Cape Peninsula
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IMPACT OF LEAN MANUFACTURING TOOLS ON MAINTENANCE MANAGEMENT AT A MANUFACTURING PLANT IN THE WESTERN CAPE

by

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DECLARATION

I, Gershwin Herschel Cornelius, declare that the contents of this dissertation represent my own work and that the dissertation has not previously been submitted for academic examination towards any qualification.

I acknowledge that the AI-based tool, ChatGPT, was used solely for refining grammar, improving readability, and assisting with proofreading throughout the duration of my mini thesis, from 2022 to 2024. The specific prompt used was: "Ensure correct grammar, tense consistency, spelling, punctuation, and enhance professionalism."

The AI tool was employed to enhance the clarity and presentation of my original work, which significantly improved the overall readability of the dissertation. However, the intellectual content, arguments, and conclusions of this thesis remain entirely my own. Furthermore, it represents my own opinions and not necessarily those of the Cape Peninsula University of Technology.

Signed

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ABSTRACT

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The research project is conducted in the maintenance department at a manufacturing company in the Western Cape, South Africa. Since the implementation of world class manufacturing, lean management has become increasingly recognised as highly desirable for manufacturing organisations. Lean tools provide data to inform the company of various losses, while production and maintenance departments can utilise this to improve productivity.

The research project investigates the impact of Mean Time to Repair (MTTR) in relation to the Overall Equipment Effectiveness (OEE). Organisations often turn to further investments when increasing their productivity. By proper utilisation of these lean tools, organisations can increase productivity via understanding the lean tools and with corrective actions which do not include hefty machine investments

The primary research objectives of this study are the following:

- To determine if a common trend between MTTR and OEE within a manufacturing plant in the Western Cape
- To determine whether an increase in MTTR results in a decrease in OEE within a manufacturing plant in the Western Cape.
- To determine whether the MTTR trend increases positively with the reduction of the six major losses within a manufacturing plant in the Western Cape

This research aims to improve productivity through the implementation of lean tools in maintenance management.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF EQUATIONS

LIST OF TABLES

GLOSSARY OF TERMS

Mean Time to Repair (MTTR):	The average time it takes to repair a system.
Key Performance Indicator (KPI):	A measurable value that demonstrates how effectively an organisation, team, or individual achieves a specific business objective.
Overall Equipment Effectiveness (OEE):	Measure of how well a manufacturing operation is utilised compared to its full potential, during the periods when it is scheduled to run.
Single Minute Exchange of Dies (SMED):	A lean manufacturing technique aimed at reducing the time it takes to switch from one production process or setup to another.
Systems, Applications, and Products (SAP):	A software company known for its enterprise resource planning systems that integrate and streamline various business processes, including finance, human resources, supply chain, manufacturing, and maintenance management.
Total Productive Maintenance (TPM):	Management strategy aimed at improving the efficiency and effectiveness of production equipment by minimising downtime and maximising productivity

CHAPTER 1: INTRODUCTION

1.1. Introduction and Motivation

Around the world, companies in the manufacturing industry are required to supply, as per customer requirements, on time and in full. When any capacity related problem arises, management instantly looks ahead to increment in the number of shifts, increases of overtime and the purchase of new equipment or machines (Nallusamy et al., 2018)

During manufacturing, the machines play a pivotal role in keeping production smooth (Nurprihatin et al., 2019). Conversely, the focus should remain on harnessing better resources and the surging in performance of the machines that already exist, which could result in reducing bottlenecks, improvising the performance of equipment, curbing overall downtime, encouraging operator performance efficiency and reducing setup time, and other losses, hence aiding in the decision on the investment of new machines (Nallusamy et al., 2018).

The commencement of lean manufacturing was developed to reduce downtime and waste in the automobile sector. De Steur et al. (2016) described it as a system that uses fewer resources to produce the same outputs while delivering greater value to customers.

When it comes to capacity related problems, organisations instantly look ahead to an increment in the number of shifts, increases in overtimes and purchases of new equipment or machines. However, even industry leaders and trademark giants with no shortage of capital, where possible, should not invest in the purchase of new machinery if the existing machinery is not correctly utilised with an Overall Equipment Effectiveness (OEE) exceeding 85%. World Class Manufacturing informs one that OEE should be one of the production's KPIs with a target of more than 85%. Maintenance, a service provider to the operations/production department, must ensure that production meets their KPI. Theoretically, this means that if the OEE of over 85% is achieved, the availability + performance + quality losses are all less than 15% (Lakhoet al., 2020). In turn, this means less waste, which means leaner capacity, ultimately reducing costs and increasing profits.

Kedaria & Deshpande (2014) explained the eight pillars of total productive maintenance (TPM) and its relationship with Mean Time to repair (MTTR). It is important to understand that correctly implementing these two key performance indicators (KPIs) will allow for better management and allocation of maintenance resources, which will increase machine availability, directly proportional to OEE.

1.2. Background

Total productive maintenance is one of the planning methods used to increase both the quantity and quality of output via the evaluation of a company's people, procedures, and machinery. OEE, which is an acceptable performance evaluation for overall equipment effectiveness to boost productivity, is one of the fundamental metrics linked to total productive maintenance (TPM) (Tobe et al.,2018).

Tobe et al. (2018) conducted a study outlining the procedures and computational findings related to OEE, loss detection, and its contributing components. Data is obtained from both direct field observation and conversations with relevant sources. Tobe et al. (2018) concludes that the dominant factor of losses is high machine downtime.

OEE can be classified into six major losses. Machine Downtime only forms part of the availability loss. According to Tobe, the six major losses can be ascribed to the below:

1.2.1. Machine Failure:

Machine failure, a pervasive challenge in manufacturing, refers to the unforeseen breakdown or malfunction of industrial equipment, disrupting normal production processes and leading to downtime, increased maintenance costs, and potential safety hazards (Nakajima, 1988). This phenomenon encompasses various issues, including mechanical breakdowns, electrical failures, and system malfunctions, often resulting from factors such as wear and tear, inadequate maintenance, manufacturing defects, environmental conditions, or human error. Addressing machine failures is crucial for optimising overall equipment effectiveness (OEE) and minimising operational disruptions. Proactive maintenance strategies, such as preventive maintenance and condition monitoring, play a vital role in mitigating the impact of machine failures by identifying and addressing potential issues before they lead to critical breakdowns (Hansen, 2001).

1.2.2. Setup and Adjustment:

These are the production times lost due to adjusting the equipment. High set-up times may be cut in half by using one of TPM's tools, Single Minute Exchange of Dies (SMED). The implementation of SMED enables manufacturing companies to become more competitive by achieving several key outcomes: a reduction in lot sizes, decreased setup times, lower planning and scheduling overheads, elimination of waste, and more efficient use of material resources. As a result, SMED supports the production of high-quality products that consistently meet customer requirements.

1.2.3. Minor Stoppages:

According to Tobe et al: 2018, idling and minor stoppages occur when machinery stops for a brief while. He emphasised that blockages, flow obstructions, incorrect settings, and cleaning can all contribute to it.

1.2.4. Decreased Speed:

Also referred to as sluggish cycles, reduced speed is the difference between a machine's design speed and its actual operating speed, according to Vijayakumar and Gajendran (2014). Reduced speed can be caused by a variety of factors, including poor equipment maintenance and unfavourable climatic conditions.

1.2.5. Defects and Reworks:

These are losses experienced as a result of machinery and equipment failing to produce goods of set quality. Okpala and Anozie (2018) describe defect and rework losses as involving several types of inefficiencies, such as losses in production time and volume due to defective items, financial losses from product downgrading, and the additional time required to repair faulty products so they can be turned into completed items.

1.2.6. Reduced Yield:

Sakti et al. (2019) explain that reduced yield pertains to the inefficiencies encountered during the time it takes for a machine to produce items that meet the required quality standards, leading to losses in production output. They noticed that reduced yield is brought on by faulty equipment handling and installation as well as unpredictable working circumstances.

Improving any of the six losses will give a positive OEE, although availability losses such as machine breakdowns is the most dominant, improvements to OEE can be made by improving any of the six losses. Mean time to repair (MTR) is a measurement tool used in lean manufacturing. This can aid maintenance managers in the tracking of results once the six losses are addressed.

1.3. Research Problem Statement

As previously explored, the six major losses as defined by OEE, are machine failures, setup and adjustment, minor stops, decreased speeds, reworks and reduced yields. These six losses can be grouped into three categories, namely, quality losses, availability losses and performance losses. These losses severely affect the productivity and it is against this background that the research problem has been formulated to read as follows:
The lack of accurate application of OEE, can result in an adverse impact on productivity.

With the correct measurement tools, such as MTTR, tracking these losses can guide organisations to increase the operational outputs without major capital expenditure. This research work therefore seeks to address the six major losses, with a specific focus on MTTR and its relationship with OEE, at a manufacturing company in the Western Cape.

1.4. Associated Research Questions

The primary research question for this dissertation reads as follows: Can lean manufacturing tools be applied within the maintenance department of a manufacturing plant in the Western Cape to address the major losses during manufacturing?

The investigative questions in support of the primary research question are listed below.

- What is the relationship between MTTR and OEE?
- How will manipulating the downtime by an increase of 50% impact OEE and MTTR?
- How do the six major losses affect MTTR?

1.5. Primary Research Objectives

The primary objective of this study is to determine whether lean manufacturing tools within the maintenance department of a manufacturing plant in the Western Cape could be used to reduce the impact of losses on manufacturing time. The secondary research objectives for this study are:

- To determine whether there is a common trend between MTTR and OEE within a manufacturing plant in the Western Cape
- To determine whether MTTR increase will result in OEE decrease within a manufacturing plant in the Western Cape
- To determine whether the MTTR trend increases positively with the reduction of the six major losses within a manufacturing plant in the Western Cape

1.6 Research Process

The research process serves as a detailed guide on how the research study will be conducted from the identification of the research topic to the final submission of the dissertation.

The six fundamental phases according to Collis and Hussey (2009) are as follow:

- Select the research topic and search for the literature to examine the current body of knowledge, thereby obtaining relevant information.
- Conduct a literature review to formulate and define the research problem and research questions.

- Design the research methodology to determine how the research will be conducted and write the research proposal.
- Conduct data collection.
- The analysis and interpretation of the research data collected.
- To write the research dissertation, thesis or report.

1.7 Research Assumption

Leedy and Ormrod (2015:62), claim that research assumptions are integral to research and without them there would be no reason for any study. These authors further assert that it is important to disclose all assumptions that could affect the problem to prevent any misinterpretations because if others know the assumptions made, they can better assess the conclusions made from such assumptions.

The following research assumptions are made for this research study:

The assumptions for this research study include the accuracy and reliability of the Systems, Applications, and Products (SAP) maintenance module in recording MTTR data and the OEE data collected via Microsoft Excel, including manual inputs for various factors. It is assumed that these manual inputs are consistently accurate, and that the selected case studies are representative of typical operational conditions, producing measurable effects on MTTR and OEE. The research questions are assumed to be relevant for understanding maintenance management and its impact on operational efficiency. The sample data from September to November 2023 is assumed to be sufficient to capture meaningful trends, with accurate data input by competent staff. Integrating downtime into the OEE formula is expected to provide clear insights, and the data collection tools are assumed to function correctly. External factors are assumed to be negligible, and the calculated metrics can be reliably compared to industry benchmarks. These assumptions ensure a transparent, methodical approach, yielding reliable insights into maintenance management and operational efficiency.

