts$
$number\ of\ defective\ parts$

The records of the data collected at XYZ manufacturing company as presented in Table 14 above will be used to extract and compute the parameters of OEE documented in the table above. Once these parameters have been evaluated, the variables of the factors of OEE can be determined using equations [8], [9], [10] and [11] as shown in Table 4 of Chapter 2. The variables of the factors of OEE to be determined as shown in [8] to [11] are the following:

- Operating time
- Operating speed rate
- Net operating rate
- Loading time

respectively.

3.3.2 OEE computation

The computation of OEE needs to be executed accurately in order for the manufacturing organisation to obtain reliable and meaningful results (Singh, Shah, Gohil, & Shah, 2013). As such, it is of great importance that the availability, performance efficiency and quality rate of the OEM production line at XYZ manufacturing company is determined through peer reviewed methods. Theory demonstrates how the computation of OEE should be done and this was adopted for the data processing exercise of the aforementioned OEM line at XYZ manufacturing company.

With the variables that affect the factors of OEE, it follows that the OEE factors can be computed using equations [1], [2] and [3] respectively as shown in the table that follows:

Table 16: Calculation of OEE factors (Singh, et al., 2013)

OEE factor	Formula
$Availabilty\ (A)$	$\frac{operating\ time}{loading\ time}$
$Quality\ Rate\ (QR)$	$\frac{(total\ number\ of\ parts) - (number\ of\ defective\ parts)}{total\ number\ of\ parts}$
$Performance\ Efficiency\ (PE)$	$(operating\ speed\ rate) \times (net\ operating\ rate)$

It follows that with the OEE factors, the OEE is then computed using equation [4] given in Chapter 2 above.

$OEE = A \times QR \times PE$

(Singh, Shah, Gohil, & Shah, 2013)

3.4 Interview questionnaire design

3.4.1 Goals of the interviews

The goal of the interviews is provide evidence that can be employed to address the research questions. Through the interviews information will be collected from individuals who were involved in the day to day operation at the OEM line during the period that is being studied. Such information will focus on the performance of the production line before TPM was implemented and will go on to look at what TPM strategies may have led to certain changes in plant performance after the implementation of TPM. It follows that from this information, unbiased deductions can ultimately be made regarding how the implementation of TPM affected OEE and this can be contrasted against literature gathered for validation or otherwise (Louis, Pruitt, & Rugeley, 2005). In addition, data collected through the interview process will eliminate researcher bias and can be used to confirm conclusions from the case study exercise (Louis, Pruitt, & Rugeley, 2005).

3.4.2 Definition of interviewees

The people to be interviewed are those that were directly involved in the day to day operation of the OEM line as they would have first-hand information about the performance of the line before and after TPM implementation. Furthermore, such individuals would have been directly involved in the implementation of TPM strategies as they would have either been the ones to align operating behaviours with TPM strategies or the ones to have overseen and enforced such behavioural changes. It follows that three machine operators from the OEM line as well as two supervisors and the line manager will be interviewed. Two artisans from the maintenance department will also be interviewed as they are also expected to have valuable input to this exercise. Eight people in total from the OEM production line will be interviewed including two junior management personnel and one mid-management individual (two line supervisors and the line manager respectively).

3.4.3 Method of reaching the interviewees

In order to obtain useful comprehensive information a standard set of questions will be drawn up and posed to all the interviewees. By so doing, a comprehensive amount of information can be collected and this can be compared to the case study results in a plea to eradicate researcher bias.

3.4.4 Interview content

The questions to be posed are directly in line with the research questions of this work and are documented in Appendix B. It is noted that the questionnaire focuses on where and how the various techniques of TPM were implemented and what the effects of such implementation were on the losses of OEE and ultimately plant performance as defined in OEE.

3.4.5 Administering the interview

The interviews will be undertaken in person as this will be convenient for both the researcher and the interviewees as immediate responses would be given by the interviewees. Furthermore, any misunderstandings and/or confusion can be addressed promptly.

3.4.6 Piloting and validating the interviews

In order to ensure that the questionnaire is fair and understandable, it would be tested on three individuals from a separate production line where TPM was also implemented at a later stage. It follows that the questionnaire was taken successfully by all three personnel without any problems related to ambiguity of questions or failure of interviewees to understand what is being asked.

3.4.7 Conducting the interview and data input

Interview data collected will be graphed so as to promote the ease of comparing the results as well as that of identifying trends in the data. On the other hand, descriptive data will be tabulated and compared after which deductions will be made based on the shared interviewee views or otherwise.

3.4.8 Interview data analysis

Once data from the interviews has been processed and presented as meaningful results, it will be compared to results from the case study. Interview data collected will be graphed and tabulated and conclusions will be drawn regarding the effects of the implementation of TPM on OEE in line with the answering of the research questions.

The comparison of results will encompass how the performance of the production line was affected by the implementation of TPM as per the results of the case study as well as deductions made from interview results. Similarities and inconsistencies thereof will be identified and analysed before being referred to theoretical predictions as presented in literature.

3.4.9 Interview questionnaire

The table that follows documents the interview questions that were drawn up to address the research questions and outlines how each interview question is meant to address the respective research question.

Table 17: Interview questionnaire design

#	**Research question 1** - What is the effect of total productive maintenance incorporation on overall equipment effectiveness?	**Research question 2** - How does the implementation of total productive maintenance affect overall equipment effectiveness in manufacturing?	**Rationale** - How the interview question addresses the research question
1	Interview question 1 aims to ensure that all participants were actively involved at the OEM line from the period before and that after TPM implementation hence does not address any of the research questions.		
2	In your opinion, which of the following losses of OEE significantly hampered/lowered/limited productivity of your line prior to the introduction of TPM?		This question creates the foundation to exploring what the effects of TPM implementation on OEE are through the initial identification of losses that affected plant performance before TPM was employed

3		Based on your knowledge gained through on the job experience and TPM training, which pillars of TPM were implemented on the OEM line? Briefly describe how these were put in place.	The 3rd interview question examines which pillars of TPM were implemented and how this was done so as to establish a platform for the probing of how such pillars would have caused certain results
4a	Please indicate which TPM pillars you believe reduced the various OEE losses listed below.		Interview question 4a addresses research question 1 by investigating what the effect of the various techniques of TPM was on OEE losses
4b	In your opinion, were the following losses of OEE reduced, increased or not affected by the implementation of TPM?		Interview question 4b aims to evaluate how OEE was affected by the implementation oif TPM hence directly addressing research question 1
5	`	Following your response in Question 2, briefly state how, in your opinion the incorporation of TPM would have resulted in the increase, decrease or otherwise of each respective OEE loss.	Interview question 5 addresses the 2nd research question as it explores the rationale behind the effects of the TPM pillars on OEE losses given prior (i.e. in question 4)

The full interview questionnaire employed for this research is documented in Appendix B of this document.

3.5 Data processing

In order to justify the validity of the OEE factors computed and archived in the organisation, raw data recorded on the production line was drawn from administrative archives and used to evaluate the downtime, quality rate and machine efficiency using the procedure presented in section 3.3 above. Appendix A documents how the parameters collected at the OEM line of XYZ manufacturing company were employed to evaluate the three factors of OEE and in turn the OEE for the month of April 2018. It follows that with the relevant data collected in the organisation from July 2017 to October 2018, the same procedure was employed for the computation of OEE for the 16month period of this study. It was also established that the procedure employed in the organisation bore the same results as that presented in section 3.3 and demonstrated in Appendix A.

3.6 Data analysis

The analysis of data for this study focused on the how the relevant factors that affect OEE are influenced by the implementation of the various pillars and strategies that come with the implementation of TPM. It follows that a quantitative analysis would be undertaken on the OEE parameters while a descriptive approach would be employed for the logic behind how TPM incorporation affected OEE in the organisation.

3.6.1 Analysis for research question 1

In order to address the first research question, production data before the implementation of TPM will be compared to data after TPM was put in place. It follows that the first research question looks at what the specific effects or results of TPM implementation on OEE are. In order to establish this, the factors of OEE will be computed over the period under consideration and the results prior to and after TPM implementation will be compared and this will be referred back to literature. The figure that follows depicts how research question one will be addressed:

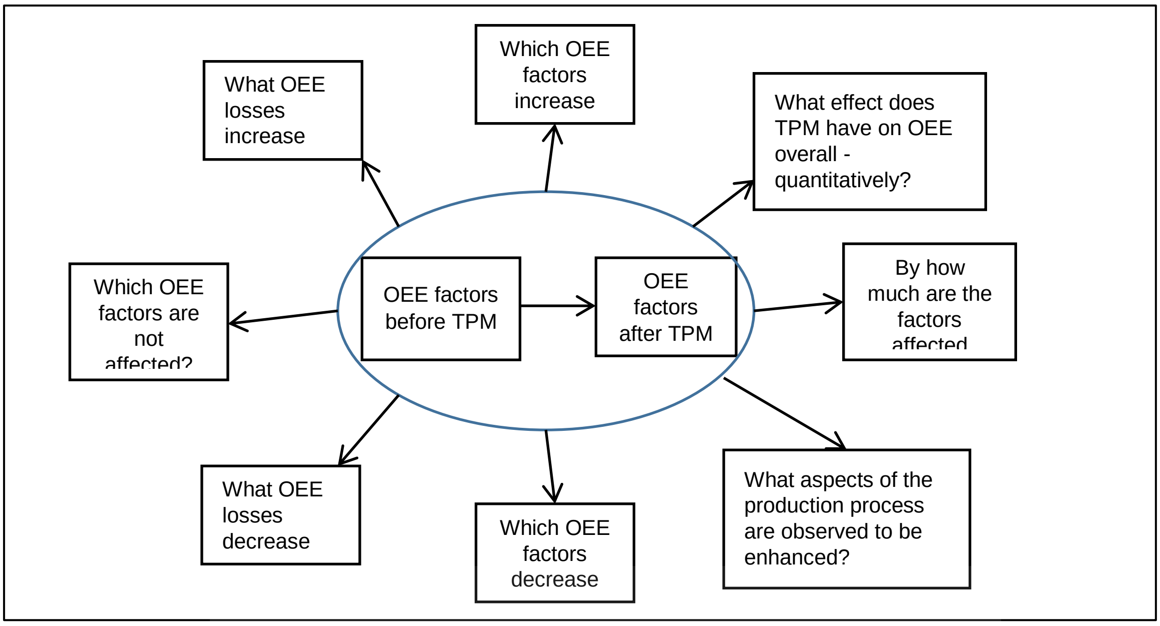


Figure 8: Analysis of research question 1

In order to clearly depict trends of the effects of the employment of TPM strategies at XYZ manufacturing company, it was essential for the critical aspects of OEE to be graphed against time from the time approaching TPM implementation to after its implementation.

3.6.2 Analysis for research question 2

The second research question focuses on investigating the logic behind how the effects of TPM on OEE determined in research question 1 are brought about. This will be achieved by analysing the applicable techniques of TPM that were incorporated to the OEM line in conjunction with the observations and production reports obtained from the administrative records of the OEM line at XYZ manufacturing company. The rationale of how relevant TPM techniques enhance respective aspects of OEE or otherwise will then be deduced with reference to literature. This analysis will dwell on the how the techniques of TPM affect the relevant losses of OEE as presented in literature alongside organisational findings.

A fair amount of time after TPM was put in place was also considered so as to demonstrate the longevity or otherwise of the effects thereof. The aspects of TPM that were put in place at XYZ manufacturing company during the period in question as well as other relevant specifics in relation to said incorporation are documented in chapter 4 that follows.

3.7 Assumptions and limitations

It is apparent that due to various policy, temporal and legal restrictions this work was subject to certain limitations which would have affected the extent to which the research activity stretched. It follows that in light of the aforementioned restrictions, certain assumptions had to be made.

3.7.1 Assumptions

- Raw data recorded on the production line was assumed to be accurate and correct
- No new data will be discovered that is relevant to this study for the time period under consideration
- Information rendered by participants regarding the TPM implementation exercise is true and free of bias

3.7.2 Limitations

- Production lines and products used for this study are not specified due to organisational policy
- Raw production data used in this study is not published in this work and access is restricted to any third party so as to sustain customer confidentiality
- The scope of the study was limited to one production line due to time and resource margins

3.8 Ethical considerations

3.8.1 Permission to use organisational data

In order to undertake this study at XYZ manufacturing company, written permission was issued to the researcher from relevant management parties and the contents of this document are available to be refereed by them.

3.8.2 Confidentiality statement

Raw data from the organisation is not presented in this work. Further, the identities of the participants of this study have been kept confidential and information about the customers of the organisation whose product is manufactured here as well as the product itself remain anonymous and protected.

3.8.3 Consent

All the participants of this research activity were informed of the nature of the work being undertaken and were informed that such participation is voluntary and optional. It is remarked that the participation of all individuals in this work was in their full knowledge and complete consent.

3.9 Conclusion

The approach and strategy employed to address the research questions of this work is outlined in this chapter. The case study research approach was deemed most appropriate for this research activity. Production records and reports, archival records alongside interview questionnaire are the sources of evidence to be employed. The factors of OEE will be computed from the variables of OEE factors after-which the OEE factors will be employed to determine the OEE for the production line in question so as to assess the organisational performance from the period before TPM implementation to that after the TPM program was introduced. By so doing, the effect of implementing TPM on OEE can be gauged on a quantitative basis. The rationale behind how such effects come about can then be analysed with reference to observed trends and organisational production reports. The structured interview questionnaire was introduced in order to avoid researcher bias in this exercise. Confidentiality and ethical considerations with respect to the parties involved in this research have been exhausted.