1.8 Research Constraints

Limitations in research are characterised as weaknesses or deficiencies within the study, while delimitations refer to the choices made by the researcher to define the scope and boundaries of the research (Collis & Hussey, 2009). Limitations typically involve factors outside the researcher's control, such as sample size or external conditions, whereas delimitations are intentional decisions made to focus the study on specific areas.

The research relies heavily on live data obtained from a manufacturing plant, specifically using the SAP maintenance module. Constraints related to the availability and accuracy of this data may impact the robustness of the analysis. Incomplete or inaccurate data could compromise the validity of findings.

1.9 Ethics

Research ethics involve a set of principles that guide researchers to conduct their work ethically (Christensen et al., 2015). According to Thomas and Hodges (2010), these ethics represent the standards of professional conduct that researchers must maintain when interacting with research participants, funders, colleagues, and the wider community. They also emphasise that these standards encompass the researcher’s duty to ensure that the study is planned and executed safely, equitably, and with integrity.

In the context of this thesis, which does not involve human participants but rather utilises research and live data systems, confidentiality and anonymity concerns related to individuals do not apply. Instead, the focus will be on adhering to data privacy and security regulations, securing access to the data, and following ethical guidelines for handling and analysing the data provided by the manufacturing plant, ensuring that proprietary and sensitive information remains confidential.

1.10 Chapter Content Analysis

Chapter 1: **The scope of the research:** This chapter provides a brief introduction and background to the research problem, therefore outlining the crux of the study.

Chapter 2: **Purpose of the study:** This chapter elaborates on the significance and value of this research.

Chapter 3: **Literature review:** In this chapter, a literature review will be performed.

Chapter 4 – Research design and methodology: In this chapter, the design and methodology to be used within the ambit of this dissertation will be elaborated upon in detail**.**

Chapter 5 –Analysis and interpretation of data: In this chapter, data gleaned from the data collection conducted within the ambit of Chapter 4 will be analysed and interpreted.

Chapter 6 – Conclusions: In this chapter, the research will be concluded, to mitigate the research problem.

1.11 Conclusion

In this chapter an introduction and motivation were provided to substantiate the need for the research to be conducted.

CHAPTER 2: PURPOSE OF THE STUDY

2.1. Significance of the Study:

The research on the interplay between MTTR and OEE within the manufacturing industry holds substantial significance due to its potential contributions and implications (Tobe et al., 2018). The study aims to provide valuable insights and bring about positive change in maintenance management practices, operational efficiency, and decision-making within manufacturing contexts. The significance of the study can be delineated -under the following eight subheadings:

2.1.1. Enhancing Maintenance Strategies

The research delves into the relationships between key maintenance metrics, shedding light on how MTTR influences OEE (Hansen, 2001). By understanding these dynamics, manufacturing companies can enhance their maintenance strategies. Insights gained from the study can guide organisations in optimising maintenance processes, reducing downtime, and improving overall equipment reliability

2.1.2. Operational Efficiency Improvement

A primary focus of the research is to uncover ways in which positive trends in MTTR contribute to operational efficiency, as reflected in OEE (Hansen, 2001). The study's findings can be instrumental in helping manufacturing plants identify and address inefficiencies, leading to improved production speed, reduced defects, and enhanced overall operational efficiency.

2.1.3. Cost Reduction and Resource Optimisation

Efficient maintenance practices directly impact cost reduction by minimising downtime and associated losses (Hansen, 2001). By optimising MTTR, organisations can allocate resources more effectively, reducing unnecessary costs associated with prolonged downtimes, emergency repairs, and inefficient resource utilisation.

2.1.4. Strategic Decision-Making

The study provides a foundation for informed decision-making in management (Alhawamdeh & Alsmairat, 2019). Organisations can use the research findings to make strategic decisions about resource allocation, preventive maintenance planning, and equipment lifecycle management. This strategic approach ensures that decisions are grounded in data-driven insights.

2.1.5. Contribution to Academic and Industrial Knowledge

The research contributes to both academic and industrial knowledge by providing empirical evidence and insights into the relationships between maintenance metrics (Hansen, 2001). It adds to the existing body of literature on OEE, MTTR, and reliability maintenance. The findings may serve as a basis for further academic research and practical applications in the manufacturing sector.

2.1.6. Benchmarking and Best Practices

The study can serve as a benchmark for manufacturing organisations to evaluate their own maintenance practices against industry best practices (Hansen, 2001). By adopting strategies that align with the findings, companies can strive to achieve and surpass world-class OEE benchmarks, thereby improving their competitive position.

2.1.7. Alignment with Industry 4.0 and Smart Manufacturing

In the context of Industry 4.0 and smart manufacturing initiatives, the study aligns with the broader trend of leveraging data and technology for enhanced efficiency (Lee et al., 2015). The findings may guide organisations in integrating digital solutions and predictive maintenance technologies to further optimise maintenance processes.

2.1.8. Long-Term Sustainability

Implementing effective maintenance strategies based on the study's findings contributes to the long-term sustainability of manufacturing operations (Nicolini & Resta, 2017). By reducing waste, enhancing quality, and ensuring the reliability of equipment, organisations can build a foundation for sustained growth and resilience in a dynamic industrial landscape.

2.2. Chapter Summary

In summary, the significance of this study lies in its potential to drive positive changes in maintenance management, improve operational efficiency, and contribute valuable knowledge to both academic and industrial communities. The research aims to empower manufacturing organisations with insights that foster innovation, competitiveness, and long-term sustainability.

CHAPTER 3: LITERATURE REVIEW

Chapter Three provides a relatable literature review by assessing and reviewing previous research and emerging trends obtained from several sources such as peer-reviewed journals, and the internet. Moreover, the review is based on the research questions and objectives highlighted in Chapter One of this mini dissertation.

The following topics will be discussed:

- Lean Manufacturing
- Overall Equipment Effectiveness
- Total Productive Maintenance and Overall Equipment Effectiveness
- Mean Time to Repair
- Reliability Maintenance
- Comparison of OEE Calculation Methods
- Application of OEE in Different Industries

3.1. Lean Manufacturing

Lean manufacturing has emerged as a dominant paradigm in contemporary manufacturing practices, aimed at optimising operational processes, reducing waste, and enhancing overall productivity. Within this framework, the relationship between lean principles and key performance indicators (KPIs) such as MTTR and OEE has garnered significant attention. This literature review delves into the interconnectedness of lean manufacturing practices with MTTR and OEE, elucidating how the implementation of lean methodologies influences maintenance efficiency and equipment performance.

Integration of Lean Principles in Manufacturing:

Lean manufacturing principles, rooted in the Toyota Production System (TPS), prioritise the elimination of non-value-added activities, continuous improvement, and the pursuit of operational excellence (Womack et al., 1990). By fostering a culture of waste reduction, standardised work, and continuous flow, lean organisations strive to optimise resource utilisation and enhance customer value (Shah & Ward, 2003). Central to lean philosophy is the notion of Kaizen, or continuous improvement, which encourages employees at all levels to identify and address inefficiencies in processes (Imai, 1986).

Impact of Lean Practices on MTTR:

MTTR is a critical maintenance metric that quantifies the average time required to repair equipment following a breakdown. Research indicates a strong correlation between the adoption of lean practices and improvements in MTTR (Al-Najjar & Alsyouf, 2003). By implementing lean methodologies such as Total Productive Maintenance (TPM), visual management, and error-proofing techniques, organisations can streamline maintenance processes, reduce downtime, and enhance responsiveness to equipment failures (Al-Najjar & Alsyouf, 2003; Bhasin & Burcher, 2006). Moreover, the empowerment of frontline employees to engage in problem-solving activities and conduct root cause analysis contributes to the expeditious resolution of maintenance issues (Parida et al., 2007).

Impact of Lean Practices on OEE:

OEE is a comprehensive metric that assesses the overall performance of equipment by considering availability, performance efficiency, and quality rate (Nakajima, 1988). Lean manufacturing practices exert a profound influence on OEE by optimising each component of the OEE equation. For instance, initiatives such as setup time reduction, standardised work, and autonomous maintenance contribute to increased equipment availability (Shingo, 1985). Similarly, improvements in production flow, cycle time reduction, and defect prevention enhance performance efficiency and quality rates (Shingo, 1985). As a result, organisations that embrace lean principles often experience significant enhancements in OEE, reflecting improved equipment utilisation and effectiveness (Nakajima, 1988; Rother & Shook, 2003).

3.2. Overall Equipment Effectiveness

Okpala and Anozie (2018) noted that OEE is a useful tool for examining equipment performance since it also considers the six biggest losses. The function truly evaluates equipment losses, they pointed out, and it depends on quality, performance rate, and availability.

The introduction of TPM in the context of lean management gave rise to OEE, which Adolph et al. (2016) said is a popular method for gauging the effectiveness of production equipment. In TPM, OEE, a fundamental quantitative metric, is used to assess the effectiveness of a productive system. OEE methodology incorporates metrics from all equipment manufacturing guidelines into a measuring system that aids manufacturing and operation teams in enhancing equipment performance and lowering maintenance costs, according to Ravishankar et al. (1992).

By locating pertinent performance opportunities, OEE may raise machine performance. Its metric, which assesses and improves machine dependability, product quality, and changeover improvements, is the ratio of an equipment’s actual production to its maximum theoretical output, Okpala and Anozie (2018).

The six key categories of TPM's six significant losses are shown in Figure 1 and include breakdown losses, changeover and setup losses, defect and rework losses, start-up losses, speed losses, and idling and small stoppage losses.

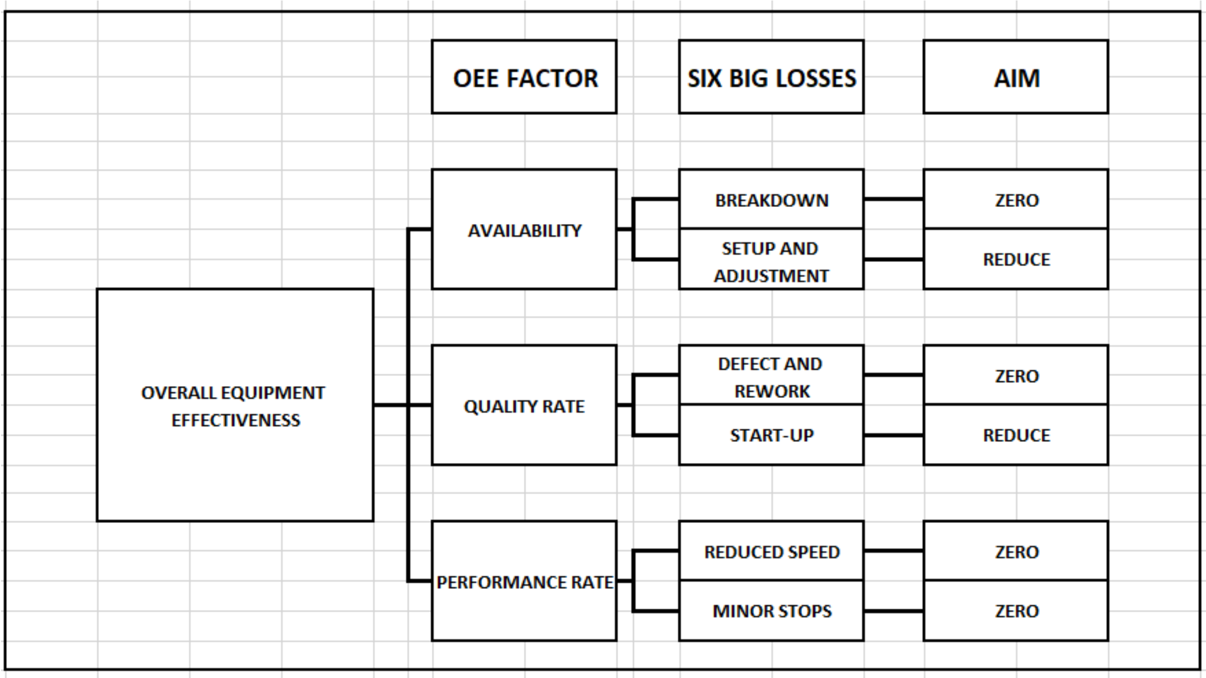

Figure 3.1: A model of overall equipment effectiveness [Adapted from Okpala and Anozie, (2018)].

According to Dal et al. (2000), OEE may be calculated based on the six major losses by calculating the product of quality losses, availability losses and performance losses.

Availability losses (A):

a. Machine breakdowns. This includes all failures on the machines that result in loss of production time.

b. Setup and adjustment. This is the downtime taken from the last good part to the first good part. All physical changeover and quality approvals for the first good part are included here.

Quality losses (Q):

a. Defects and rejects. This is the defective parts produced by the machine during the production run.

b. Start-up losses. The start-up rejects produced by the machine before obtaining the first good part. Set up scrap.

Performance losses (P):

c. Minor stops. These are all the minor blockages due to minor malfunctions of the machine. These malfunctions are usually resolved by the operator with no maintenance department support.

d. Reduced speeds. The machine runs at reduced speeds resulting in lower outputs.

The above six losses are calculated in the components of OEE.

$$OEE = A * P * Q$$

Equation 3.1: Formula for calculating OEE: Source Nakajima, S. (1988)

Where;

$$A = \left(\frac{Total\ Planned\ Production\ Time - \ Total\ Downtime\ Losses}{Total\ Planned\ Production\ Time}\right) * \ 100$$

Equation 3.2: Formula for calculating Availability within OEE: Source Okpala, and Anozie, (2018)

$$P = \left(\frac{Cycle\ Time * Total\ Pieces\ Produced}{Total\ Planned\ Production\ Time - \ Total\ Downtime\ Losses}\right) * \ 100$$

Equation 3.3: Formula for calculating Performance losses within OEE: Source Okpala, and Anozie, (2018).

$$Q = \left(\frac{Total\ Pieces\ Produced - Defective\ Parts\ Produced}{Total\ Pieces\ Produced}\right) * 100$$

Equation 3.4: Formula for calculating Quality losses within OEE: Source Okpala, and Anozie, (2018).

The manufacturing organisation’s maintenance performance is assessed using the world-class OEE as a standard. This benchmark is also used to strengthen the maintenance policy and to drive continual improvement in the manufacturing systems. Table 3.1 shows that the OEE, Availability, Performance rate, and Quality rate world class targets are 85, better than 90%, greater than 95%, and greater than 99%, respectively. The manufacturing organisation is considered to be in excellent condition if the computed OEE is equivalent to world class OEE, but if the OEE is lower, immediate improvement of maintenance policies and strategies is needed; or else, the manufacturing organisation would find it challenging to sustain it.

Table 3.1: World class goals for OEE Source: Nakajima, (1988)

OEE Factors	**World Class Rate (%)**
Availability	>90
Performance Rate	>95
Quality Rate	>99
OEE	> 85

3.3. Total Productive Maintenance and Overall Equipment Effectiveness

In the context of contemporary manufacturing, achieving optimal operational efficiency has become a paramount objective. Two significant methodologies contributing to this endeavour are TPM and OEE. TPM, as introduced by Adolph et al. (2016), is recognised as a comprehensive system for maintaining and improving the integrity of production and quality systems. Its core principles revolve around preventive and predictive maintenance, aiming to minimise downtime and enhance productivity.

The literature indicates a growing body of research exploring the integration and synergy between TPM and OEE. Nakajima (1988) emphasises that the incorporation of TPM principles can significantly enhance OEE by addressing equipment failure downtime, a notable contributor to availability losses. This alignment involves adopting proactive maintenance practices that resonate with OEE metrics, fostering a culture of continuous improvement.

This literature underscores the symbiotic relationship between TPM and OEE. Organisations aiming for manufacturing excellence can leverage TPM's proactive maintenance strategies to enhance OEE metrics, thereby fostering a culture of continuous improvement. The challenges identified in integrating these methodologies highlight the importance of a holistic approach, acknowledging both technical and human factors in the pursuit of operational efficiency.

3.4. Mean Time to Repair

Maintenance management plays a pivotal role in sustaining the efficiency and reliability of industrial systems. This literature review delves into the importance of MTTR within the realm of maintenance management, emphasising its impact on operational continuity and overall equipment reliability.

MTTR, as a key metric in maintenance management, represents the average time required to restore a system or equipment to operational status following a failure. MTTR is linked to the reduction of downtime. In maintenance management, the primary objective is to swiftly address and resolve equipment failures to minimise disruptions to production schedules.

Maintenance management strategies often focus on optimising MTTR to enhance overall operational efficiency. By implementing effective maintenance planning, scheduling, and execution, organisations can streamline repair processes, thereby improving the speed and effectiveness of corrective actions (Moubray, 1997).

Efficient maintenance management involves the judicious allocation of resources. MTTR plays a crucial role in resource utilisation by influencing the planning of manpower, spare parts inventory, and equipment availability. Minimising MTTR allows organisations to allocate resources more effectively, reducing unnecessary costs associated with prolonged downtimes (Kelly, 2006).

Predictive maintenance strategies leverage technology and data analytics to forecast potential equipment failures. By proactively addressing issues before they lead to breakdowns, organisations can significantly reduce MTTR. Incorporating predictive maintenance into the overall maintenance management strategy enhances the reliability of assets (Parida & Kumar, 2007).

3.5. Reliability Maintenance

Reliability maintenance is a critical aspect of industrial management aimed at ensuring the continuous and optimal performance of machinery.

Reliability maintenance encompasses various proactive strategies designed to prevent equipment failures and maximise operational efficiency. These strategies include preventive maintenance, predictive maintenance, and condition-based maintenance (Moubray, 1997). Preventive maintenance involves scheduled inspections and component replacements to prevent failures, while predictive maintenance relies on data analysis and monitoring to predict when maintenance is required (Kelly, 2006). Condition-based maintenance utilises real-time equipment data to make maintenance decisions based on the actual condition of the machinery (Parida & Kumar, 2007).

The primary goal of reliability maintenance is to enhance machine availability, a crucial component of OEE. Availability is the ratio of the actual production time to the total available time.

Performance, another component of OEE, measures the speed at which equipment operates compared to its optimal speed. Reliability maintenance directly influences performance by addressing issues that may hinder machinery from operating at its full potential. Preventive maintenance, for instance, ensures that equipment operates at optimal performance levels by replacing worn-out components and addressing potential performance-related issues (Moubray, 1997).

Quality, the third component of OEE, measures the ratio of good-quality products to the total products produced. Reliability maintenance indirectly influences quality by minimising unexpected breakdowns and disruptions in the production process. Preventive maintenance practices ensure that machinery consistently produces products that meet quality standards, reducing the likelihood of defects and waste (Parida & Kumar, 2007).

3.6. Comparison of OEE Calculation Methods

The quest for operational excellence within the realm of manufacturing has led to the widespread adoption of performance metrics, which among OEE stands as a pivotal indicator. OEE encapsulates the efficiency of production processes by considering factors such as equipment availability, performance rate, and quality rate (Singh, Jain, & Bhatti, 2015). However, the calculation methods for OEE exhibit variations, prompting a critical examination of these approaches to enhance accuracy and applicability.

Abdulmalek and Rajgopal (2007) emphasised the integration of lean manufacturing principles and value stream mapping in OEE assessments. Their work laid the foundation for understanding OEE within the broader context of lean practices, setting the stage for subsequent research on the intricacies of calculation methods.

The literature reviewed highlights the significance of accurate OEE calculations and the need to carefully choose calculation methods. The integration of lean principles, comparative analyses, and real-world case studies collectively contribute to a nuanced understanding of OEE computation. Future research in this domain should continue to explore emerging methodologies and their implications for enhancing manufacturing efficiency.

3.7. Application of OEE in Different Industries

OEE has become a crucial metric in assessing the efficiency of production processes across diverse industries. This section explores how OEE is implemented and utilised in various sectors, showcasing its adaptability and impact on operational efficiency.

In the automotive industry, OEE is instrumental in enhancing productivity and minimising downtime by identifying and addressing inefficiencies in machine performance (Singh et al., 2015). This application has led to improved overall equipment performance and resource utilisation.

In the food and beverage industry, OEE is applied to enhance efficiency in processing and packaging operations. OEE methodologies help companies reduce waste, improve production speed, and maintain product quality, aligning with the industry's stringent standards (Abdulmalek & Rajgopal, 2007).

OEE has found relevance in the energy sector, where it assesses the performance of power generation facilities. By evaluating the efficiency of turbines, generators, and other equipment, OEE contributes to optimising energy production and minimising unplanned downtime, supporting the overall reliability and sustainability of energy generation processes.

The application of OEE is not confined to specific industries but extends to diverse sectors, including healthcare, logistics, and aerospace. In healthcare, OEE optimises the performance of medical equipment, ensuring seamless operations in critical settings (Singh et al., 2015). Logistics companies leverage OEE to enhance the efficiency of warehousing and distribution processes, leading to improved throughput and reduced operational costs.

The widespread application of OEE across different industries underscores its versatility and effectiveness in evaluating and improving operational performance. The adaptability of OEE makes it a valuable tool for organisations seeking to enhance productivity, reduce downtime, and maintain high standards of quality across various sectors.

3.8. Chapter Summary

Overall, this chapter provided an in-depth review of the literature on lean manufacturing, OEE, TPM, MTTR, and reliability maintenance. It elucidates how these concepts interrelate and contribute to optimising manufacturing efficiency and productivity, supported by empirical evidence and real-world applications across various industries. This comprehensive review sets the stage for further exploration and application of these methodologies in achieving operational excellence.

CHAPTER 4: RESEARCH METHODOLOGY

In this chapter the research design and methodology to be used within the ambit of this dissertation will be elaborated upon in detail. Leedy and Ormrod (2015) describe research as a systematic process involving the collection, analysis, and interpretation of information or data to enhance our understanding of a phenomenon of interest or concern.

4.1. Data Collection Design and Methodology

In the pursuit of enhancing maintenance strategies and operational efficiency within a manufacturing context, this research employs a comprehensive quantitative analysis of live data obtained from a manufacturing plant. The focal points of investigation include MTTR and OEE. The primary goal is to contribute valuable insights to the discourse on maintenance management strategies and their profound impact on operational efficiency.