4 Data collection, analysis and results

In this section, data collected from the interviews is presented in such a manner that it can be interpreted for comparison against results obtained from production data and ultimately be evaluated against theoretical principles. The manufacturing losses together with their origins are specified and analysed for the period leading to the implementation of TPM as well as that following it. TPM strategies employed to address the manufacturing losses and in effect raise or enhance OEE of the manufacturing process or otherwise are outlined. Other relevant aspects that could have had an effect on the performance of the equipment and machinery as well as man-power in this line are also deliberated in this part of the research. The various factors computed for the XYZ manufacturing company OEM line that affect OEE are graphed against time for the period July 2017 to October 2018. The trends thereof are discussed and analysed with reference to the TPM strategies that were employed.

4.1 Interview data analysis

As outlined in Chapter 3 of this work, nine interviews would be conducted in order to gather valuable information pertaining to the implementation of TPM at the OEM line of XYZ manufacturing company. The individuals that were primarily involved in the day to day operation of the OEM line would be targeted for the interviews and a total of nine individuals including line operators, supervisors and maintenance personnel were among the interviewees also as discussed in Chapter 3.

4.1.1 Interview question 1 - was the interviewee present when TPM was implemented?

The first interview question was as follows:

Question 1
Were you present when the TPM program was implemented at the OEM line between July 2017 to October 2018?
Yes ☐ No ☐

The aim of this question was to disallow individuals who were not working at the OEM line of XYZ manufacturing company from partaking in this exercise as their responses would potentially be biased or based on invalid information. All the respondents answered 'Yes' to this question hence all nine interviewees continued to complete the interview.

4.1.2 Interview question 2 - losses that affected productivity

The second interview question was as follows:

Question 2a In your opinion, which of the following losses of OEE significantly hampered/lowered/limited productivity of your line prior to the introduction of TPM? Please indicate with an X in the box whether the listed loss had a negative effect (Y –Yes) or if it did not contribute to the performance (N – No)

This question listed the theory prescribed losses of OEE in the manufacturing environment. The interviewees would indicate which of the losses they had encountered during the period before TPM was implemented at the OEM line of XYZ manufacturing company. By so doing, the theoretical losses of OEE would be validated by industry experience. At the same time, inconsistencies would be identified and the logic behind them analysed.

The graph that follows in Figure 9 shows for each loss of OEE, the percentage of respondents who had experienced the respective loss versus those that responded that they did not think that the loss had adversely affected plant performance during the period in question.

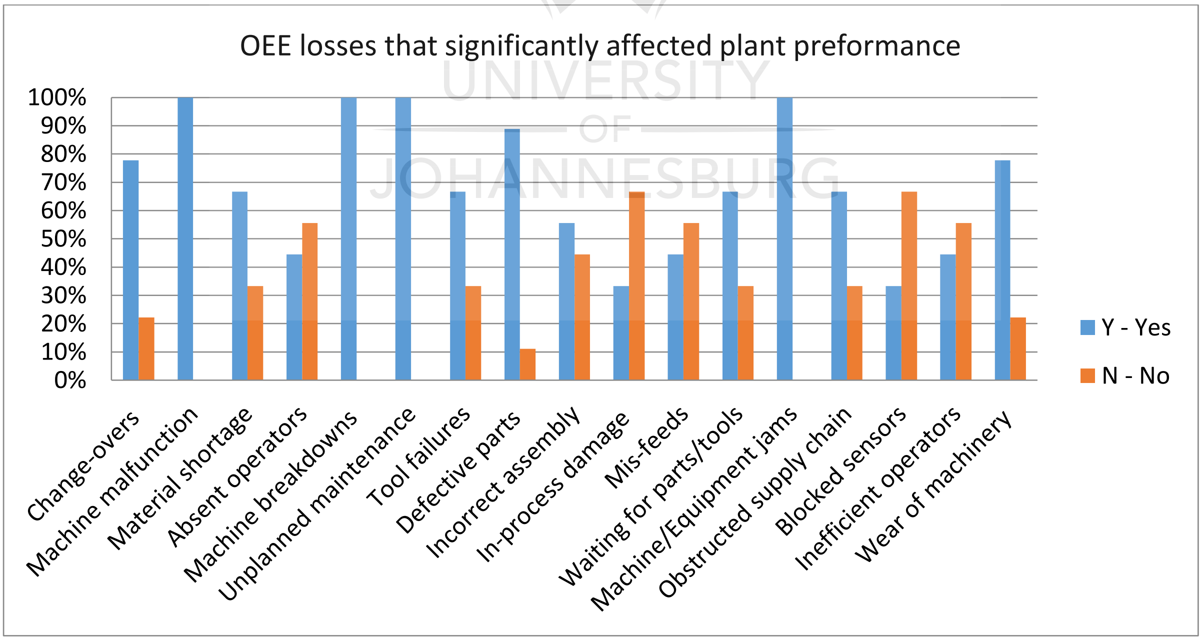


Figure 9: Interview question 2 - losses that affected productivity

It can be seen from the graph above that at-least fifty per-cent of the interviewees attested to the presence of twelve of the seventeen losses listed prior to the implementation of TPM. In this regard the interview results are in-line with what literature dictates. On the other hand, the losses that less than half of the respondents had experienced include the following:

- Absent operators
- In process damage
- Mis-feeds
- Blocked sensors
- Inefficient operators

Appendix C documents the absenteeism records of the production line. It can be seen that attendance is consistent hence lowered plant performance cannot be attributed to it. Further, due to the 5S regime having been incorporated on the production line in question prior to the period under study it follows that the work environment was kept clean and organised consistently therefore losses related to in process damage, inefficient operators and disorganisation of the production flow would have been lowered.

It is noted that despite the fact that less than fifty per cent of the interviewees listed in process damage and mis-feeds as OEE losses that hampered plant performance, these losses could have been present. This is due to the fact that since a considerable ratio of the respondents were operators, it is possible that bias may have swayed the results in terms of the responses to the presence of operator inefficiency. Nevertheless, around 40% of the respondents alluded to the presence of inefficient operators, mis-feeds and in process damage as OEE losses that negatively affected plant performance which is in agreement with literature.

It can be deduced that due to the clean working environment and relatively new machinery and equipment on the OEM line at the time, issues such as blocked sensors may not have arisen. However, considering that only maintenance personnel dealt with breakdowns, operators may not have been aware of the causes of machine mal-functions and breakdowns. It follows that the low ratio of interviewees that confirmed the presence of blocked sensors as a significant loss of OEE prior to the implementation of OEE can be attributed to this.

4.1.3 Interview question 3 - how TPM pillars were implemented?

The third interview question was as follows:

Question 3

Based on your knowledge gained through on the job experience and TPM training, which pillars of TPM were implemented on the OEM line? Briefly describe how these were put in place.

Interview question 3 aimed to investigate which of the various pillars of TPM were actually implemented at the OEM line of XYZ manufacturing company. Further, it also explored the manner in which each respective pillar was integrated with the production process in order to evaluate how the effect of the pillar on the losses of OEE would have been brought about.

In order to extract conclusive information, the responses to interview question 3 were documented and similarities as well as patterns in the responses were explored. It follows that where at least 4 of the 9 respondents attested to a particular theme, this would be considered and analysed for inclusion in the summary of responses. Further, where at-least two respondents alluded to a particular theme, this would be verified with the interviewees before consideration and further analysis for inclusion in the summary of responses. However, where less than two respondents attested to a theme, this was scrutinised against theory and verified with the interviewees before consideration.

For example, all the interviewees listed autonomous maintenance, planned maintenance, education and training, equipment and process improvement, early management of new equipment, quality maintenance and office TPM as the TPM pillars that were implemented at the OEM line of XYZ manufacturing company over the time period in question. It follows that the aforementioned pillars of TPM were all included as part of the summary of responses presented in Table 18 below. However, one respondent had given that in addition to the seven pillars mentioned above, safety and health was also introduced as part of the TPM programme. After further investigation and verification with all parties involved, it was established that safety and health was not part of this exercise. Further, it is noted that responses that were not logical were disregarded. Table 18 that follows documents the summary of the responses to this question:

Table 18: Interview question 3

#	**Autonomous Maintenance**	**Equipment & Process Improvement**	**Planned Maintenance**	**Education & Training**
1	TPM team was established from	TPM goals communicated to all	Planned maintenance had	Training provided to all

	management down to operator level in the organization. Accountability processes put in place for all involved personnel	management and TPM team as per organizational strategy	already been part of the maintenance strategy; but due to personnel being saturated by breakdowns-it was not effective	employees involved in the production process in a plea to effect understanding and familiarity with TPM ideology and theme
2	Daily checking and condition monitoring checklist for equipment	Efficiency, Quality and Availability data collected daily and trended to monitor and communicate performance	All maintenance information on machines in OEM line gathered, i.e. maintenance history, operational manuals, spare parts usage	All operators and maintenance personnel sent for training on machine operation and best maintenance practices
3	Issues with equipment discussed and resolved in daily TPM meetings	Improvement opportunities for the 3 OEE aspects discussed in TPM meetings; action plan accountability processes established	Critical, Key and Non-critical equipment defined by entire TPM team and Critical equipment prioritized for preventive maintenance tasks	Knowledge deficiencies and skills gaps discussed in TPM meetings and remedial action taken by accountable parties
4	Daily maintenance task (lubrication, cleaning, etc.) checklist for operators executed exhaustively and	Corrective maintenance adopted as main maintenance strategy with monitoring of repeated component failure by maintenance and engineering teams	Non-critical and Key equipment substituted for when gaps exist; spares for critical equipment tracked effectively and kept in stock at all times at	All employees made aware of the relationship between plant maintenance, productivity and organizational performance to ensure all understand their

			agreed upon stock levels	role in the process
5	Production supervisors and higher level TPM personnel empowered to stop production whenever corrective action is required	Baselines/Thresholds established for OEE parameters (as a guide to gauge plant performance at every work station on OEM line	Preventive maintenance frequency and strategy evaluated by all TPM team members and effected by designated maintenance personnel	At-least 3 store-men sent for ERP system training (SAP warehousing) so as to relieve pressure on material store in terms of issuing capacity (1 store-man) part of TPM team
	Quality Management	**Office TPM**	**Early Management of New Equipment**	
1	Reject rate baselines put in place in the OEM line and quality performance monitored and communicated to entire organisation	Mainly looked at streamlining the issuing of material from store to OEM line as heavy delays were experienced here	Information on existing machinery availed before the implementation of new plant so as to assure that past mistakes are not repeated	
2	Quality issues arising on the line are discussed in daily TPM meetings and corrective actions implemented in correct accountability lines	TPM team identifies unnecessary tasks in the issuing of raw materials from store and such tasks were relegated (e.g. inspection of packaged extrusions)	All operators and maintenance personnel sent for training before new equipment is implemented	
3	Quality management processes	All tedious paperwork that does not add value to the final	Past design issues deliberated by	

	streamlined on the line (e.g. checking fixtures instead of manual measurement of parts)	product computerised where necessary otherwise scrapped	TPM team and operators to ensure ease of operation and maintainability of systems	
4	Continuous improvement of quality management systems put in place and improvement opportunities deliberated by entire team	All materials stored in defined locations in the warehouse also reflecting on ERP system. Non-moving stock scrapped or quarantined to allow ease of access in and out of store		
5		Housekeeping in store monitored by accountable personnel, delays on OEM store caused by material issue deliberated in TPM meetings		

4.1.4 Interview question 4 - TPM pillars that reduced specific OEE losses

Interview question 4a was as follows:

Question 4a Please indicate which TPM pillars you believe reduced the various OEE losses listed below. Indicate with a cross in the box of each pillar that reduced the corresponding loss.