Data Collection and Analysis Protocol:

Commencing with a robust quantitative methodology, the research spans data analysis across September, October, and November of 2023. The SAP maintenance module, renowned for its accuracy, will serve as the primary data source for obtaining MTTR data. Utilising case studies, downtime inputs will be manipulated to showcase scenarios of varying downtime, allowing for a nuanced examination of the consequential effects on MTTR.

To gather data on the OEE of the manufacturing plant located in the Western Cape, historical records will be retrieved from the plant's daily OEE tracking tool. This tool, developed within Microsoft Excel, features manual inputs including machine speed, machine losses, production outputs, planned downtime and other relevant factors. These inputs enable the calculation of performance, availability, and quality losses, which are pivotal for this study's analysis.

Following the acquisition of these metrics, a comparative analysis will be conducted, juxtaposing MTTR with OEE to discern correlations and patterns. Furthermore, the integration of downtime into the availability formula of OEE will provide additional insights into the direct influence of downtime on OEE scores. Graphical representations of case studies, emphasising higher and lower downtime scenarios, will visually illustrate the impact on OEE, MTTR. A meticulous comparative analysis of manipulating downtime on OEE with MTTR will be undertaken to unravel the interconnected dynamics of these maintenance metrics.

The methodology extends to address Investigative Question 2, which shifts focus to the six major losses. Similar to the approach, the impact of manipulated downtime, quality defects and performance losses will be examined.

Investigative Question 3 will involve a graphical representation plotting OEE against MTTR, utilising the same downtime variable. This visual exploration aims to establish and elucidate the relationship between these two critical metrics. As downtime improves, at what point will a positive trend in MTTR and OEE reflect?

This comprehensive methodology is meticulously structured to unveil nuanced insights into the interplay of MTTR, and OEE within a manufacturing environment. By leveraging live data and employing a multifaceted approach, the research aims to provide a solid foundation for informed decision-making in maintenance management. The overarching goal is to contribute to continuous improvement in manufacturing processes, ultimately optimising operational efficiency and reliability.

4.2. Ethics

Research ethics involve a set of guidelines that researchers must adhere to in order to conduct ethical research (Christensen et al., 2015). According to Thomas and Hodges (2010), research ethics are the standards of professional conduct that researchers need to maintain when interacting with research participants, funders, colleagues, and the broader community. These standards also include the researcher's responsibility to ensure that the research is designed and executed in a safe, fair, and ethical manner.

According to Leedy and Ormrod (2015), most ethical issues fall within one of four categories namely protection from harm, voluntary and informed participation, right to privacy and honesty with professional colleagues. These categories will be expanded upon below.

- **Protection from harm:** Participants should be protected against unnecessary physical or psychological harm whether it is human or animal participants. The general rule is that the risk of participating in the research study should not be significantly more than the normal day-to-day living of the participant. For example, the participant should not be at risk of losing a limb/life or be subjected to abnormal stress, embarrassment, or loss of confidence.

Voluntary and informed participation: Participants should be informed of the overall purpose of the study and should be given the choice to participate voluntarily. Participants should be informed that if they agree to participate, they can withdraw at any moment, and should not feel pressured by anyone regardless of their position. Written informed consent must be obtained from all participants.

- **Right to privacy:** Participants' right to privacy should be respected at all times. How a participant behaved or responded should under no circumstances be reported in a way that such information is revealed to other people unless written permission is granted. The quality and nature of participants' performance should be kept confidential at all times.

- **Honesty with professional colleagues:** Researchers should report research results completely and honestly. To not intentionally misrepresent or distort research findings, includes fabricating data to substantiate a specific conclusion as such action “constitutes scientific fraud” (Leedy & Ormrod, 2015).

  Potential ethical issues are acknowledged, particularly concerning data privacy and confidentiality. The collection of data related to maintenance practices may involve sensitive information about equipment performance. It is imperative to ensure the privacy and confidentiality of this data.

  In guaranteeing the quality and integrity of the research, a meticulous approach has been adopted. From design and methodology selection to data collection, analysis, and interpretation, each step has been carefully planned. Ethical considerations are paramount, and necessary approvals have been secured to safeguard data privacy. The transparency of methodologies, criteria, and limitations will be integral to reporting the research process clearly.

  To maintain the independence and objectivity of the research, a series of rigorous measures are being implemented. Clearly defined research objectives serve as a guiding framework, ensuring focus and objectivity. Peer review by experts in the field will subject the research to external scrutiny, enhancing transparency and minimising bias.

  Steps will be taken to prevent harm to the environment in the research on the impact of lean manufacturing tools in maintenance. This includes promoting sustainable data collection methods and prioritising digital data management to minimise resource consumption and waste generation.

  In the context of the research, there are no potential risks to individuals, communities, or the environment. The researcher is committed to ethical practices and ensures responsible conduct throughout the study.

4.3. Research Constraints

The research relies heavily on live data obtained from a manufacturing plant, specifically using the SAP maintenance module. Constraints related to the availability and accuracy of this data may impact the robustness of the analysis. Incomplete or inaccurate data could compromise the validity of the findings.

The study spans data analysis across three months (September, October, and November of 2023). The limited timeframe may pose constraints on the ability to capture long-term trends or seasonal variations that could affect maintenance metrics.

The research utilises case studies to manipulate downtime scenarios for analysis. Constraints may arise if the selected case studies do not adequately represent the diversity of situations in different manufacturing contexts, limiting the generalisability of the findings.

The reliance on the SAP maintenance module for MTTR data introduces constraints associated with the system's limitations. The SAP module may have specific functionalities or constraints that could affect the accuracy and comprehensiveness of the data.

The research considers manipulated downtime scenarios, but external factors beyond the scope of the study (e.g., unforeseen events, changes in regulations, or economic fluctuations) may influence downtime. These external factors are difficult to control and may introduce variability.

Resource constraints, including time and personnel, may limit the scope and scale of the research. Comprehensive data collection and analysis require adequate resources, and limitations in this regard may impact the thoroughness of the study.

Acknowledging and addressing these constraints in the research design and analysis is crucial for maintaining transparency and ensuring that the study's limitations are appropriately communicated. Additionally, researchers should strive to mitigate these constraints to the extent possible to enhance the reliability and validity of the findings.

4.4. Research Assumptions

Leedy and Ormrod (2015), claim that research assumptions are integral to research and without them there would be no reason for any study. These authors further assert that it’s important to disclose all assumptions that could affect the problem to prevent any misinterpretations because if others know the assumptions made, they can better assess the conclusions made from such assumptions.

The following research assumptions are made for this research study:

It is assumed that the SAP maintenance module accurately records and reports MTTR data. The system is presumed to be reliable and precise in capturing relevant maintenance events and durations.

The OEE data, collected via the plant's daily tracking tool in Microsoft Excel, is assumed to be accurate and reflective of actual operational conditions. This includes the manual inputs for machine speed, machine losses, production outputs, planned downtime, and other factors.

It is assumed that the manual inputs into the OEE tracking tool are consistently accurate and free from significant human error. This ensures that the data used for analysis is reliable.

The selected case studies for manipulating downtime scenarios are assumed to be representative of typical operational conditions within the manufacturing plant. These case studies are expected to provide a valid basis for examining the effects on MTTR and OEE.

It is assumed that the manipulated downtime scenarios will produce measurable and significant effects on MTTR and OEE, allowing for a clear analysis of the relationship between these variables.

The investigative questions posed in the research are assumed to be relevant and significant for understanding the dynamics of maintenance management and its impact on operational efficiency. This includes the focus on the six major losses and their correlation with MTTR and OEE.

The sample techniques used involved the download of the production data from Microsoft Excel which includes the planned production time, production volumes packed, losses and the line speeds for eight of the plant's production lines. This data was recorded for months September, October and November of year 2023. The three-month period (September, October, and November 2023) is assumed to be sufficient to capture meaningful data and identify trends in MTTR and OEE. The data is considered accurate as it is input by competent staff and the Excel formulas are verified daily. This timeframe is considered adequate for conducting a robust analysis.

It is assumed that integrating downtime into the availability formula of OEE will provide clear and insightful results on the direct influence of downtime on OEE scores.

The data collection tools and methodologies, including the SAP maintenance module and the Excel-based OEE tracking tool, are assumed to be functioning correctly and free from technical issues that could compromise data integrity.

It is assumed that external factors, such as changes in regulations or unforeseen events, will not significantly skew the data or the outcomes of the manipulated downtime scenarios. The research assumes a controlled environment where these external variables are either constant or negligible.

The study assumes that the calculated OEE and MTTR metrics can be reliably compared against industry benchmarks and world-class standards to validate the findings.

By clearly stating these assumptions, the research methodology is grounded in a transparent and methodical approach, ensuring that the data collected, and the subsequent analysis will yield meaningful and reliable insights into maintenance management and operational efficiency.

4.5. Delineation of the Research

The research aims to explore the intricate dynamics of maintenance management within the manufacturing industry, with a specific focus on the interplay between MTTR and OEE. The delineation of the research involves a systematic investigation into the relationships and impacts of these key maintenance metrics on operational efficiency. The following delineation provides a structured overview of the research components:

The research is situated within the manufacturing sector, where companies face the challenge of maintaining optimal production operations. The study draws insights from a manufacturing plant, employing live data obtained from the SAP maintenance module to ensure relevance to real-world scenarios.

The central metrics under investigation are MTTR and OEE. MTTR represents the average time required to restore equipment to operational status after a failure and OEE is a composite metric gauging overall equipment efficiency. The study aims to delineate the roles and interactions of these metrics in influencing manufacturing performance.

The research unfolds over a specific timeframe, spanning September, October, and November of 2023. This temporal scope is chosen to capture a snapshot of maintenance dynamics during this period and to observe trends and variations.

The study employs a robust quantitative analysis, leveraging live data from the SAP maintenance module. Case studies are utilised to manipulate downtime scenarios, allowing for a nuanced examination of the consequential effects on MTTR and OEE. The data collection methodology is designed to provide a comprehensive understanding of maintenance metrics within the manufacturing context.

The research addresses three investigative questions:

Investigative Question 1: Examines the relationship between positive MTTR results and a positive OEE.

Investigative Question 2: Explores how manipulating the downtime by an increase of 50% will impact MTTR and OEE.

Investigative Question 3: Investigates how a positive trend in MTTR correlates with a reduction in the six major losses, namely machine failures, setup and adjustment, minor stops, decreased speeds, reworks, and reduced yields.

The literature review provides a theoretical framework for the research, exploring concepts such as OEE, the six major losses, MTTR, and reliability maintenance. It establishes a foundation for understanding the significance of these metrics and their implications in maintenance management.

The study delineates the potential implications of its findings on maintenance strategies within the manufacturing sector. It aims to contribute valuable insights to the discourse on maintenance management, guiding decisions for enhancing operational efficiency.

By delineating these components, the research establishes a structured framework for investigating the complex relationship between maintenance metrics and their impact on manufacturing performance. The systematic approach ensures clarity and transparency in the research design and methodology.

4.6. Data Validity and Reliability

Data validity in this dissertation ensures that the measurements accurately reflect the constructs of MTTR and OEE in the context of manufacturing maintenance and operational efficiency. To achieve high data validity, the following measures were implemented:

The constructs of MTTR and OEE are measured using well-established frameworks and methodologies in maintenance management. These frameworks are rooted in theoretical foundations and best practices in the industry.