This question was meant to investigate which losses of OEE were reduced by each respective pillar of TPM implemented. Following interview question 3 which probed which pillars of TPM were implemented, question 4a goes on to look at which pillars are deemed to have had an impact on specific losses of OEE. The graph that follows shows the percentage of respondents stating the losses of OEE that were reduced by the TPM pillars listed below:

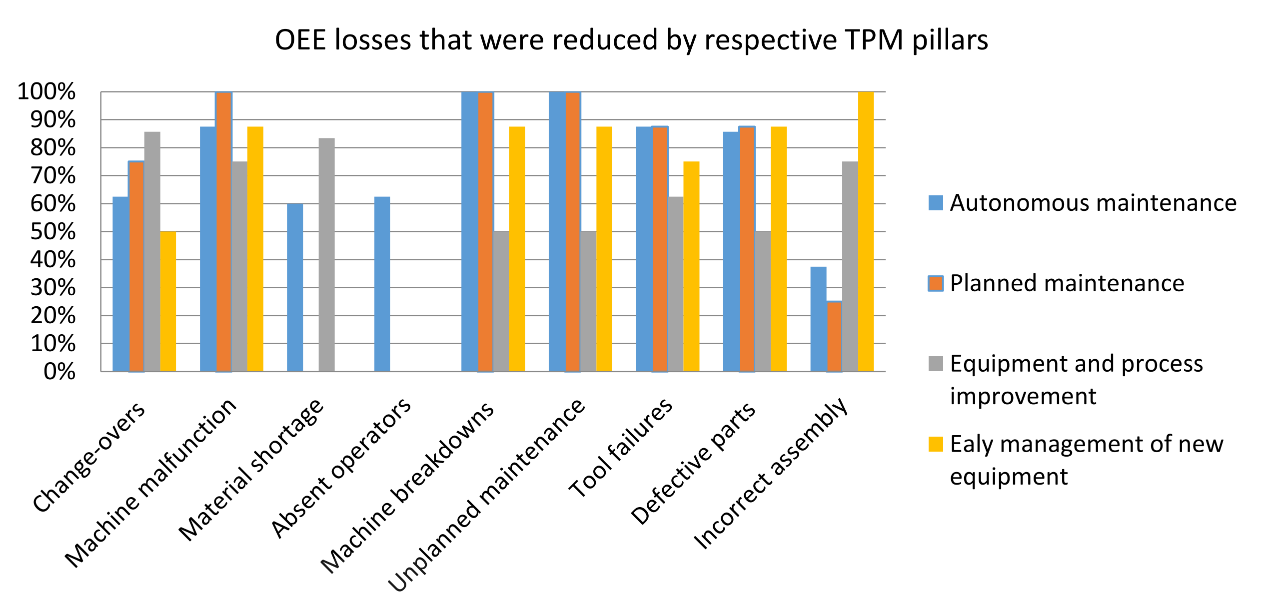
- Autonomous maintenance

- Planned maintenance
- Equipment and process improvement
- Early management of new equipment

In order to establish the percentage of interviewees stating that a particular loss was reduced by a certain pillar of TPM, the number of respondents marking with a cross that a respective TPM pillar reduced a respective OEE loss is divided by the total number of respondents and then multiplied by 100%. The total number of respondents is defined here as all respondents that either placed a cross the box or left it blank. The interviewees that marked with a circle to indicate that they were unsure of the effect of a certain TPM pillar on an OEE loss were not included so as to avoid sway of results as a result of interviewee lack of knowledge in that regard.

For example, if 5 of 9 interviewees responded that autonomous maintenance reduced the frequency of breakdowns and no interviewees indicated that they were unsure then the percentage is evaluated as follows:

$$PERCENTAGE = \frac{5}{9} \times 100\% = 56\%$$



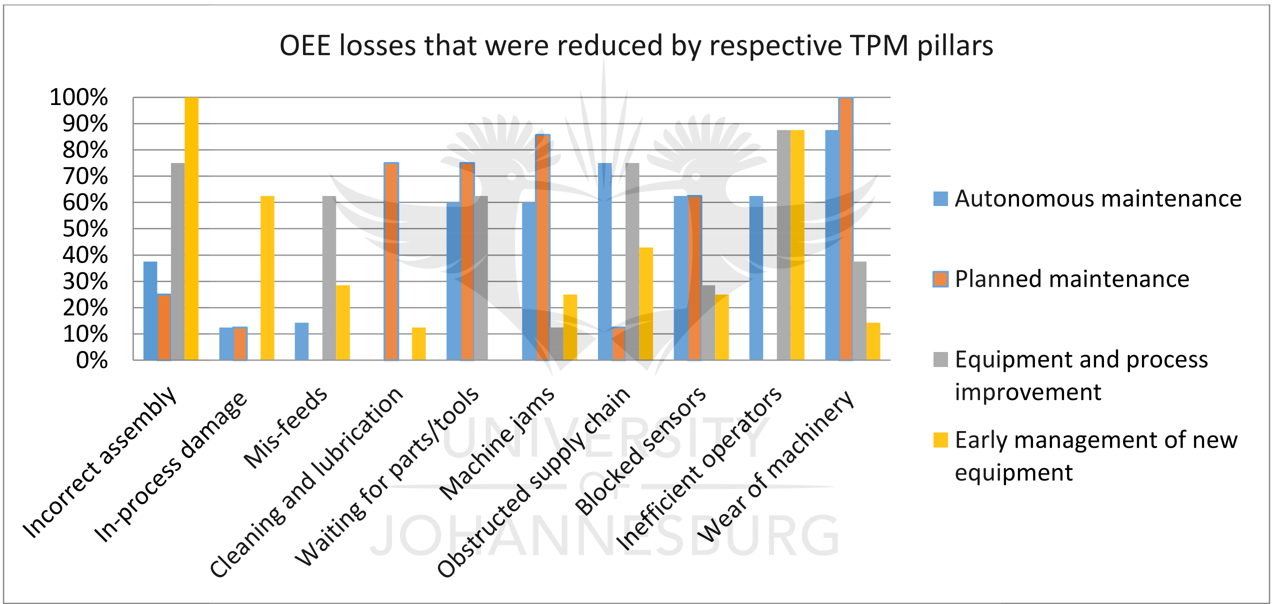


Figure 10: Interview question 4a

It can be seen in Figure 10 above that at-least 50% of the respondents indicated that the first four pillars of TPM listed (i.e. autonomous maintenance, planned maintenance, equipment and process improvement and early management of new equipment) reduced all of the losses of OEE listed below:

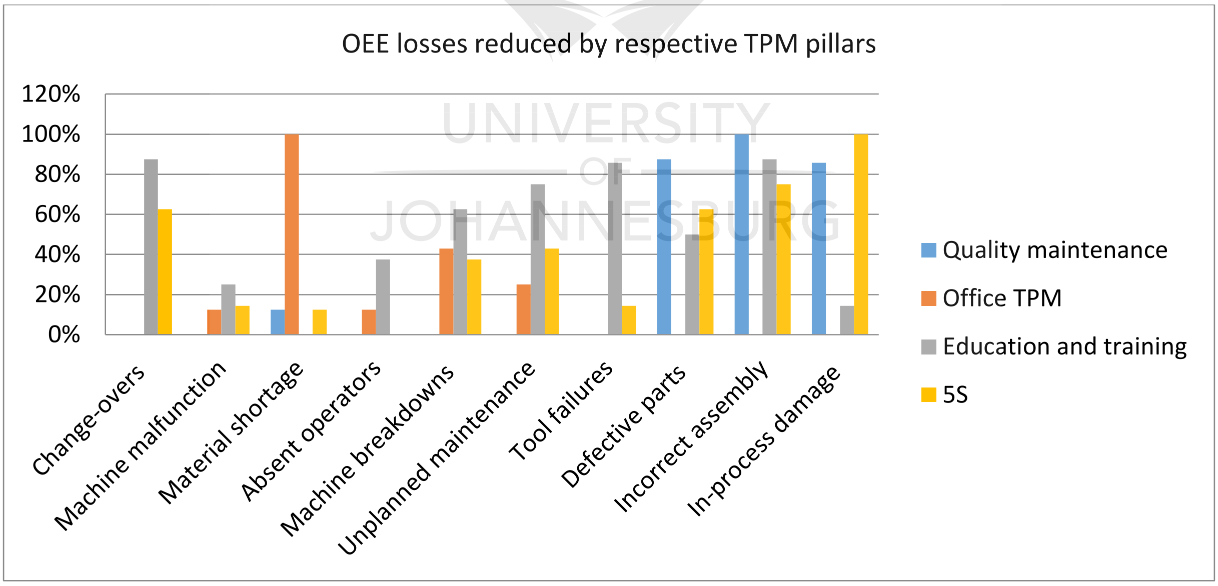
- Changeovers
- Machine malfunction
- Machine breakdowns
- Unplanned maintenance

- Tool failures
- Defective parts

On the other hand, autonomous maintenance was found to have also reduced absenteeism, material shortage, machine jams, waiting for parts, obstructed supply chain, blocked sensors, inefficient operators and wear of machinery which is in line with theoretical predictions presented in literature. Planned maintenance reduced additional OEE losses including waiting for tools, cleaning and lubrication losses, machine jams, blocked sensors and wear of machinery. Equipment and process improvement had a positive impact on other losses of OEE including material shortage, incorrect assembly, mis-feeds, waiting for parts, obstructed supply chain and inefficient operators. Lastly, early management of new equipment reduced additional OEE losses namely incorrect assembly, in-process damage, and in-efficient operators. It follows that the reasoning behind how the pillars of TPM affect the respective losses of OEE is explored in interview question 5.

The figure that follows shows the percentage of respondents stating the losses of OEE that were reduced by the TPM pillars listed below:

- Quality maintenance
- Office TPM
- Education and training
- 5S



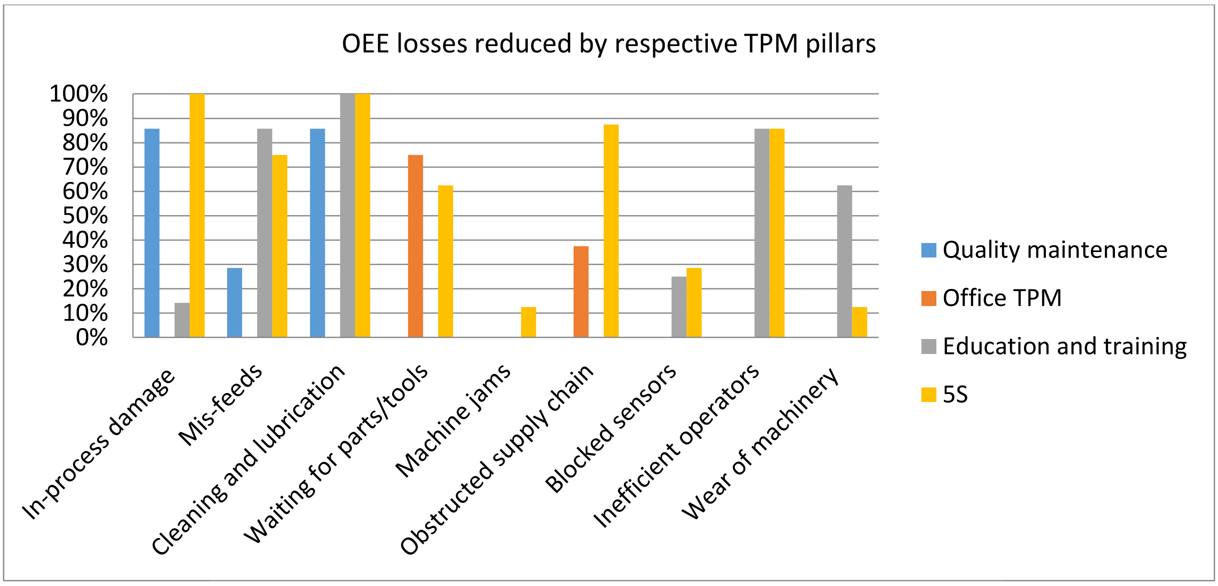


Figure 11 : Interview question 4a

It can be seen from Figure 11 above that the 5S regime reduced the following losses of OEE as at-least 50% of the interviewees attested to this:

- Change-overs
- Defective parts
- Incorrect assembly
- In process damage
- Mis-feeds
- Cleaning and lubrication losses
- Waiting for parts/tools
- Obstructed supply chain
- Inefficient operators

It can be seen from section 2.5.3 of Chapter 2 that the results of the interviews are in line with literature in this regard. On the other hand, at least 50% of the interviewees responded that quality maintenance regimes reduced defective parts, incorrect assembly, in-process damage and cleaning and lubrication related losses. Further, education and training was found to have a positive impact on all of the losses of OEE listed below:

- Change overs
- Machine breakdowns
- Unplanned maintenance
- Tool failures
- Defective parts

- Incorrect assembly
- Mis-feeds
- Cleaning and lubrication losses
- Inefficient operators
- Wear of machinery

This is consistent with literature since education and training promotes a better skilled work force which is more competent and makes less human error related mistakes on the production line. It can be read from the graph that office TPM reduced the instance of waiting for parts and material shortages which also agrees with theoretical predictions and outlined in Table 10 in the literature section of this work.

The second part of the fourth interview question was as follows:

Question 4b
In your opinion, were the following losses of OEE reduced, increased or not affected by the implementation of TPM?

The aim of interview question 4b was to evaluate what the impact of TPM implementation was on the losses of OEE on the OEM line of XYZ manufacturing company. The interviewees were to indicate which losses of OEE they found to increase, decrease or remain constant with the adoption of the TPM techniques on the production line during the period when TPM was implemented.