The data on MTTR is sourced from the SAP maintenance module, which is known for its precision and comprehensiveness in capturing maintenance-related data. OEE data is derived from a detailed daily tracking tool within Microsoft Excel, ensuring a wide range of relevant factors are considered.

The use of case studies with manipulated downtime scenarios provides a thorough examination of how varying conditions affect MTTR and OEE, ensuring that the study captures a broad spectrum of possible operational scenarios.

The calculated MTTR and OEE metrics are compared against industry benchmarks and world-class standards, ensuring that the data reflects true operational performance.

The study uses historical records from the manufacturing plant's daily OEE tracking tool, ensuring that the data is rooted in real-world operations and conditions.

The study controls for various factors such as machine speed, production outputs, and planned downtime, ensuring that the observed effects on MTTR and OEE are due to the manipulated variables rather than external confounders.

Data reliability ensures the consistency and stability of the measurements of MTTR and OEE over time. The following strategies were employed to achieve high data reliability:

A subset of data collection instruments and methodologies were applied multiple times to the same scenarios at different points in time to verify consistency in the measurements.

Regular calibration and maintenance of data collection tools, especially those used in capturing machine performance and downtime, were conducted to ensure the accuracy and reliability of the measurements.

By implementing these rigorous measures, the study ensures that the data collected is both valid and reliable, providing a solid foundation for drawing meaningful and actionable conclusions. The careful attention to data quality enhances the credibility and robustness of the research findings, which are crucial for informed decision-making in maintenance management and operational efficiency within the manufacturing context.

In summary, the approach to data validity and reliability involves meticulous planning, comprehensive data sources and controlled experimental designs. These efforts collectively ensure that the research outcomes are trustworthy and valuable for advancing maintenance strategies and improving operational efficiency in manufacturing processes.

4.7. Chapter Summary

This chapter provides a robust foundation for the research by detailing the data collection design, ethical considerations, constraints, assumptions, and methodologies. By ensuring high data validity and reliability, the study aims to produce trustworthy and actionable insights. The comprehensive approach outlined in this chapter sets the stage for analysing the interplay between MTTR and OEE, ultimately contributing to enhanced maintenance strategies and operational efficiency in the manufacturing sector. The meticulous planning and rigorous methodologies ensure that the research findings will be credible and valuable, guiding informed decision-making in maintenance management.

CHAPTER 5: RESEARCH FINDINGS

5.1. Establishing The Commonalities Between Mean Time to Repair and Overall Equipment Efficiency.

The tables 5.1 to 5.7 below offer a comprehensive overview of the OEE at a manufacturing plant over the course of three months: September, October, and November 2023. The below is summarised to the first 5 days, refer to Appendix A for full tables.

According to Tobe et al: 2018, OEE is a crucial performance metric that assesses the efficiency of manufacturing processes by evaluating three key components: availability, performance, and quality. The data presented in the tables are derived from real-time monitoring systems and reflect the daily performance of the manufacturing operations.

Table 5.1: OEE at a manufacturing plant for September 2023

September 2023 - OEE				
Day	**Availability**	**Performance**	**Quality**	**OEE**
1	91%	87%	95%	75%
2	88%	96%	78%	66%
3	86%	85%	70%	51%
4	88%	87%	90%	68%
5	86%	92%	79%	62%

Table 5.2: OEE at a manufacturing plant for October 2023

October 2023 – OEE				
Day	**Availability**	**Performance**	**Quality**	**OEE**
1	82%	89%	81%	60%
2	92%	89%	73%	60%
3	91%	88%	78%	63%
4	94%	86%	84%	68%
5	94%	87%	81%	67%

Table 5.3: OEE at a manufacturing plant for November 2023

November 2023 – OEE				
Day	**Availability**	**Performance**	**Quality**	**OEE**
1	91%	85%	78%	61%
2	92%	86%	75%	60%
3	81%	80%	76%	49%
4	90%	87%	87%	67%
5	94%	89%	87%	73%

5.1.1. Interpretation and Analysis of OEE for September to November 2023:

Over the course of three months, the OEE data reflects distinct trends and patterns. September shows moderate fluctuations in OEE, starting at lower levels and improving gradually towards the end of the month, with values ranging from 45% to 72%. October follows a similar trend with more varied OEE levels, fluctuating between 39% and 83%. The highest values appear mid-month, followed by a slight decrease as the month concludes. In contrast, November displays greater stability, with OEE ranging from 49% to 81%, and generally holds higher levels than the previous months despite some variability.

Availability, performance, and quality each have unique impacts on OEE outcomes, with days of higher availability and performance generally resulting in better OEE levels. Variability in quality can lead to mixed effects on OEE. However, even exceptional performance or quality does not guarantee high OEE if availability is low, underscoring the importance of balanced metrics to achieve optimal OEE.

The analysis of OEE data for September, October, and November 2023 underscores the dynamic nature of manufacturing operations and the multifaceted factors influencing overall efficiency. While variability exists across the months, a consistent focus on improving availability, performance, and quality is essential for sustaining high levels of OEE. By leveraging real-time data insights and implementing targeted improvement initiatives, manufacturing plants can optimise their operations, reduce downtime, and drive continuous enhancement in productivity and competitiveness.

Mean Time To Repair is a critical metric in manufacturing, indicating the average time required to resolve equipment breakdowns and restore production. The data presented in Tables 5.4, 5.5 and 5.6 for September, October, and November 2023 respectively, offer insights into the maintenance efficiency and responsiveness of the manufacturing plant during each month. Mean Time To Repair is derived from the cumulative breakdown minutes and the number of breakdown occurrences, providing a measure of the plant's ability to swiftly address equipment failures.

Table 5.4: MTTR at a manufacturing plant for September 2023

September 2023 - MTTR			
Day	**Breakdown Min**	**Breakdown Occurrences**	**MTTR**
1	742	29	26
2	999	29	34
3	1283	28	46
4	1080	39	28
5	1144	36	32

Table 5.5: MTTR at a manufacturing plant for October 2023

October 2023 – MTTR			
Day	**Breakdown Min**	**Breakdown Occurrences**	**MTTR**
1	1563	21	74
2	674	42	16
3	732	35	21
4	565	24	24
5	510	12	43

Table 5.6: MTTR at a manufacturing plant for November 2023

November 2023 - MTTR			
Days	**Breakdown Min**	**Breakdown Occurrences**	**MTTR**
1	723	37	20
2	678	33	21
3	1748	49	36
4	1057	45	23
5	621	37	17

5.1.2. Interpretation and Analysis of MTTR for September to November 2023:

Throughout the three months, MTTR data reveals distinct monthly trends. September experiences significant MTTR variability, ranging from 10 to 52 minutes. The month starts with higher MTTR values that gradually decline, suggesting improvements in maintenance practices over time. October follows a similar trend, with MTTR ranging from 11 to 74 minutes. Initial high values progressively decrease, indicating increased maintenance efficiency. In

November, MTTR exhibits the widest range, fluctuating between 6 and 81 minutes, with intermittent high values that reflect some inconsistency in maintenance effectiveness.

The impact of availability, performance, and quality metrics on MTTR is also notable. Increased availability and performance typically result in lower MTTR, while quality variations seem to have a less direct effect. Nonetheless, high performance or quality alone does not necessarily reduce MTTR if availability is low, emphasizing the importance of balanced metrics for achieving optimal MTTR outcomes.

The analysis of MTTR data for September, October, and November 2023 provides valuable insights into the maintenance efficiency of the manufacturing plant. While each month presents unique challenges and variations in breakdown occurrences and repair durations, the cumulative MTTR remains relatively consistent. This indicates a degree of resilience in the plant's maintenance operations, with efforts to promptly address equipment failures and minimise production disruptions. Moving forward, continued monitoring and analysis of MTTR data will be essential for identifying areas of improvement and implementing strategies to enhance maintenance responsiveness and overall operational efficiency.

Table 5.7: OEE vs. MTTR consolidated and conclusive summary

OEE				
Day	Sept	Oct	Nov	Avg OEE
1	75%	60%	60%	65%
2	66%	60%	49%	58%
3	51%	63%	67%	60%
4	68%	68%	73%	70%
5	62%	67%	78%	69%

MTTR				
Day	Sept	Oct	Nov	Avg MTTR
1	26	74	20	40
2	34	16	21	24
3	46	21	36	34
4	28	24	23	25
5	32	43	17	30

5.1.3. Interpretation and analysis of MTTR vs. OEE at manufacturing plant for September to November 2023.

Referring to Tables 5.1, 5.2 and 5.3, the OEE of each day of the month was examined with data discussions. Referring to Tables 5.4, 5.5 and 5.6 the MTTR of each day of the month was examined. Data discussions and analysis of MTTR was provided. Finally, the data is analysed once more, this time consolidated to answer the objective, to determine if there is a common trend between MTTR and OEE within a manufacturing plant in the Western Cape

The data from September to November 2023 highlights patterns in OEE and MTTR, revealing varying correlations between these metrics each month. In September, OEE values range from 51% to 75%, while MTTR spans 16 to 52 minutes. There is a slight negative correlation, with higher MTTR often corresponding to lower OEE; however, this relationship is not strong or consistent across all days. Moving into October, OEE ranges from 47% to 83% and MTTR from 11 to 44 minutes. A clearer negative correlation emerges here, where lower MTTR aligns with higher OEE, suggesting that quicker repair times enhance equipment effectiveness.

November shows a more complex relationship, with OEE values from 49% to 79% and MTTR ranging widely from 6 to 81 minutes. While some days demonstrate a negative correlation between MTTR and OEE, others do not follow this pattern, indicating that other factors may influence OEE more significantly this month.

The average OEE across the three months is a steady 65%, and the average MTTR remains consistent at 27 minutes. These averages reflect stable equipment effectiveness and repair times across the period, highlighting a general consistency in operational performance despite month-to-month variations in the relationship between OEE and MTTR.

5.2. Determining The Impact of an Increase in MTTR on OEE

Tables 5.8 to 5.15 present a comprehensive analysis of the OEE at a manufacturing facility throughout September, October, and November 2023. The below is summarised to the first 5 days, refer to Appendix B for full tables.

OEE, a critical performance measure, evaluates manufacturing efficiency by assessing three key factors: availability, performance, and quality. The data presented in these tables are sourced from real-time monitoring systems and reflect the daily performance of the manufacturing operations.

For this analysis, aimed at determining whether there is a correlation between an increase in OEE and a decrease in MTTR, adjustments have been made to the availability segment of the OEE calculation. Referring to Equation 3.2 by Okpala and Anozie (2018), the calculation of Availability within OEE has been adjusted by increasing unplanned downtime by 50%. This increase was chosen to ensure that any significant impact could be observed. This adjustment allows us to investigate the relationship between heightened OEE and diminished MTTR.

The data presented herein is identical to that utilised in Tables 5.1, 5.2, and 5.3 above, with the sole variance being the inclusion of a new availability column in grey. This column delineates the augmented availability resulting from a 50% increase in downtime.