Figure 12 below shows the percentages of respondents who either selected that the loss in question was reduced, increased or remained constant:

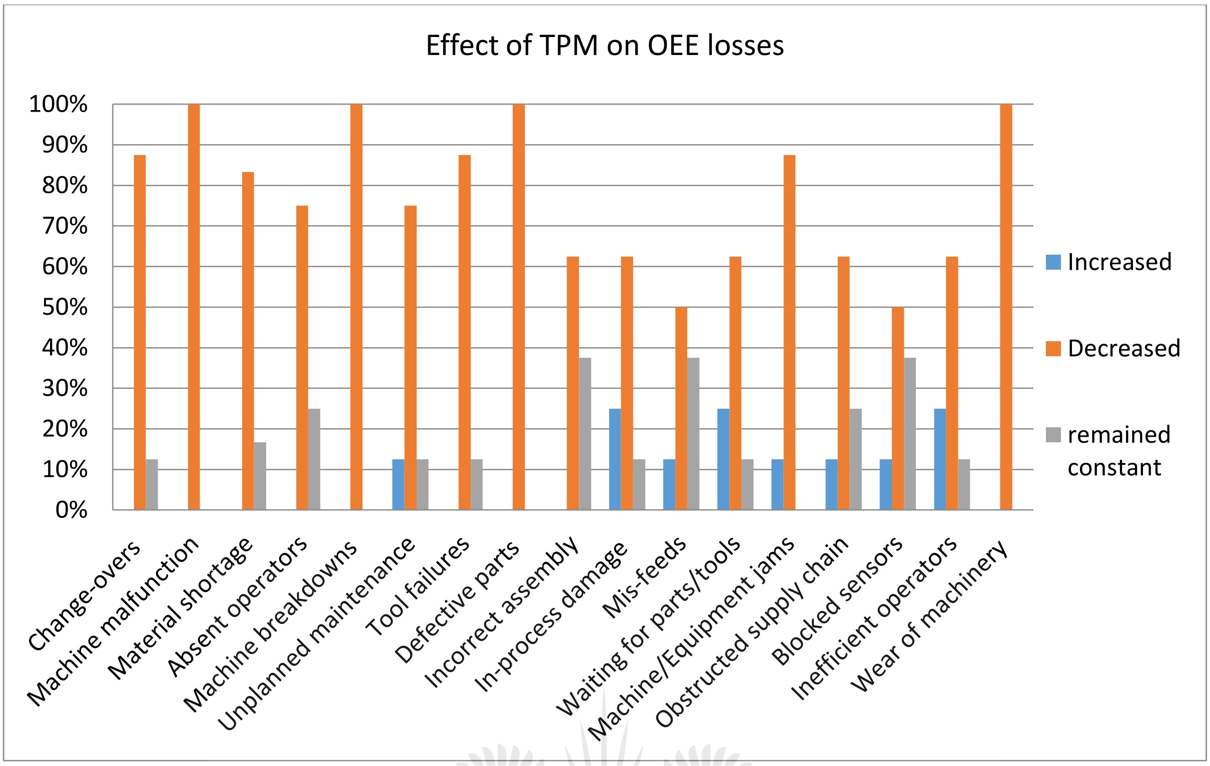


Figure 12 : Interview question 4b

It can be seen from the graph above that the interviewees generally agreed that the various losses of OEE listed decreased after TPM was implemented which is in line with theoretical predictions outlined in literature. All the respondents stated that after TPM was implemented at the OEM line of XYZ manufacturing company the frequency/incidence of machine malfunction, breakdowns, defective parts and machine wear decreased. Furthermore, at least 50% of the respondents alluded that the rest of the losses of OEE were reduced following the adoption of TPM techniques. This goes hand in hand with literature which lists the aforementioned losses as OEE losses which can be lowered through the use of TPM strategies (see Table 11, Chapter 2).

4.1.5 Interview question 5 - how TPM techniques affected OEE losses

The fifth interview question was as follows:

Question 5 Following your responses to Question 4, briefly state the rationale behind how, in your opinion the incorporation of TPM would have resulted in the increase, decrease or otherwise of each respective OEE loss.

Interview question 5 looked at qualitatively probing the logic behind how the various pillars of TPM implemented at the OEM line brought about the said outcome in interview question 4. As stated in section 4.1.4, the interviewees alluded to the fact that the OEE losses were mostly reduced when TPM strategies were adopted at the OEM line.

The responses to interview question 5 were documented and analysed to probe similarities and trends in a plea to extract conclusive evidence. The documented data was perused through in a plea to identify themes as per the responses of the interviewees. Once the themes were identified and listed, these were then reviewed against the interview extracts in order to ensure that the responses given were in line with the identified theme. By so doing, similar responses from the interviewees that made logical sense were grouped together and summarised while outliers were analysed and vetted for logic and validity.

Table 19 that follows documents the summary of the logic presented by the interviewees as part of the responses given in interview question 5. It follows that only the themes that at least five of the nine interviewees agreed on (i.e. common themes or ideas) as per the responses to the interview questions were extracted and included in the summary of responses given that they made logical sense. Those where less than two interviewees attested to were verified with the interviewees and analysed before being put into consideration since this would not represent a pattern or trend. It is noted that those responses lacking logic were discarded.

Table 19 : How TPM pillars employed affected OEE losses

TPM Pillar	Losses addressed	Rationale
Autonomous Maintenance	Machine breakdown; Machine mal-function; Tool failures; Blocked sensors; Equipment jams; Wear of machinery; Absent operators	Breakdowns reduced due to early detection of machine component problems since daily inspection is done by operators. Daily execution of small maintenance tasks also e.g. greasing keeps equipment in good condition. Absenteeism reduced because operators feel responsible for their equipment and accountable for plant performance
	Preventive maintenance; Machine breakdown; Machine mal-function;	Designated maintenance personnel recover time to attend to more critical maintenance work such as planned overhauls, corrective maintenance

Office TPM	Late supply from stores; Material shortage; Waiting for parts/tools	Delays identified were mainly due to cumbersome administrative tasks and procedures involved with the issuing of raw materials from stores. With the use of the 5S regime, unnecessary tasks and procedures that do not add values to the product are eliminated and those that are needed are streamlined to increase process efficiency
Process Quality Management	Quality issues (inconsistent part dimensions, faulty equipment causing anomalies, setup losses); Defective parts; In-correct assembly;	The detection of quality defects and the rectification thereof was seen to significantly contribute to quality related time and material losses. the introduction of quality improvement projects such as implementation of rectification jigs and checking fixtures in the OEM line would reduce scrapped material and minimise quality check durations
Training and Education	Setup losses; Change-overs;	Better skilled operators and maintenance personnel will get the machine up to operational condition quicker
	Minor stoppages & Idling	Supervisors are equipped to educate employees about TPM and the effects of unnecessary stoppages on organisational performance
	Breakdowns	Employees are brought up to speed on the relationship between maintenance and productivity and through training they will take initiative to better keep equipment in good condition
	Late supplies from stores	Training of a number of plant level employees on the use of enterprise resource planning software SAP would lessen delays due to waiting for material to be booked out on the system as more designated plant

		level personnel can issue material
Equipment and Process Improvement	Breakdown maintenance	Corrective maintenance and redesign of components that fail repeatedly to improve service life and reliability reduces likelihood of machine breakdown
	Preventive maintenance	Increased service life of equipment insinuates less frequent preventive maintenance which increases machine uptime and frees maintenance personnel for other process improvement activities
	Setup losses & Tool changeovers	The discarding of cumbersome setup procedures and subsequent introduction of more technologically capable process as part of the continuous improvement exercise in TPM increases machine availability
Early Management of new Equipment	Preventive maintenance	Informed decisions can be made on how to setup machinery in such a manner that it is simple to perform component replacements and other preventive maintenance tasks in a plea to minimise downtime
	Breakdowns	Machinery and equipment is designed and installed to last longer with information from TPM corrective actions undertaken before
	Setup times	Through knowledge gained in TPM programs, informed decisions can be made to minimise commissioning, setup stabilisation times of new machinery

It can be seen that the losses documented here have a direct adverse impact on the OEE of the organisation and plant performance at large. Naturally the implementation of TPM would target the reduction of the impact of the aforementioned factors on plant performance so as to minimise costs related to manufacturing by cutting down on losses.

4.2 Production data analysis

The implementation of TPM at the OEM production line was done over three months from February 2018 and was fully underway by April 2018. The key performance indicators were closely monitored in this manufacturing line from six months leading to the TPM implementation project. It is noted that the adoption of TPM was a continuous recurring and advancing process as all the elements required time to be integrated with current organisational processes. As such, the pillars of TPM related directly to the major losses being experienced at the time would be addressed first.

In order to determine the effects that the incorporation of Total Productive Maintenance had on Overall Equipment Effectiveness of the OEM line at XYZ manufacturing company, the parameters that affect plant OEE and in effect organisational performance were computed.

Other relevant parameters that were deemed to potentially have an effect on the deductions made were also taken into consideration and are presented in this section. Such parameters include absenteeism rates over the period being looked at. Appendix C documents the absenteeism statistics at the OEM line at XYZ manufacturing company for the period under consideration in this research. It can be seen from the graph in Appendix C that average head count values at the OEM section during the aforementioned period remained fairly constant from month to month. It can be deduced hence that absenteeism did not have a significant effect on the trends observed at the OEM line prior to and post the implementation of TPM. It is noted that the computation of OEE parameters presented here was undertaken as presented in Appendix A.

4.2.1 Effect of corrective maintenance on breakdowns

Figure 13 that follows depicts the trends in corrective and breakdown maintenance carried out prior to and post TPM implementation. It can be seen in the figure that prior to the implementation of TPM, the majority of maintenance job cards raised in the OEM production line were of breakdown maintenance in nature i.e. in response to equipment breakdowns during operating time. It is seen that due to the fact that breakdown maintenance was the main maintenance activity being undertaken, plenty of operating time was used up by this activity and the available time for corrective maintenance exercises was condensed.

From the graph, it is also apparent that during the adoption of TPM (February – April 2018), the number of corrective maintenance jobs rises acutely. This can be attributed to the fact that operators began performing small maintenance tasks (e.g.

lubricating, condition monitoring, cleaning) hence opening up time for designated maintenance personnel to undertake more specialised tasks. Further, it can be deliberated that the decrease in the number of breakdowns on the OEM line after April of 2018 is a result of corrective maintenance actions that were being undertaken at a larger scale at the onset of TPM implementation.

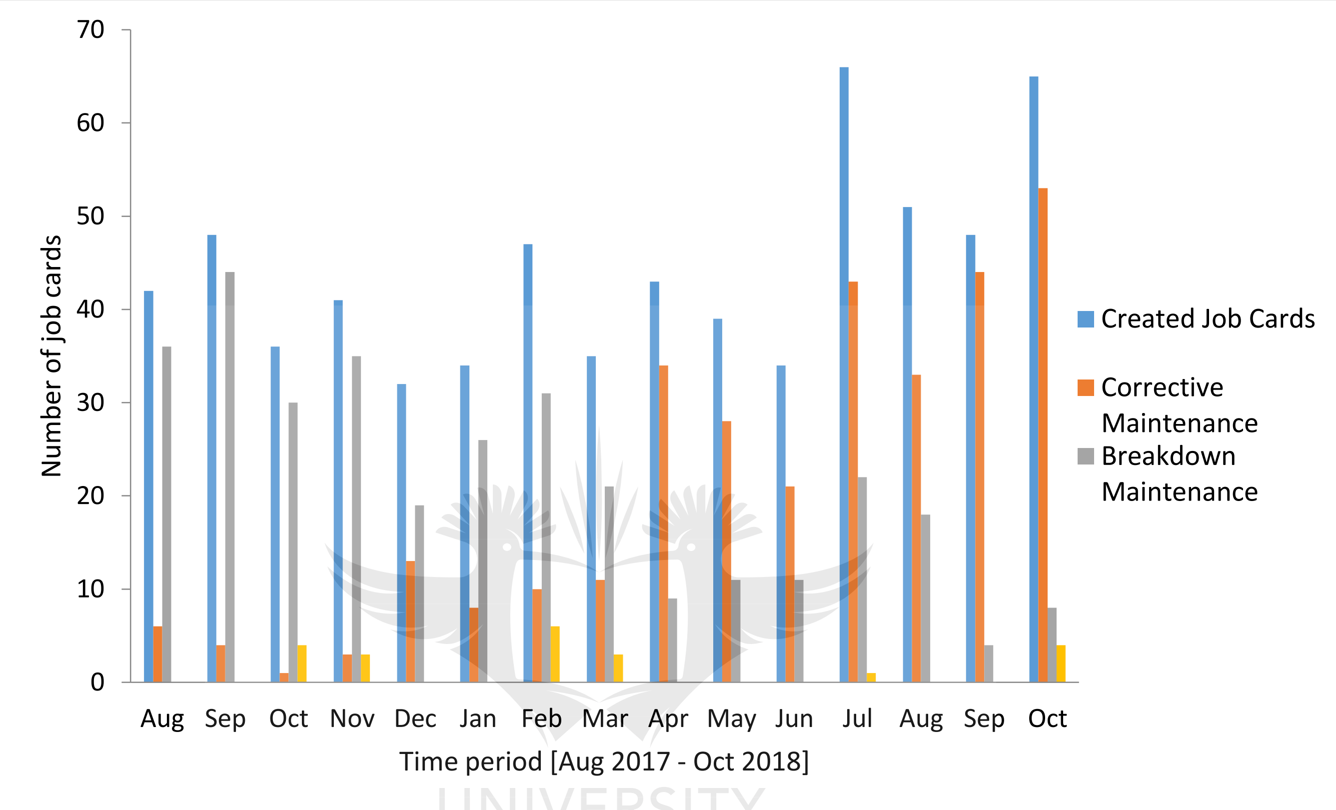


Figure 13: Breakdown vs Corrective Maintenance

It can be concluded that the implementation of TPM on the OEM line reduced the number of equipment breakdowns significantly as corrective maintenance improved component reliability and enhanced plant service life. In addition, autonomous maintenance strategies introduced freed maintenance personnel allowing them to focus on corrective and preventive maintenance exercises.

4.2.2 Downtime

The losses experienced on the OEM line at XYZ manufacturing company were recorded from July 2017 to January 2018. In so doing, the organisation would establish a clear picture of the relevance or impact of each respective loss on organisational performance. Thereafter, the heaviest losses would then be targeted by the implementation of TPM strategies that address the losses in question. For the period July 2017 to January 2018, the figure below depicts the significance by percentage of the most critical downtime losses that were experienced and documented on the production line in question.

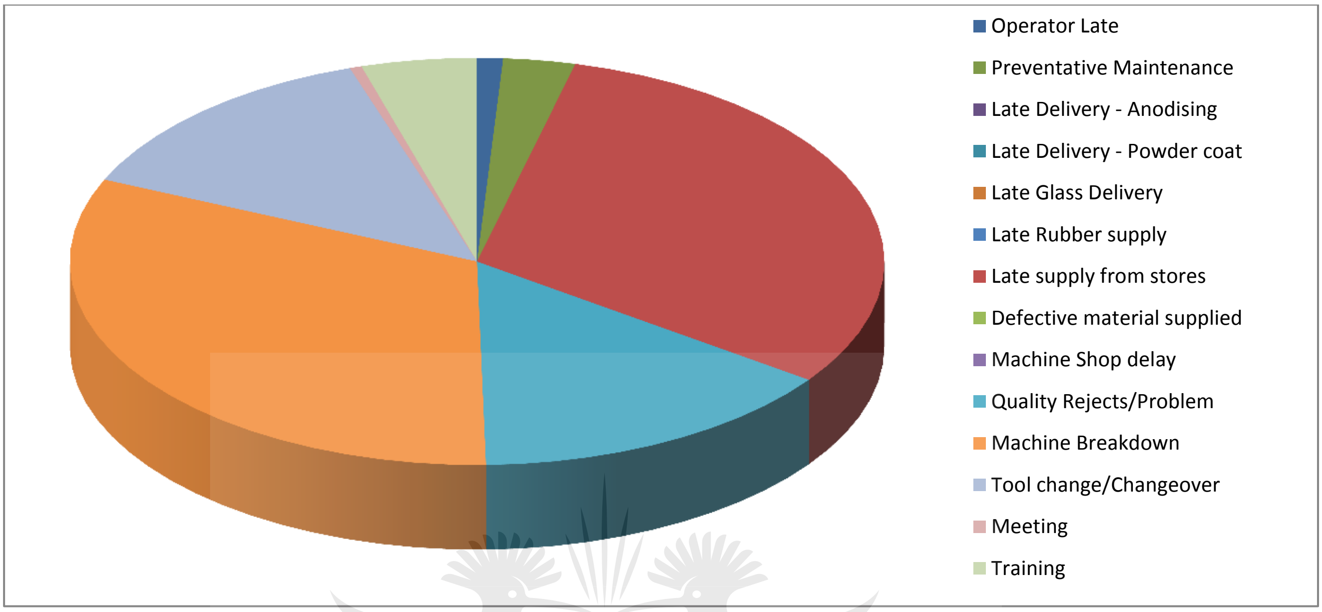


Figure 14: Downtime Losses at OEM Line

It can be seen that machine breakdowns, late supply from stores, quality issues, tool changeovers and operator training were the largest contributors to inefficiency of the production line in question. It is seen that preventive maintenance activities also had a fair contribution to lost operating time which agrees with literature. These losses can be broken down and categorised into the OEE losses described in the literature.
The graph that follows illustrates the variation of downtime on the OEM line over the period from July 2017 to October 2018. TPM is introduced first in February 2018 and a slight decrease in downtime is experienced in the first three months.

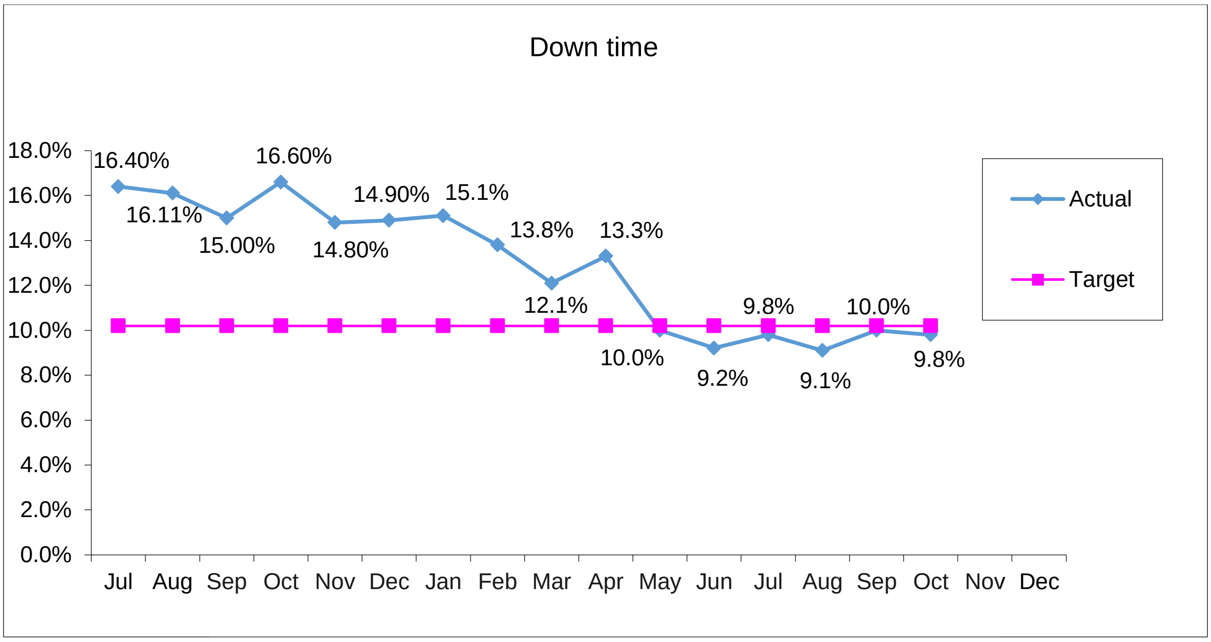


Figure 15: Downtime on OEM line

Thereafter, it can be seen that machine downtime drops to sub-10% figures for the rest of the period under consideration. It has been pointed out in section 4.2.1 above that the drop in the number of breakdowns after TPM can be attributed to the corrective maintenance actions that were adopted. It can further be stated that due to the reduction in the number and severity of machine breakdowns on the OEM line, the amount of machine downtime was bound to decrease. Autonomous maintenance would also have brought about more proactive maintenance behaviour by machine operators which would have promoted the upkeep of machine condition. It follows that the implementation of TPM can be directly linked to the drop in machine downtime that is seen in the figure above.

4.2.3 Availability

Figure 16 that follows is a diagrammatic representation of the variation of plant availability over the time period being studied. It is apparent from the graph that plant availability begins to rise at the onset of TPM implementation (February 2018). By May 2018, Plant availability reaches the organisational target and also world class plant availability standard of 90%. Thereafter, it is consistently maintained at this level till October of 2018.

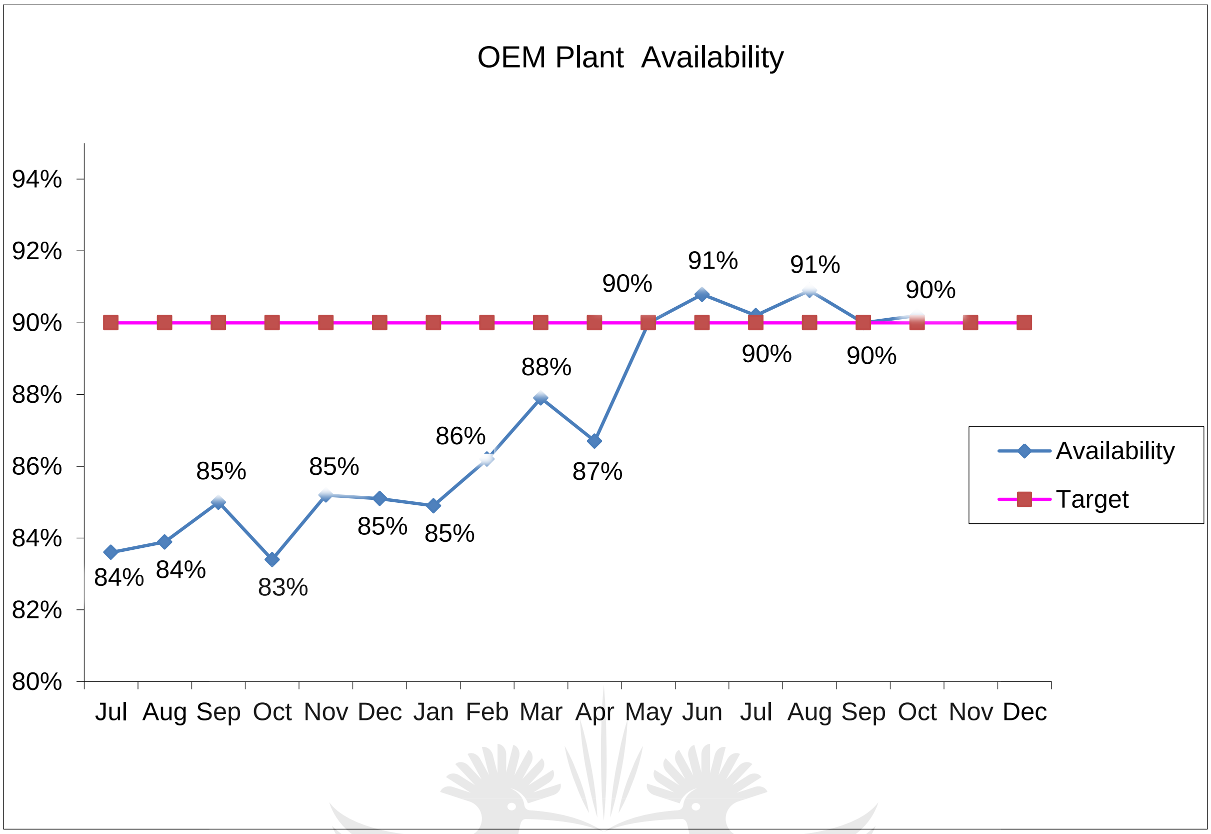


Figure 16 : Plant Availability

The seen enhancement of plant availability is a result of a combination of lowered breakdowns and downtime (see 4.2.1 & 4.2.2 above), as well as training regimes that operators were provided on how to better maintain their equipment and how best to setup production processes on said machinery. Better skilled operators would not only maintain machinery in good operating condition, but would also avoid errors or mistakes that could lead to machine malfunctioning and breakdowns. It follows that as a result, setup time and breakdown maintenance times are reduced hence increasing actual operating time and in-turn improving machine availability. The incorporation of TPM is seen to enhance plant availability on the OEM line at XYZ manufacturing company.

4.2.4 Rejects and quality rate

It has been outlined in the previous sections that reject rates are undesirable in the production process as they increase manufacturing costs. Figure 17 below shows the recorded reject rates for the case study period.

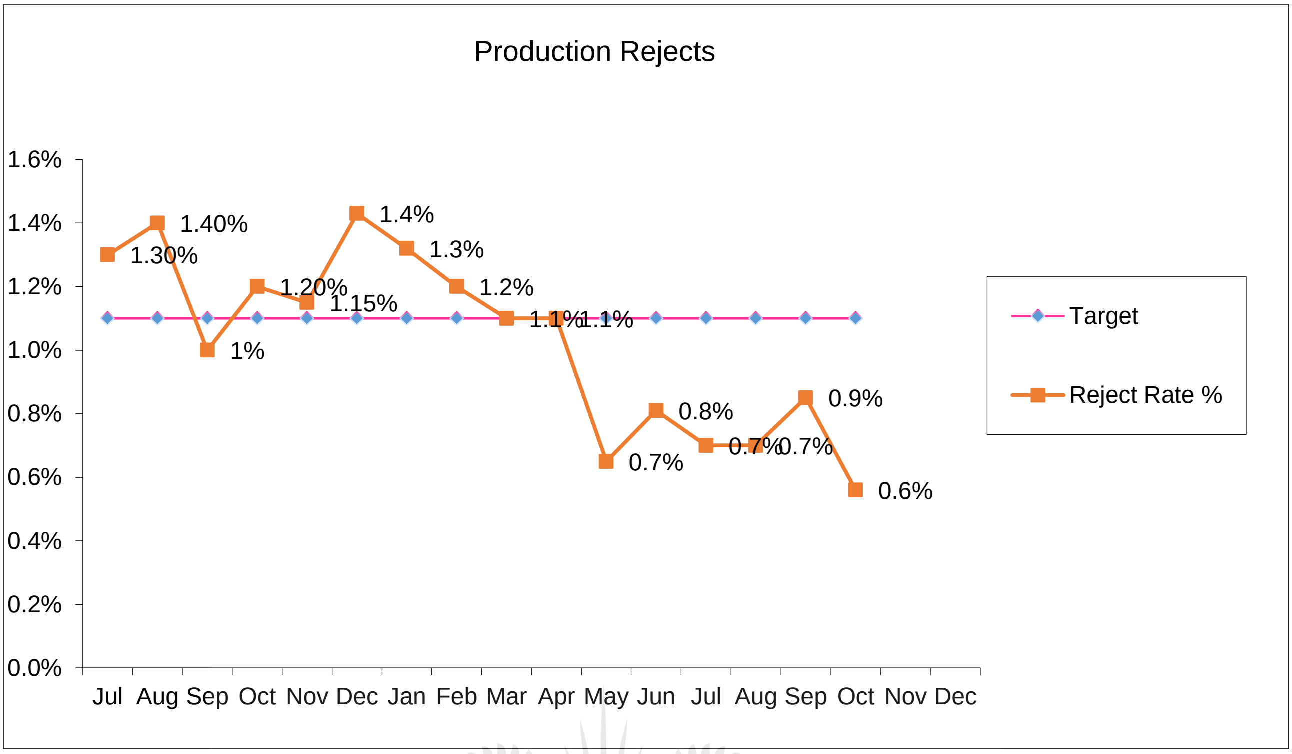


Figure 17 : Production Rejects

By April 2018, reject rates are seen to be above the organisational target threshold. This is a result of better skilled operators who are able to effectively setup machines without excessive setup material and time losses. In addition, the implementation of a reject rate threshold on the OEM line ensured that operators are conscious of quality issues as they are held accountable when the targets are not met. The figure that follows shows how quality rate which is one of the aspects affecting OEE fairs as a result of the reject rates shown above.