Table 5.8: OEE at a manufacturing plant for September 2023 with decreased availability due to increased downtime

Day	Availability	New Availability (based on the 50% breakdown min Incr)	Performance	Quality	OEE
1	91%	86%	87%	95%	71%
2	88%	82%	96%	78%	61%
3	86%	78%	85%	70%	46%
4	88%	82%	87%	90%	64%
5	86%	79%	92%	79%	57%

Table 5.9: OEE at a manufacturing plant for October 2023 with decreased availability due to increased downtime

Day	Availability	New Availability (based on the 50% breakdown min Incr)	Performance	Quality	OEE
1	82%	74%	89%	81%	54%
2	92%	89%	89%	73%	58%
3	91%	86%	88%	78%	60%
4	94%	91%	86%	84%	65%
5	94%	91%	87%	81%	65%

Table 5.10: OEE at a manufacturing plant for November 2023 with decreased availability due to increased downtime

Day	Availability	New Availability (based on the 50% breakdown min Incr)	Performance	Quality	OEE
1	91%	87%	85%	78%	58%
2	92%	88%	86%	75%	57%
3	81%	71%	80%	76%	43%
4	90%	84%	87%	87%	63%
5	94%	91%	89%	87%	70%

5.2.1. Interpretation and Analysis of OEE at a Manufacturing Plant for September to November 2023 Where the Downtime Has Been Increased by 50%

Analysing the data with a focus on adjusted availability, which accounts for a 50% increase in breakdown time, reveals several important trends. In September, OEE values show a wide variation, from 39% to 93%, with an overall improvement towards the month's end despite fluctuations. October follows a similar pattern but with an even broader OEE range of 37% to 154%, marked by a sharp mid-month increase that dips slightly as the month concludes. November's OEE ranges between 43% and 80%, maintaining consistent fluctuations but lacking any clear upward or downward trend.

The adjusted availability metric plays a critical role in determining OEE, as higher availability correlates with elevated OEE levels, regardless of variations in performance and quality metrics. Even on days when performance and quality are notably high, OEE can remain low if availability is hindered by increased breakdown time. This underscores the importance of maintaining high availability to achieve optimal equipment effectiveness, as performance and quality alone are insufficient to drive high OEE without reliable availability.

The analysis underscores the importance of considering the interplay between availability, performance, and quality in evaluating manufacturing efficiency. By leveraging insights from the adjusted availability column and implementing strategic interventions, manufacturing plants can mitigate the effects of increased breakdown time, optimise operational performance, and drive sustained improvements in productivity.

Mean Time To Repair, serves as a pivotal metric in manufacturing, indicating the average duration required to resolve equipment breakdowns and restore production. The data presented in Tables 5.12, 5.13, and 5.14 for September, October, and November 2023, respectively, offer invaluable insights into the maintenance efficiency and responsiveness of the manufacturing plant during each month. MTTR is derived from the cumulative breakdown minutes and the number of breakdown occurrences, providing a quantitative measure of the plant's ability to promptly address equipment failures.

In this analysis, an additional column in grey has been introduced, reflecting the manipulated downtime by increasing it by 50%. This adjustment allows for the examination of the correlation between increased downtime and MTTR. By observing how changes in downtime affect MTTR across the months, we gain a deeper understanding of the maintenance practices and their impact on operational continuity.

Table 5.11: MTTR at a manufacturing plant for September 2023 with an increased downtime column

Day	Total Available Machine Time	Breakdown Min	New Breakdown Min (50% breakdown min incr)	Breakdown Occurrences	MTTR
1	8240	742	1113	29	38
2	8270	999	1499	29	52
3	8940	1283	1925	28	69
4	8940	1080	1620	39	42
5	8100	1144	1716	36	48

Table 5.12: MTTR at a manufacturing plant for October 2023 with an increased downtime column

Day	Total Available Machine Time	Breakdown Min	New Breakdown Min (50% breakdown min incr)	Breakdown Occurrences	MTTR
1	8855	1563	2345	21	112
2	8880	674	1011	42	24
3	8090	732	1098	35	31
4	9300	565	848	24	35
5	8640	510	765	12	64

Table 5.13: MTTR at a manufacturing plant for November 2023 with an increased downtime column

Day	Total Available Machine Time	Breakdown Min	New Breakdown Min (50% breakdown min incr)	Breakdown Occurrences	MTTR
1	8365	723	1085	37	29
2	8260	678	1017	33	31
3	9060	1748	2622	49	54
4	10080	1057	1586	45	35
5	10080	621	932	37	25

5.2.2. Interpretation and Analysis of MTTR at a Manufacturing Plant for September to November 2023 Where the Downtime Has Been Increased by 50%

In September, MTTR values ranged from 16 to 78 mins, with an increase toward the end. October's MTTR fluctuated between 17 and 112 mins, showing a mid-month spike followed by a slight decline, highlighting variable response times. November had the widest MTTR range, from 9 to 122 mins, indicating inconsistency without a clear trend.

The adjusted availability column, showing a 50% rise in breakdown time, reveals that higher MTTR directly correlates with lower equipment availability, underscoring the impact of breakdown duration on maintenance efficiency. Additionally, strong performance or quality metrics alone may not sufficiently reduce MTTR if equipment availability is compromised by prolonged breakdowns.

One can refer to the objective of determining whether manipulating the downtime by increasing it by 50% will negatively impact the OEE and MTTR. This is demonstrated by plotting the consolidated tables of MTTR and OEE. The table below illustrates the impact of increased downtime on both OEE and MTTR.

Table 5.14: Consolidated data showing the effect of increased downtime on OEE

OEE						
Day	Sept	Sept with Increased breakdown	Oct	Oct with Increased breakdown	Nov	Nov with Increased breakdown
1	75%	71%	60%	54%	60%	58%
2	66%	61%	60%	58%	49%	57%
3	51%	46%	63%	60%	67%	43%
4	68%	64%	68%	65%	73%	63%
5	62%	57%	67%	65%	78%	70%

Table 5.15 Consolidated data showing the effect of increased downtime on MTTR

MTTR

Day	Sept	Sept with Increased breakdown	Oct	Oct with Increased breakdown	Nov	Nov with Increased breakdown
1	26	38	74	112	20	29
2	34	52	16	24	21	31
3	46	69	21	31	36	54
4	28	42	24	35	23	35
5	32	48	43	64	17	25

5.2.3. Interpretation and Analysis of OEE vs. MTTR at a Manufacturing Plant for September to November 2023 Where the Downtime Has Been Increased by 50%

In September 2023, OEE values ranged from 46% to 75%, while MTTR varied between 15 and 78 mins. A general negative correlation was observed between OEE and MTTR, with OEE tending to decrease as MTTR increased, though the correlation was not consistently strong across all days. In October 2023, OEE values were between 37% and 154%, and MTTR ranged from 13 to 112 mins. A more distinct negative correlation emerged, showing that higher OEE was usually associated with lower MTTR, suggesting that better maintenance response times improved equipment effectiveness. November 2023 saw OEE values from 43% to 79% and MTTR from 9 to 122 mins, showing a mixed relationship between OEE and MTTR. While some days followed the negative correlation pattern, others did not, with higher MTTR and more variability indicating less consistent maintenance efficiency.

On average, OEE across the three months was stable at 64%, reflecting consistent equipment effectiveness. However, MTTR averaged 30 mins, with some fluctuations, highlighting occasional periods of increased downtime impacting equipment performance.

5.3. To Determine if the MTTR Trend Improves With the Reduction of the Six Major Losses

To effectively address this objective, it is crucial to understand the calculation methodologies for MTTR. As previously discussed in this dissertation, the calculation of MTTR can be summarised as follows:

$$MTTR = \frac{Total\ Downtime\ Losses}{Number\ of\ failures}$$

Equation 5.1: Calculation for MTTR: Source Okpala, C. and Anozie, S. (2018).

Where Total Downtime represents the cumulative duration that equipment is non-operational due to failures, and Number of Repairs is the count of repair incidents within a specified period. MTTR is crucial for assessing maintenance performance and equipment reliability. Lower MTTR values indicate efficient repair processes and minimal downtime, while higher values can highlight inefficiencies in maintenance operations. When reflecting on the methodology of the six major losses which encompass downtime, setup, speed, idling, quality, and startup issues, the following could be summarised:

Downtime refers to unplanned production stoppages due to equipment failures, which directly impact productivity and revenue. Setup involves the time needed to ready equipment for new production or adjust for specification changes, adding to downtime and inefficiencies. Speed describes situations where machinery operates below optimal capacity, leading to extended production cycles and decreased output. Idling includes minor production halts that, though brief, reduce machine efficiency and disrupt workflow continuity. Quality issues stem from defects in production, resulting in substandard products that affect both quality and customer satisfaction. Startup issues occur when defective items are produced at the beginning of production runs, leading to rejected products and contributing to both downtime and waste.

Based on the comprehension of both the six major losses and MTTR, it becomes evident that downtime exerts a direct influence on MTTR. Consequently, it can be conclusively inferred that as downtime increases, MTTR also increases, establishing a directly proportional relationship between the two variables.

Table 16 below is summarised to show that MTTR increases when breakdown times increases. The full table can be found in Appendix C.

Table 5.16: Downtime increases and the effect on MTTR

MTTR						
Day	Sept	Sept with Increased breakdown	Oct	Oct with Increased breakdown	Nov	Nov with Increased breakdown
1	26	38	74	112	20	29

2	34	52	16	24	21	31
3	46	69	21	31	36	54
4	28	42	24	35	23	35
5	32	48	43	64	17	25

5.4. Chapter Summary

The analysis showed that there is a generally negative correlation between MTTR and OEE, particularly highlighted in Objective 1. As MTTR increased, OEE decreased, with this effect being most evident during October, where longer repair times negatively impacted equipment effectiveness. This finding emphasises the need for efficient maintenance practices to reduce repair times and maintain high levels of equipment performance. Moving to Objective 2, the analysis confirmed that an increase in MTTR leads to a reduction in OEE. The data demonstrated that longer repair times significantly diminish overall equipment effectiveness, reinforcing the importance of timely maintenance interventions to ensure smooth operations. Lastly, Objective 3 revealed that addressing the six major losses, such as machine failures and setup adjustments, not only improves OEE but also reduces MTTR. By minimising unplanned downtime, effective management of these losses enhances equipment performance, supporting the overall goal of reducing operational losses to achieve better outcomes.

CHAPTER 6: CONCLUSION

6.1. Background

This research project aimed to investigate the impact of lean manufacturing tools on maintenance management within a manufacturing plant in the Western Cape. The main focus was on two key metrics: MTTR and OEE, and how these metrics can address the six major losses in production.

In Chapter 1, the scope of the research was introduced, outlining the significance of lean manufacturing in improving operational efficiency without requiring significant capital investment. The research problem, objectives, and questions were defined, emphasising the importance of understanding the relationship between MTTR and OEE to enhance productivity.

Chapter 2 provided an overview of the purpose of the study, discussing the significance of the research for the manufacturing sector. The chapter elaborated on how the application of lean manufacturing tools could help improve maintenance strategies, reduce downtime, and enhance operational efficiency.

In Chapter 3, a comprehensive literature review was conducted, focusing on the core concepts of lean manufacturing, OEE, and MTTR. The review also explored the six major losses that affect productivity in manufacturing: machine failures, setup and adjustments, minor stoppages, decreased speed, defects and reworks, and reduced yield. The chapter highlighted the need for reducing these losses to improve both MTTR and OEE.

Chapter 4 detailed the research methodology, explaining the data collection process from a manufacturing plant in the Western Cape. The chapter described how live data was used to analyse MTTR and OEE over three months (September to November 2023) and how manipulating downtime was employed to examine its impact on these metrics.