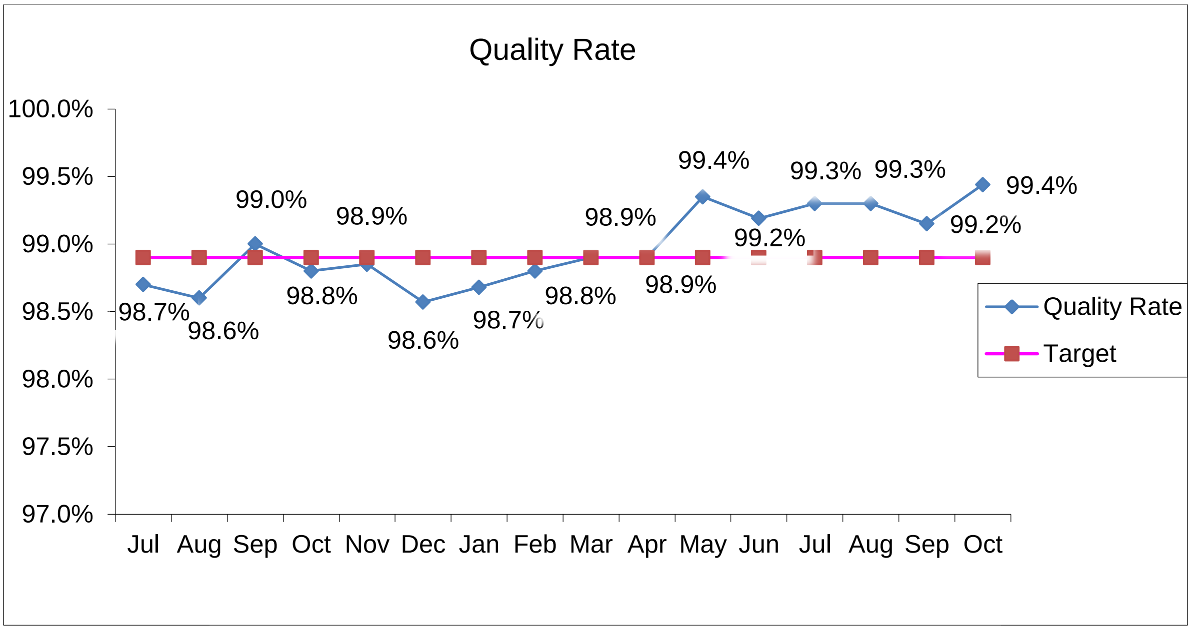


Figure 18 : Quality Rate

Reduced rejects imply increased quality rate. This is seen in the Quality Rate graph above where the quality rate is seen to rise at the onset of TPM implementation around March to April 2018 which is also in-line with theory. It follows that the triggers of reject rate decline are the same as those of quality rate enhancement.

4.2.5 Plant Efficiency

The graph presented in Figure 19 below illustrates how the efficiency of plant faired over the period from prior to and post the implementation of TPM. From the time that TPM was introduced, it can be read from the graph the plant efficiency began to rise steadily from mid-70% values into the 80%s and eventually reaching the organisational target value of 90% efficiency of machinery by July 2018. It can therefore be deduced from the graph that the implementation of TPM had a positive impact on machine efficiency on the OEM line.

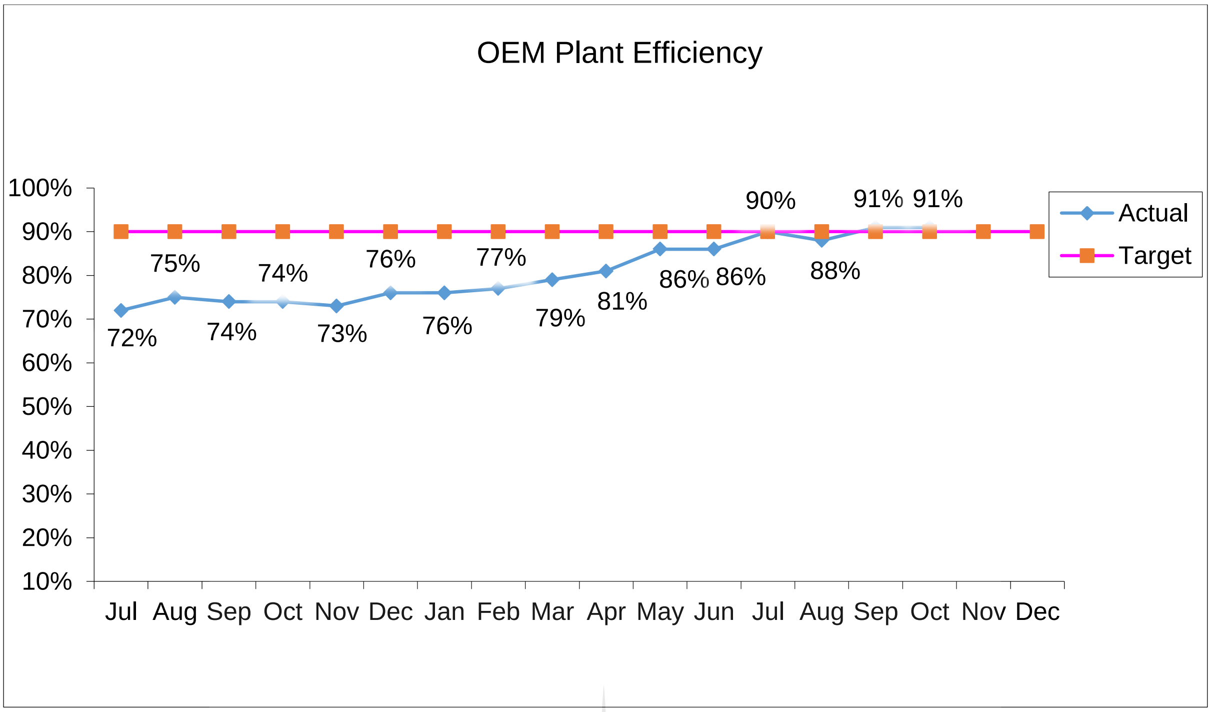


Figure 19 : Plant Efficiency

The improvement in plant efficiency that is noticed after the implementation of TPM on the OEM line can be attributed to the elimination of various aspects that had been causing machinery to not operate at its design speed. Such aspects include machine component wear as well as poor machine condition related to poor maintenance strategies. Due to the introduction of autonomous maintenance strategy, daily condition monitoring by machine operators insured that faulty components on machinery are identified promptly and where possible replaced by the operators or otherwise replaced by designated maintenance personnel during planned maintenance activities.

The adoption of machine process improvement initiatives for maintenance personnel and corrective maintenance over breakdown maintenance also had the effect of enhancing machine performance as this reduced failures and minor stoppages caused by jams and blocked pathways as machine operation was constantly streamlined. Autonomous maintenance and the 5S regime are seen to have reduced the frequency of machine malfunctions that are related to dirty sensors and clogged feed passages as the operators took responsibility for the cleaning of their machinery. It is also noted that due to the fact that maintenance personnel had been freed from small maintenance tasks, they had more time to plan and effect maintenance strategies that are in line with continuous improvement which also had a positive effect on the performance of machinery.

4.2.6 Overall equipment effectiveness

Figure 20 that follows is a depiction of how OEE was affected by the incorporation of TPM strategies at the OEM line of XYZ manufacturing company. It follows that the OEE values computed and presented here were also evaluated using organisational data and the methodology shown in chapter 3 above for the period from July 2017 to October 2018. Prior to the implementation of TPM (July 2017 – Jan 2018), an average OEE value of 62% is computed. On the other hand, when TPM is fully implemented it is noted that the average OEE value (May – October 2018) is 79.52% (as shown in Appendix A). This insinuates a 17.5% increase in average OEE from prior to post TPM implementation respectively. It can also be read from the graph below that once the incorporation of TPM is underway in February 2018, the OEE value begins to rise significantly indicating that OEE on the OEM line was enhanced or improved by TPM strategy.

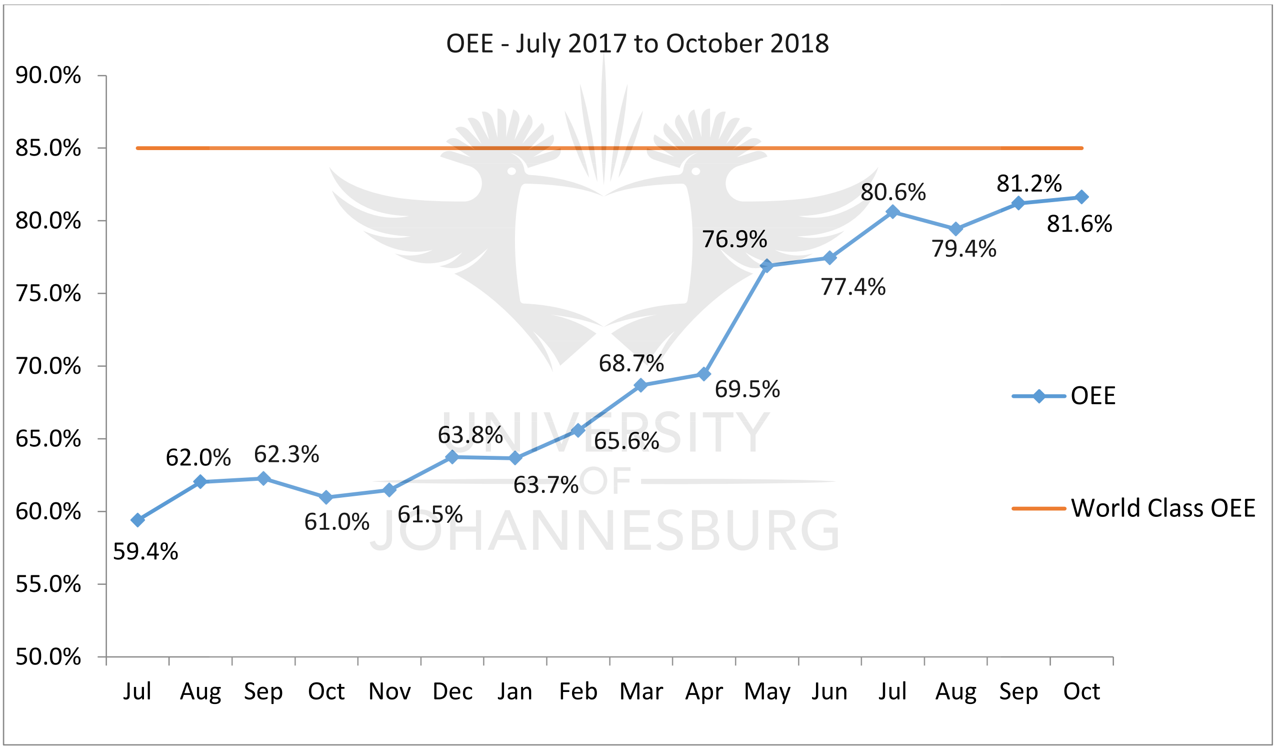


Figure 20 : Overall Equipment Effectiveness

Literature has pointed out that OEE is a parameter used for the measurement of the performance of manufacturing plant from individual machines and systems to entire production facilities. OEE is calculated as the product of quality rate, performance efficiency and plant availability as presented in chapter 2 above. The better the performance of each individual OEE factor, the higher the OEE where high OEE levels insinuate better business competitiveness. It is clear that the manufacturing organisation must ensure that its OEE is kept at optimal levels at all times. In order to achieve this, theory suggests that TPM be implemented in the manufacturing company.

Section 4.2 has presented how the various factors affecting OEE were affected by the implementation of TPM at the OEM manufacturing line at XYZ manufacturing company. It is observed that the majority of losses that were experienced on this line were attributed to breakdowns, machine start-up, material issuing delays and tool change-overs which is in line with the six big losses proposed by literature. Other losses observed at XYZ manufacturing company that impacted performance negatively include quality rejects and unforeseen stoppages during operating time which also agrees with theoretical predictions. The implementation of TPM on the OEM line would then focus on the elimination of such losses so as to reduce the cost of manufacturing.

4.3 Convergence of evidence

The preceding sub-sections document the analyses of the interview results and the production data. It is imperative for validation purposes that evidence drawn from the interview exercise be contrasted with deductions made from production data. This can then be referred back to literature so as to draw conclusive deductions. It follows that in this sub-section the information from the two aforementioned sources of evidence will be summarised and in-consistencies thereof outlined.

4.3.1 Plant availability

Autonomous maintenance is said to have freed time for designated maintenance personnel to focus on specialised maintenance work such as corrective and preventive maintenance through the interview exercise. This is alluded to by production data which shows that after the implementation of TPM, more corrective maintenance rather that breakdown maintenance jobs were completed on a monthly basis. By so doing, corrective actions taken on equipment promote longer service life of plant which reduces the frequency of preventive and breakdown maintenance thereby minimising unplanned down-time which is also attested to by both interview results and production data findings. As a result of lessened unplanned downtime, plant availability is seen to rise thereby enhancing plant OEE. Further, through autonomous maintenance operators took more initiative in the upkeep of the condition of their machinery which also had an impact on the frequency of machine breakdowns.

The training of all machine operators resulted in a more versatile workforce as predicted by literature in chapter 2 above. This brought about means of mitigating the effects of absenteeism as the skill set of an absent employee could be covered for by another employee. It follows that in so doing critical machinery in the plant does not fail to run production due to the absence of operators thereby ensuring that availability and in-turn OEE does not decline.

On the other hand, the effective skilling of operators and maintenance personnel in terms of machine operation was observed promote employee morale as well as the fluidity of the machine set-up and tool change-over processes and this agrees with theoretical predictions. This is due to the fact that minimal time is spent while trial and error exercises are being executed to get equipment to stabilise for production since operators are well versed in the operation of said equipment. It is apparent that such reduction of set-up and change-over losses improved plant availability in this respective production line as well.

4.3.2 Performance efficiency

In order to enhance OEE, the factors causing the decline of plant performance efficiency would need to be minimised. Autonomous maintenance strategies have been said to have kept machinery at its optimal operation condition for longer periods of time which in effect resulted optimal performance of equipment on the line. Further, as lamented in the interview results, corrective maintenance as well as continuous improvement regimes adopted reduced the likelihood of equipment components to rapidly deteriorate which insinuates that machinery would be in their prime state of operation for longer stretches of time before their condition declined. As such, this promoted the operation of equipment at its optimal speed and efficiency which resulted in the enhancement of performance efficiency and in-turn plant OEE as shown in the production data analysis.

Continuous improvement strategies together with early management of new process equipment went a long way in eliminating wastages of time and material while equipment was online. Problems related to machine jams were reduced due to the daily cleaning and inspection undertaken by machine operators as part of the autonomous maintenance strategy. Material mis-feeds were avoided by the introduction of clamping jigs that hold the material while machinery undertakes the operation also as per the interview results. On the other hand, autonomous maintenance techniques which include condition monitoring of equipment reduced the prevalence of component wear which would also have resulted in better functioning equipment and higher efficiency shown in the analysis of production data. Theory states that training and up-skilling of personnel can also be employed as a strategy to increase efficiency on the product line. This is seen at XYZ manufacturing company where delays due to incorrect machine settings as well as those resulting from operator mistakes are reduced as per the interview results.

On the other hand, the introduction of the 5S program contributed to improved plant efficiency on the OEM line. This is due to the fact that the production line was continually streamlined to promote smoother flows of work. The strategic organisation of the manufacturing process eliminated unnecessary delays on the line which enhanced performance efficiency. On the other hand, through the implementation of office TPM the efficiency of the production line was enhanced since various issues generated in administrative tasks related to the production process were eliminated. Such tasks that were streamlined include support operations such as the entry and release of production orders as well as the subsequent issuing and booking of raw materials and stock respectively. It can be seen that office TPM strategies such as the elimination of tasks that do not add value to the product would have caused improved efficiency of the process at large.

4.3.3 Quality rate

The causes of poor quality rate observed at XYZ manufacturing company include products that do not conform to quality standards as well as losses occurring whilst machine start-up is executed according to the results of the interviews carried out. Further, the associated inspections and rework of products would only exacerbate the situation. It follows that in order to minimise product inspection losses, the process of quality monitoring was effected as part of the continuous improvement program of TPM. The introduction of checking fixtures was seen to effectively minimise the effort required for the product quality inspection exercises as go/no-go gauges were employed at every milestone on the production line. Further, also as part of the continuous improvement regime, the implementation of rectification jigs respective production stations was found have a positive impact on the losses related to product rework. This is due to the fact that mechanical mechanisms were used for the rework of defective products as opposed to manual rectification of non-conforming parts which is more labour intensive and less accurate.

The quality rate would have also been improved through the up-skilling of operators. This comes as a better skilled workforce was seen to be more consistent in terms of performing manufacturing tasks which reduced the number of non-conforming products particularly in processes that are reliant on both man and machine. Machine malfunction frequency dropped also as a result of autonomous maintenance and corrective maintenance exercises as pointed out previously. It is apparent that less occurrences of malfunctioning machinery resulted in reduced numbers of defective products originating from such equipment behaviour.

It is noted that employees were seen take more responsibility for quality issues following the setting of an accountability system for all production personnel. Careless handling of material and products resulting in damage would have been impacted by the system of accountability as the parts can be traced through the process.

4.4 Chapter conclusion

In this chapter, the results of the interviews undertaken regarding the TPM implementation project at the OEM line of XYZ manufacturing company are documented. The major losses leading to the implementation of TPM in the aforementioned production line included machine breakdowns and breakdown maintenance, late issuing of raw materials from stores, machine setup losses, material and time losses, quality losses and preventive maintenance. It follows that certain pillars of TPM were introduced to eliminate or reduce these losses or to at-least mitigate their implications on organisational performance where possible. It follows that the elimination or reduction of such losses would effectively enhance plant performance. It is observed that the various pillars of TPM as well as the 5S program were put in place so as to address the recurring issues that adversely affect OEE. The implementation of TPM focused on the promotion of permanent fixes through corrective maintenance and continuous improvement efforts aimed at eliminating the losses of OEE. It was found that by employing specific TPM strategies, OEE losses on the production line were either reduced or eliminated which then improved the factors of OEE namely quality rate, availability and performance efficiency as part of the results drawn from organisational production data. It follows that through the implementation of TPM at the XYZ manufacturing company OEM line, the OEE of the production line in question was increased.

5 Conclusions and recommendations

Problem Statement: *Overall equipment effectiveness of manufacturing companies is adversely affected when the principles of total productive maintenance are neglected in the manufacturing process.*

As presented in Chapter 1, the overall equipment effectiveness of manufacturing companies is negatively affected when the principles of total productive maintenance are neglected. Poor levels of overall equipment effectiveness cause the organisational competitiveness of manufacturing companies to decrease which may result in market-share loss and other adverse financial repercussions. This comes as low levels of OEE insinuate poor utilisation of machinery and equipment and in-turn inefficient production processes. However, the goals of TPM include the enhancement of productivity, reduction of cycle times, and the extension of useful life of production equipment. As such, it follows that manufacturing concerns must employ the principles of TPM to sustain and maintain OEE. The following are the research questions posed for the purpose of this research:

1. What is the effect of Total Productive Maintenance incorporation on Overall Equipment Effectiveness?
2. How does the implementation of Total Productive Maintenance affect Overall Equipment Effectiveness in manufacturing?

The research questions were addressed through peer reviewed literature as well as by means of case study on a production line of a manufacturing company.

5.1 Conclusion

5.1.1 Research question 1

It was determined through literature and by case study that the adoption of TPM in manufacturing companies results in the enhancement of OEE. This was established through the interview exercise as the results of interview question 4b (sub-section 4.1.4) indicate that that the implementation of TPM techniques brings about a decrease in the various losses of OEE. Further, it was also determined from the computation of archival data and production reports in section 4.2 that the OEE at XYZ manufacturing increased significantly (from 62% average OEE to 79% average OEE after TPM) after TPM was introduced at the OEM line. It is noted that these findings are in line with theoretical predictions in this regard. The effects of TPM implementation on OEE as per the findings of this research activity are as follows:

- Downtime is decreased which means plant availability is raised thereby enhancing OEE
- Production rejects are reduced thereby heightening quality rate and OEE in-turn
- Delays and machine performance losses are inhibited thereby increasing performance efficiency and enhancing OEE as a result

In subsection 5.1.2 that follows, the logic behind how TPM implementation brings about said effects on OEE is discussed.

5.1.2 Research question 2

In this subsection, the conclusions regarding how the implementation of TPM affects OEE in manufacturing concerns are documented for each TPM strategy and technique based on theoretical predictions, interview results and production documentation (production reports and archival data) findings as per this research activity. Interview question 3 documents how the pillars of TPM were implemented in the organisation whereas interview question 4a probes which specific pillars had an effect on the respective losses of OEE. Furthermore, interview question 5 explores how the losses of OEE were actually affected by the respective TPM pillars. This is compared back to literature in sections 2.5 and 2.6 before conclusions are drawn.

Autonomous maintenance

- Daily cleaning, inspection and condition monitoring by operators ensures that machinery and equipment operate at optimal state, thereby reducing breakdowns and increasing availability
- Machinery is kept in good operating condition which minimises inefficiencies related to poor machine condition hence increasing performance efficiency
- Availability is further enhanced because maintenance personnel are relieved of smaller tasks (e.g. cleaning, inspection, lubrication) and focus on continuous improvement and corrective maintenance which provide permanent fixes for recurring breakdowns
- Machinery that is in poor condition is more likely to malfunction and make defective parts, through autonomous maintenance defects are minimised since machine condition is monitored and maintained continuously

Planned Maintenance

- Maintenance activities are planned in advance in such a manner that production is not interrupted thereby up-keeping plant available production time
- The maintenance schedule is based on predicted component and equipment failure which works to avoid unforeseen breakdowns thereby reducing the chances of breakdown maintenance downtime
- Preventive maintenance ensures that machinery is kept at optimal operating condition hence superior levels of machine efficiency, lowered breakdown frequency and lowered machine condition related defects
- Reduces time lost waiting for spares since the maintenance program addresses spares inventory based on historical breakdown trends

<u>Education and training</u>

- The training of employees on the principles of TPM enforces a TPM oriented organisational culture whereby all personnel behave in the consciousness of OEE improvement
- The training of operators on the operation of the machinery and equipment that they use enhances their efficiency which in-turn raises the performance efficiency of the process
- Operators are trained to effectively undertake basic production equipment maintenance which promotes machine operating condition and allows for designated maintenance personnel to execute continuous improvement activities

<u>Quality Management</u>

- The management of quality control processes ensures that equipment and tools used are ever calibrated and in good operating condition which ensures that quality rate is effectively established and gauged
- The causes of recurring quality issues are identified and resolved permanently which reduces the frequency of defects
- Quality levels are also enhanced through the implementation of error proofing methods such as checking fixtures and the subsequent employment of rectification mechanisms which can be used to effectively and promptly rectify quality issues on the line while still early in the production process

<u>Office TPM</u>

- Administrative tasks that are part of the production process are streamlined in such a manner that avoids unnecessary delays and cumbersome activities which makes the production process more efficient

Early Management of New Equipment

- The use of historical knowledge regarding the implementation of similar machinery or equipment to guide the execution of current projects ensures that past mistakes are avoided
- Processes are set up in such a way that machine set-up, tool change overs and maintenance activities are easy to undertake which reduces the amount of related downtime hence enhancing plant availability
- Process work flows are organised in the most efficient arrangements which heightens performance efficiency
- The use of existing machine installation knowledge reduces the amount of time required to get machinery to production levels

Equipment & Process Improvement

- Recurring problems that cause waste and losses on the production line are systematically identified and addressed in such a manner that permanent fixes are implemented
- The implementation of permanent solutions to causes of waste results is lessened breakdown frequency, reduced quality issues and enhanced process efficiency which cause higher levels of availability, quality rate and performance efficiency respectively

5S

- Machinery and equipment are organised in the most efficient manner which increases performance efficiency and avoids in-process damage to material and parts thereby raising quality rate
- Standardisation of work flows raises the efficiency of operators as they exercise repetitive tasks which also reduces chances of mistakes in-turn avoiding rejects
- The work place is kept clean at all times which prevents machine malfunction due to dirty sensors or dust ingress into bearings and components which ensures that equipment stays in good operating condition

- Following procedures provides traceability of the origin of issues and wastes in the production process thereby providing the opportunity for corrective actions against such losses resulting in OEE enhancement

It is seen that in today's global market, manufacturing organisations must aim to maximise their productivity if they are to meet customer demand and yet make profit while remaining competitive. In order to achieve this, it is imperative that the overall equipment effectiveness of the manufacturing company is kept at superior levels. This suggests lowered frequencies of machine breakdowns and quality rejects, lessened minor stops and delays on the line, optimised changeover processes, heightened customer satisfaction and superior cost saving regimes. This work has shown that through the implementation of the techniques of total productive maintenance all the aforementioned conditions for organisational success can be achieved. Therefore, manufacturing organisations must incorporate total productive maintenance as part of their business strategy if they are to retain and grow their market-shares.