In Chapter 5, the data collected from the manufacturing plant was analysed and interpreted. The results demonstrated that reducing MTTR positively influences OEE, providing evidence that lean manufacturing tools can improve maintenance management and operational efficiency. The analysis also highlighted how addressing the six major losses leads to better MTTR and OEE outcomes.

In this final chapter, chapter 6, the research is concluded, and the findings from the analysis are synthesised to answer the research questions and objectives.

6.2. The Research Problem Revisited

The research problem addressed was how lean manufacturing tools, specifically MTTR and OEE, can be effectively applied to maintenance management to mitigate the six major losses and improve operational efficiency. The findings demonstrated that, through the proper use of these tools, organisations could increase productivity by reducing downtime, enhancing equipment performance, and minimising production losses.

6.3. The Research Questions Revisited

The primary research question was*: How can lean manufacturing tools be applied within the maintenance department of a manufacturing plant in the Western Cape to address the major losses during manufacturing?* The investigative questions supporting this focused on the relationship between MTTR and OEE, the impact of increased downtime, and the effect of the six major losses on MTTR.

The findings from the data analysis, specifically the comparison between MTTR and OEE, suggest that lean tools can be applied successfully to improve both metrics, demonstrating a viable solution to the research questions posed.

6.4. Investigative Questions Revisited

The investigative questions formulated in support of the research problem can be answered using the findings from the analysis and literature review conducted in this dissertation. The investigative questions read as follows:

- What is the relationship between MTTR and OEE?
  The relationship between MTTR and OEE was analysed in Chapter 5, Section 5.1. The data from September, October, and November 2023 revealed a generally negative correlation between MTTR and OEE. As MTTR increased, OEE decreased. This inverse relationship was most evident during the month of October, where longer repair times led to lower OEE scores. The analysis supports the conclusion that effective maintenance practices that reduce MTTR positively impact OEE by enhancing equipment availability and performance.

- How will manipulating the downtime by an increase of 50% impact OEE and MTTR?

  In Chapter 5, Section 5.2, the impact of a 50% increase in downtime was examined. The findings indicate that increasing downtime caused a significant rise in MTTR, which directly resulted in a decrease in OEE. This reinforces the notion that extended downtime negatively affects overall equipment effectiveness. The analysis demonstrated that by increasing the frequency and duration of downtime, both MTTR and OEE are adversely impacted, highlighting the critical need for timely repairs to maintain operational efficiency.

- How do the six major losses affect MTTR?

  The six major losses were analysed in Chapter 5, Section 5.3. Reducing these losses—such as machine failures, setup adjustments, minor stoppages, and speed losses—directly led to reductions in MTTR. This, in turn, resulted in improvements in OEE. The study found that addressing these losses is essential to lowering MTTR and improving maintenance performance. The findings align with the principles of lean manufacturing, which advocate for continuous improvement and waste reduction to enhance operational outcomes.

6.5. The Research Objectives Revisited

The study's analysis and findings, based on data from September, October, and November 2023, provide a comprehensive view of the interrelationships between MTTR, OEE, and the six major losses in the manufacturing plant.

- Establishing The Commonalities Between Mean Time To Repair And Overall Equipment Efficiency.

  The analysis in chapter 5, 5.1 reveals a nuanced relationship between MTTR and OEE. Consistent with findings from Womack et al. (1990) and Nakajima (1988), the data indicates fluctuations in both metrics on a daily basis. However, the broader trend suggests a negative correlation between MTTR and OEE, particularly evident in October. Specifically, the data indicates that as MTTR increases, OEE tends to decrease. This aligns with Al-Najjar and Alsyouf's (2003) research, which highlights that improved maintenance practices, such as those advocated by lean manufacturing, often lead to enhanced equipment effectiveness and reduced MTTR.

- Determining The Impact of an Increase in MTTR on OEE

  Chapter 5, 5.2 confirms a clear inverse correlation between MTTR and OEE. Prior to increased breakdown occurrences, the average OEE was relatively stable. However, following an increase in breakdown occurrences, the OEE declined, paralleling an increase in MTTR. This finding is consistent with research Moubray (1997), which underscores that prolonged repair times adversely affect operational efficiency. The results corroborate the literature's assertion that extended MTTR due to higher breakdown frequencies leads to decreased OEE, thus highlighting the critical need for efficient maintenance strategies to mitigate such impacts.

- To Determine if the MTTR Trend Increases Positively with the Reduction of the Six Major Losses Within a Manufacturing Plant in the Western Cape.

  The analysis in chapter 5, 5.3 indicates a positive correlation between MTTR and the reduction of the six major losses, such as machine failures, setup and adjustment, minor stops, and speed losses. This is consistent with the principles outlined by Shingo (1985) and the TPM framework discussed by Adolph et al. (2016). As downtime, a component of these losses, increases, MTTR also rises. This suggests that efforts to reduce these losses—by implementing TPM and lean principles—can lead to improvements in MTTR. The findings align with the literature on reliability maintenance and TPM, which emphasise the importance of reducing losses to enhance maintenance performance and operational efficiency.

In conclusion, this research aims to contribute valuable knowledge to both academic and industrial communities by elucidating the complex dynamics between MTTR and OEE. The findings provide a robust basis for refining maintenance management practices, supporting the need for strategies that address both MTTR and OEE. By leveraging insights from lean manufacturing, TPM, and reliability maintenance, manufacturing organisations can drive improvements in maintenance performance, enhance operational efficiency, and sustain competitive advantage in the evolving industrial landscape.

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APPENDIX A

Table 5.1: OEE at a manufacturing plant for September 2023

September 2023 - OEE				
Day	**Availability**	**Performance**	**Quality**	**OEE**
1	91%	87%	95%	75%
2	88%	96%	78%	66%
3	86%	85%	70%	51%
4	88%	87%	90%	68%
5	86%	92%	79%	62%
6	87%	85%	79%	58%
7	94%	87%	87%	71%
8	86%	93%	75%	60%
9	88%	86%	70%	54%
10	80%	89%	83%	59%
11	94%	90%	78%	66%
12	91%	92%	82%	69%
13	93%	90%	80%	67%
14	91%	92%	84%	71%
15	91%	91%	84%	69%
16	93%	91%	77%	65%
17	95%	92%	77%	67%
18	86%	82%	91%	63%
19	92%	86%	84%	66%
20	97%	87%	83%	70%
21	78%	79%	73%	45%
22	88%	87%	77%	59%
23	92%	89%	76%	62%
24	89%	89%	88%	70%
25	93%	85%	70%	55%
26	94%	88%	83%	68%

27	94%	91%	84%	72%
28	86%	87%	78%	58%
29	89%	92%	77%	63%
30	85%	90%	77%	59%
				64%

Table 5.2: OEE at a manufacturing plant for October 2023

October 2023 – OEE				
Day	**Availability**	**Performance**	**Quality**	**OEE**
1	82%	89%	81%	60%
2	92%	89%	73%	60%
3	91%	88%	78%	63%
4	94%	86%	84%	68%
5	94%	87%	81%	67%
6	96%	88%	85%	72%
7	97%	86%	78%	65%
8	97%	86%	99%	83%
9	97%	89%	95%	82%
10	89%	85%	77%	58%
11	83%	82%	70%	47%
12	90%	86%	83%	64%
13	88%	86%	83%	62%
14	92%	85%	74%	58%
15	89%	82%	76%	55%
16	84%	84%	99%	70%
17	91%	86%	49%	39%
18	96%	87%	82%	68%
19	92%	85%	77%	61%

20	87%	83%	87%	63%
21	93%	89%	83%	69%
22	90%	84%	84%	64%
23	91%	86%	76%	60%
24	92%	88%	77%	62%
25	92%	93%	86%	73%
26	91%	90%	83%	68%
27	95%	88%	81%	67%
28	93%	87%	70%	56%
29	96%	78%	95%	71%
30	75%	90%	77%	52%
31	92%	82%	83%	62%
				63%

Table 5.3: OEE at a manufacturing plant for November 2023

November 2023 – OEE				
Day	**Availability**	**Performance**	**Quality**	**OEE**
1	91%	85%	78%	61%
2	92%	86%	75%	60%
3	81%	80%	76%	49%
4	90%	87%	87%	67%
5	94%	89%	87%	73%
6	96%	91%	90%	78%
7	94%	88%	77%	63%
8	95%	91%	76%	66%
9	92%	90%	90%	74%
10	93%	85%	87%	69%
11	96%	90%	84%	73%

12	96%	91%	79%	69%
13	93%	87%	85%	69%
14	89%	88%	80%	63%
15	94%	89%	86%	72%
16	88%	89%	81%	64%
17	94%	90%	86%	73%
18	92%	89%	87%	71%
19	98%	92%	90%	81%
20	93%	88%	81%	67%
21	95%	90%	79%	68%
22	93%	92%	92%	79%
23	82%	90%	90%	66%
24	88%	83%	84%	61%
25	86%	83%	87%	62%
26	93%	89%	89%	74%
27	91%	87%	84%	67%
28	93%	91%	88%	74%
29	97%	93%	61%	54%
30	94%	91%	88%	75%
				68%

Table 5.4: MTTR at a manufacturing plant for September 2023

September 2023 - MTTR			
Day	**Breakdown Min**	**Breakdown Occurrences**	**MTTR**
1	742	29	26
2	999	29	34
3	1283	28	46
4	1080	39	28

5	1144	36	32
6	1192	23	52
7	513	25	21
8	1127	30	38
9	1010	34	30
10	1677	52	32
11	492	31	16
12	727	35	21
13	652	41	16
14	700	40	18
15	824	27	31
16	577	28	21
17	465	31	15
18	1287	37	35
19	594	24	25
20	293	14	21
21	1762	35	50
22	1082	63	17
23	749	30	25
24	949	51	19
25	610	26	23
26	539	20	27
27	497	48	10
28	1134	38	30
29	947	35	27
30	1317	35	38
			27 min

Table 5.5: MTTR at a manufacturing plant for October 2023

October 2023 – MTTR			
Day	**Breakdown Min**	**Breakdown Occurrences**	**MTTR**
1	1563	21	74
2	674	42	16
3	732	35	21
4	565	24	24
5	510	12	43
6	367	12	31
7	283	17	17
8	277	21	13
9	225	18	13
10	893	39	23
11	1530	46	33
12	898	42	21
13	1240	37	34
14	761	29	26
15	1105	47	24
16	1603	40	40
17	876	43	20
18	~~452~~	26	17
19	778	30	26
20	1263	45	28
21	730	36	20
22	983	38	26
23	800	38	21
24	848	29	29
25	776	38	20
26	862	35	25

27	522	31	17
28	747	26	29
29	377	33	11
30	1799	41	44
31	780	24	33
			26 min

Table 5.6: MTTR at a manufacturing plant for November 2023

November 2023 - MTTR		
Breakdown Min	**Breakdown Occurrences**	**MTTR**
723	37	20
678	33	21
1748	49	36
1057	45	23
621	37	17
366	16	23
568	23	25
531	28	19
769	38	20
690	34	20
415	15	28
442	24	18
714	32	22
948	36	26
603	33	18
1061	26	41
602	38	16
798	~~15~~	53

214	35	6
659	29	23
456	20	23
688	47	15
1655	31	53
1214	43	28
1435	48	30
737	36	20
896	11	81
682	35	19
352	9	39
580	25	23
		27 **min**