5.2 Recommendations

- XYZ manufacturing company should continually benchmark its OEE improvement strategies to other large high volume manufacturing companies within the same industry so as to gauge its performance in the market as well as to develop knowledge on alternative approaches for the enhancement of OEE
- Maintenance personnel at XYZ manufacturing company must remain well equipped for both current and future technological needs of the organisation. As such, it is imperative that maintenance personnel are continually developed in terms of their technological acumen
- In today's fast moving production environment the manual recording of production data on the production line has become impractical. As such, the organisation must look into investment into technologies that make data recording a live digital system on the production so as to save time and promote accuracy

5.3 Future research areas

This subsection documents some topics that should be considered for future research in order to solidify the foundation of knowledge about the effects of TPM implementation on OEE in manufacturing organisations. The areas of consideration are as follows:

- The effects of organisational structure management and organisational politics on the success of the implementation of TPM for the enhancement of organisational OEE should be investigated
- There is no set framework addressing how the training of operators and personnel should be executed in line with knowledge of TPM techniques and TPM implementation. Work should be done to investigate how best training should be conducted in line with TPM implementation and a framework developed for the benefit of industry and scholars

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Appendix A – OEE calculation procedure (April 2018 example)

XYZ manufacturing company OEE computation example (April 2018):

(A)

$$total\ shift\ time = 11051mins\ ;\ planned\ down\ time = 775mins$$
$$loading\ time = total\ shift\ time - planned\ down\ time$$
$$loading\ time = 11051 - 775$$
$$loading\ time = 10276mins$$

(B)

$$(actual\ downtime\ and\ stop\ time) = 1082mins$$
$$operating\ time = total\ shift\ time - (actual\ downtime\ and\ stop\ time)$$
$$operating\ time = 11051 - 2082$$
$$operating\ time = 8969mins$$

(C)

$$Availabilty\ (A) = \frac{operating\ time}{loading\ time}$$
$$Availabilty\ (A) = \frac{8969}{10276}$$
$$Availabilty\ (A) = 87.2\%$$

(D)

$$theoretical\ cycle\ time = 15mins\ ;\ actual\ cycle\ time = 16.33mins$$
$$operating\ speed\ rate = \frac{theoretical\ cycle\ time}{actual\ cycle\ time}$$
$$operating\ speed\ rate = \frac{15}{16.33}$$
$$operating\ speed\ rate = 91.86\%$$

(E)

$$actual\ processing\ time = 11.5mins\ ;\ operating\ time = 13mins$$
$$net\ operating\ rate = \frac{actual\ processing\ time}{operating\ time}$$
$$net\ operating\ rate = \frac{11.5}{13}$$
$$net\ operating\ rate = 0.885$$

(F)

$$Performance\ Efficiency = (operating\ speed\ rate) \times (net\ operating\ rate)$$
$$Performance\ Efficiency = (0.9186) \times (0.885)$$
$$Performance\ Efficiency = 81.3\%$$

(G)
$(total\ number\ of\ parts) = 816$; $(number\ of\ defective\ parts) = 9$

$$Quality\ Rate\ (QR) = \frac{(total\ number\ of\ parts) - (number\ of\ defective\ parts)}{total\ number\ of\ parts\ produced}$$

$$Quality\ Rate\ (QR) = \frac{(816) - (9)}{816}$$

$$Quality\ Rate\ (QR) = 98.9\%$$

(H)
With equation [4], OEE is computed as:

$$OEE = PE \times A \times Q$$

$$OEE = 81.3 \times 87.2 \times 98.9$$

$$OEE = 70.11\%$$

<u>Average OEE value between May and October 2018</u>

May; $OEE = 76.9\%$
June; $OEE = 77.4\%$
July; $OEE = 80.6\%$
August; $OEE = 79.4\%$
September; $OEE = 81.2\%$
October; $OEE = 81.6\%$

Therefore, $Average\ OEE\ (May - Oct\ 2018) = \frac{76.9+77.4+80.6+79.4+81.2+81.6}{6}$

$$Average\ OEE\ (May - Oct\ 2018) = 79.52\%$$

Appendix B – Interview questionnaire

Enhancement of Overall Equipment Effectiveness through Total Productive Maintenance

Minor dissertation interview questionnaire as per the requirement for the Master of Engineering Management degree in 2019

UNIVERSITY
OF
JOHANNESBURG

I am currently studying towards my Master of Engineering in Engineering Management degree at the University of Johannesburg in the year 2019.

In order to complete the minor dissertation that forms part of the curriculum for the aforementioned program, I am conducting interviews pertaining to how the incorporation of Total Productive Maintenance affected plant performance at the OEM production line at XYZ manufacturing company during the period beginning July of 2017 to October 2018.

Your participation in this activity will significantly benefit this work by supplementing the literature required to validate the results of this research. Please provide as much relevant information as possible to the best of your knowledge. Your participation is highly appreciated and all correspondence will be kept strictly confidential.

Sincerely,

Tawandah Musengi.

Question 1
Were you present when the TPM program was implemented at the OEM line between July 2017 to October 2018?
Yes ☐ No ☐
If no, please discontinue the interview and contact the researcher.

Question 2
In your opinion, which of the following losses of OEE significantly hampered/lowered/limited productivity of your line prior to the introduction of TPM? Please indicate with an X in the box whether the listed loss had a negative effect (Y –Yes) or if it did not contribute to the performance (N – No)

	Y – Yes	N – No
Change-overs	☐	☐
Machine malfunction	☐	☐
Material shortage	☐	☐
Absent operators	☐	☐
Machine breakdowns	☐	☐
Unplanned maintenance	☐	☐
Tool failures	☐	☐
Defective parts	☐	☐
Incorrect assembly	☐	☐
In-process damage	☐	☐
Mis-feeds	☐	☐
Waiting for parts/tools	☐	☐
Machine/Equipment jams	☐	☐
Obstructed supply chain	☐	☐
Blocked sensors	☐	☐
Inefficient operators	☐	☐
Wear of machinery	☐	☐

Question 3	
Based on your knowledge gained through on the job experience and TPM training, which pillars of TPM were implemented on the OEM line? Briefly describe how these were put in place.	
TPM Pillar	**Description of how it was implemented**

Autonomous maintenance	
Planned maintenance	
Equipment and process improvement	
Early management of new equipment	
Quality maintenance	
Office TPM	
Education and training	
Safety and environmental management	

5S	

Question 4a

Please indicate which TPM pillars you believe reduced the various OEE losses listed below. Indicate with a cross in the box of each pillar that reduced the corresponding loss. If unsure, please indicate with a circle otherwise leave blank.

For example, in the figure below, tea breaks would have been reduced by autonomous maintenance, planned maintenance and office TPM. On the other hand, the circle indicates that the interviewee is unsure of the effect of 5S on tea-breaks. Lastly, the blank boxes indicate that the respective pillars of TPM had no effect on the loss.

	Autonomous maintenance	Planned maintenance	Equipment & process imprvmnt	Early mngmnt of new equipment	Quality maintenance	Office TPM	Education and training	Safety & environmental mngmnt	5S
Tea breaks (Example)	☒	☒	☐	☐	☐	☒	☐	☐	O

	Autonomous maintenance	Planned maintenance	Equipment & process imprvmnt	Early mngmnt of new equipment	Quality maintenance	Office TPM	Education and training	Safety & environmental mngmnt	5S
Tea breaks (Example)	☒	☒	☐	☐	☐	☒	☐	☐	☐
Change-overs	☐	☐	☐	☐	☐	☐	☐	☐	☐
Machine malfunction	☐	☐	☐	☐	☐	☐	☐	☐	☐
Material shortage	☐	☐	☐	☐	☐	☐	☐	☐	☐
Absent operators	☐	☐	☐	☐	☐	☐	☐	☐	☐
Machine breakdowns	☐	☐	☐	☐	☐	☐	☐	☐	☐

Unplanned maintenance	☐	☐	☐	☐	☐	☐	☐	☐	☐
Tool failures	☐	☐	☐	☐	☐	☐	☐	☐	☐
Defective parts	☐	☐	☐	☐	☐	☐	☐	☐	☐
Incorrect assembly	☐	☐	☐	☐	☐	☐	☐	☐	☐
In-process damage	☐	☐	☐	☐	☐	☐	☐	☐	☐
Mis-feeds	☐	☐	☐	☐	☐	☐	☐	☐	☐
Cleaning and lubrication	☐	☐	☐	☐	☐	☐	☐	☐	☐
Waiting for parts/tools	☐	☐	☐	☐	☐	☐	☐	☐	☐
Machine jams	☐	☐	☐	☐	☐	☐	☐	☐	☐
Obstructed supply chain	☐	☐	☐	☐	☐	☐	☐	☐	☐
Blocked sensors	☐	☐	☐	☐	☐	☐	☐	☐	☐
Inefficient operators	☐	☐	☐	☐	☐	☐	☐	☐	☐
Wear of machinery	☐	☐	☐	☐	☐	☐	☐	☐	☐

Question 4b

In your opinion, were the following losses of OEE reduced, increased or not affected by the implementation of TPM?

	Increased	Not affected	Reduced
Change-overs	☐	☐	☐
Machine malfunction	☐	☐	☐
Material shortage	☐	☐	☐
Absent operators	☐	☐	☐
Machine breakdowns	☐	☐	☐
Unplanned maintenance	☐	☐	☐
Tool failures	☐	☐	☐
Defective parts	☐	☐	☐
Incorrect assembly	☐	☐	☐
In-process damage	☐	☐	☐
Mis-feeds	☐	☐	☐
Cleaning and lubrication	☐	☐	☐
Waiting for parts/tools	☐	☐	☐
Machine/Equipment jams	☐	☐	☐
Obstructed supply chain	☐	☐	☐
Blocked sensors	☐	☐	☐
Inefficient operators	☐	☐	☐
Wear of machinery	☐	☐	☐

Question 5

Following your response in Question 2, briefly state the rationale behind how, in your opinion the incorporation of TPM would have resulted in the increase, decrease or otherwise of each respective OEE loss.

OEE loss	**Possible cause of result stated in Question 3**
Change-overs	
Machine malfunction	
Material shortage	
Absent operators	
Machine breakdowns	
Unplanned maintenance	
Tool failures	
Defective parts	
Incorrect assembly	
In-process damage	
Mis-feeds	
Waiting for parts/tools	
Machine/Equipment jams	
Obstructed supply chain	
Blocked sensors	
Inefficient operators	
Wear of machinery	

Thank you very much for completing this questionnaire, the information that you have shared is greatly valued!

Appendix C – Factory attendance

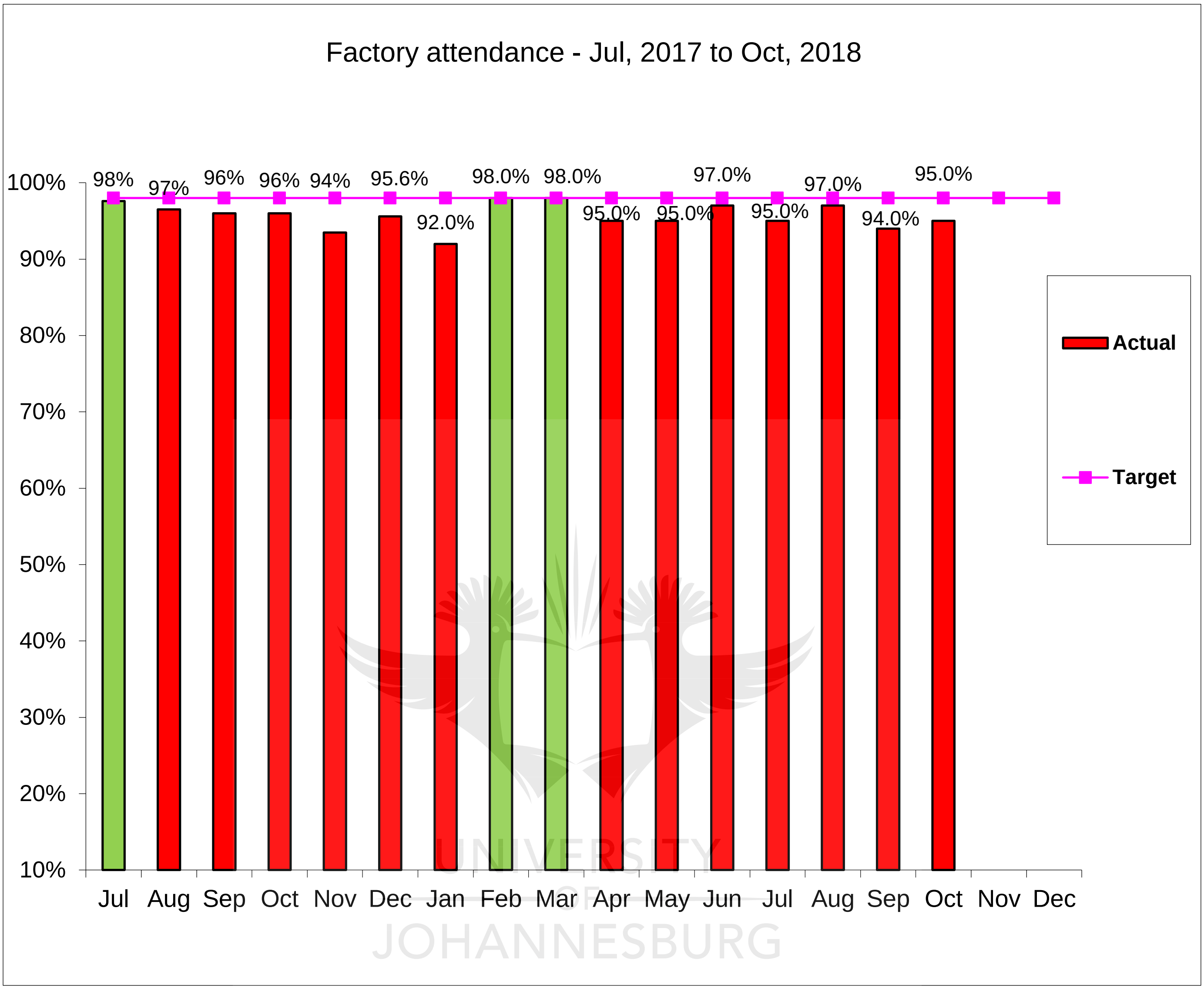

Figure 21: Absenteeism statistics