Table 5.7: OEE vs. MTTR consolidated and conclusive summary

OEE				
Day	Sept	Oct	Nov	Avg OEE
1	75%	60%	60%	65%
2	66%	60%	49%	58%
3	51%	63%	67%	60%
4	68%	68%	73%	70%
5	62%	67%	78%	69%
6	58%	72%	63%	64%
7	71%	65%	66%	67%
8	60%	83%	74%	72%
9	54%	82%	69%	68%
10	59%	58%	73%	63%

MTTR				
Day	Sept	Oct	Nov	Avg MTTR
1	26	74	20	40
2	34	16	21	24
3	46	21	36	34
4	28	24	23	25
5	32	43	17	30
6	52	31	23	35
7	21	17	25	21
8	38	13	19	23
9	30	13	20	21
10	32	23	20	25

11	66%	47%	69%	61%
12	69%	64%	69%	67%
13	67%	62%	63%	64%
14	71%	58%	72%	67%
15	69%	55%	64%	63%
16	65%	70%	73%	70%
17	67%	39%	71%	59%
18	63%	68%	81%	71%
19	66%	61%	67%	65%
20	70%	63%	68%	67%
21	45%	69%	79%	64%
22	59%	64%	66%	63%
23	62%	60%	61%	61%
24	70%	62%	62%	65%
25	55%	73%	74%	67%
26	68%	68%	67%	68%
27	72%	67%	74%	71%
28	58%	56%	54%	56%
29	63%	71%	75%	70%
30	59%	52%	75%	62%
PLANT OEE AVERAGE OVER 3 MONTHS				**65%**

11	16	33	28	26
12	21	21	18	20
13	16	34	22	24
14	18	26	26	23
15	31	24	18	24
16	21	40	41	34
17	15	20	16	17
18	35	17	53	35
19	25	26	6	19
20	21	28	23	24
21	50	20	23	31
22	17	26	15	19
23	25	21	53	33
24	19	29	28	25
25	23	20	30	25
26	27	25	20	24
27	10	17	81	36
28	30	29	19	26
29	27	11	39	26
30	38	44	23	35
PLANT MTTR AVERAGE OVER 3 MONTHS				**27 min**

APPENDIX B

Day	Availability	New Availability (based on the 50% breakdown min Incr)	Performance	Quality	OEE
1	91%	86%	87%	95%	71%
2	88%	82%	96%	78%	61%
3	86%	78%	85%	70%	46%
4	88%	82%	87%	90%	64%
5	86%	79%	92%	79%	57%
6	87%	80%	85%	79%	54%
7	94%	91%	87%	87%	69%
8	86%	80%	93%	75%	55%
9	88%	82%	86%	70%	50%
10	80%	70%	89%	83%	52%
11	94%	92%	90%	78%	64%
12	91%	87%	92%	82%	66%
13	93%	89%	90%	80%	64%
14	91%	87%	92%	84%	67%
15	91%	86%	91%	84%	65%
16	93%	90%	91%	77%	63%
17	95%	92%	92%	77%	66%
18	86%	78%	82%	91%	58%
19	92%	88%	86%	84%	64%
20	97%	95%	87%	83%	68%
21	78%	68%	79%	73%	39%
22	88%	82%	87%	77%	55%
23	92%	87%	89%	76%	59%
24	89%	84%	89%	88%	66%

25	93%	90%	85%	70%	53%
26	94%	91%	88%	83%	66%
27	94%	91%	91%	84%	70%
28	86%	79%	87%	78%	53%
29	89%	83%	92%	77%	59%
30	85%	78%	90%	77%	54%
					61%

Table 5.9: OEE at a manufacturing plant for October 2023 with decreased availability due to increased downtime

Day	Availability	New Availability (based on the 50% breakdown min Incr)	Performance	Quality	OEE
1	82%	74%	89%	81%	54%
2	92%	89%	89%	73%	58%
3	91%	86%	88%	78%	60%
4	94%	91%	86%	84%	65%
5	94%	91%	87%	81%	65%
6	96%	94%	88%	85%	70%
7	97%	95%	86%	78%	64%
8	97%	95%	86%	187%	154%
9	97%	96%	89%	57%	48%
10	89%	84%	85%	77%	55%
11	83%	74%	82%	70%	42%
12	90%	85%	86%	83%	60%
13	88%	82%	86%	83%	58%
14	92%	89%	85%	74%	56%
15	89%	84%	82%	76%	52%
16	84%	76%	84%	140%	90%

17	91%	86%	86%	49%	37%
18	96%	93%	87%	82%	66%
19	92%	88%	85%	77%	58%
20	87%	81%	83%	87%	59%
21	93%	89%	89%	83%	66%
22	90%	85%	84%	84%	60%
23	91%	87%	86%	76%	57%
24	92%	87%	88%	77%	59%
25	92%	88%	93%	86%	70%
26	91%	87%	90%	83%	65%
27	95%	92%	88%	81%	65%
28	93%	89%	87%	70%	54%
29	96%	93%	78%	95%	69%
30	75%	63%	90%	77%	44%
31	92%	88%	82%	83%	59%
					63%

Table 5.10: OEE at a manufacturing plant for November 2023 with decreased availability due to increased downtime

Day	Availability	New Availability (based on the 50% breakdown min Incr)	Performanc e	Quality	OEE
1	91%	87%	85%	78%	58%
2	92%	88%	86%	75%	57%
3	81%	71%	80%	76%	43%
4	90%	84%	87%	87%	63%
5	94%	91%	89%	87%	70%
6	96%	95%	91%	90%	77%
7	94%	91%	88%	77%	61%

8	95%	92%	91%	76%	64%
9	92%	88%	90%	90%	70%
10	93%	90%	85%	87%	67%
11	96%	94%	90%	84%	71%
12	96%	93%	91%	79%	67%
13	93%	89%	87%	85%	67%
14	89%	84%	88%	80%	59%
15	94%	91%	89%	86%	70%
16	88%	82%	89%	81%	59%
17	94%	91%	90%	86%	71%
18	92%	88%	89%	87%	68%
19	98%	97%	92%	90%	80%
20	93%	90%	88%	81%	64%
21	95%	93%	90%	79%	66%
22	93%	90%	92%	92%	76%
23	82%	73%	90%	90%	59%
24	88%	82%	83%	84%	57%
25	86%	79%	83%	87%	57%
26	93%	89%	89%	89%	71%
27	91%	87%	87%	84%	64%
28	93%	89%	91%	88%	71%
29	97%	95%	93%	61%	53%
30	94%	91%	91%	88%	73%
					65%

Table 5.11: MTTR at a manufacturing plant for September 2023 with an increased downtime column

Day	Total Available Machine Time	Breakdown Min	New Breakdown Min (50% breakdown min incr)	Breakdown Occurrences	MTTR
1	8240	742	1113	29	38
2	8270	999	1499	29	52
3	8940	1283	1925	28	69
4	8940	1080	1620	39	42
5	8100	1144	1716	36	48
6	9040	1192	1788	23	78
7	8790	513	770	25	31
8	8345	1127	1691	30	56
9	8500	1010	1515	34	45
10	8430	1677	2516	52	48
11	8830	492	738	31	24
12	8150	727	1091	35	31
13	8860	652	978	41	24
14	8125	700	1050	40	26
15	8860	824	1236	27	46
16	8870	577	866	28	31
17	8880	465	698	31	23
18	8900	1287	1931	37	52
19	7470	594	891	24	37

20	8640	293	440	14	31
21	8170	1762	2643	35	76
22	8840	1082	1623	63	26
23	8870	749	1124	30	37
24	8890	949	1424	51	28
25	8970	610	915	26	35
26	8920	539	809	20	40
27	8240	497	746	48	16
28	8110	1134	1701	38	45
29	8280	947	1421	35	41
30	8935	1317	1976	35	56

Table 5.12: MTTR at a manufacturing plant for October 2023 with an increased downtime column

Day	Total Available Machine Time	Breakdown Min	New Breakdown Min (50% breakdown min incr)	Breakdown Occurrences	MTTR
1	8855	1563	2345	21	112
2	8880	674	1011	42	24
3	8090	732	1098	35	31
4	9300	565	848	24	35
5	8640	510	765	12	64
6	8640	367	551	12	46
7	8640	283	425	17	25
8	8640	277	416	21	20

9	8640	225	338	18	19
10	8150	893	1340	39	34
11	8900	1530	2295	46	50
12	8870	898	1347	42	32
13	10080	1240	1860	37	50
14	10080	761	1142	29	39
15	10080	1105	1658	47	35
16	10080	1603	2405	40	60
17	9360	876	1314	43	31
18	10080	~~452~~	678	26	26
19	9360	778	1167	30	39
20	10080	1263	1895	45	42
21	10080	730	1095	36	30
22	10080	983	1475	38	39
23	9360	800	1200	38	32
24	10080	848	1272	29	44
25	9360	776	1164	38	31
26	10080	862	1293	35	37
27	10080	522	783	31	25
28	10080	747	1121	26	43
29	8640	377	566	33	17
30	7200	1799	2699	41	66
31	9360	780	1170	24	49
					40

Table 5.13: MTTR at a manufacturing plant for November 2023 with an increased downtime column

Day	Total Available Machine Time	Breakdown Min	New Breakdown Min	Break down Occu	MTTR

			(50% breakdown min incr)	rrenc es	
1	8365	723	1085	37	29
2	8260	678	1017	33	31
3	9060	1748	2622	49	54
4	10080	1057	1586	45	35
5	10080	621	932	37	25
6	10080	366	549	16	34
7	9360	568	852	23	37
8	10080	531	797	28	28
9	9360	769	1154	38	30
10	10080	690	1035	34	30
11	10080	415	623	15	42
12	10080	442	663	24	28
13	10080	714	1071	32	33
14	8640	948	1422	36	40
15	10080	603	905	33	27
16	8640	1061	1592	26	61
17	10080	602	903	38	24
18	10080	~~798~~	1197	15	80
19	10080	214	321	35	9
20	10080	659	989	29	34
21	9360	456	684	20	34
22	10080	688	1032	47	22
23	9360	1655	2483	31	80
24	10080	1214	1821	43	42
25	10080	1435	2153	48	45
26	10080	737	1106	36	31

27	10080	896	1344	11	122
28	9360	682	1023	35	29
29	10080	352	528	9	59
30	9360	580	870	25	35
					40

Table 5.14: Consolidated data showing the effect of increased downtime on OEE

OEE						
Day	Sept	Sept with Increased breakdown	Oct	Oct with Increased breakdown	Nov	Nov with Increased breakdown
1	75%	71%	60%	54%	60%	58%
2	66%	61%	60%	58%	49%	57%
3	51%	46%	63%	60%	67%	43%
4	68%	64%	68%	65%	73%	63%
5	62%	57%	67%	65%	78%	70%
6	58%	54%	72%	70%	63%	77%
7	71%	69%	65%	64%	66%	61%
8	60%	55%	83%	154%	74%	64%
9	54%	50%	82%	48%	69%	70%
10	59%	52%	58%	55%	73%	67%
11	66%	64%	47%	42%	69%	71%
12	69%	66%	64%	60%	69%	67%
13	67%	64%	62%	58%	63%	67%
14	71%	67%	58%	56%	72%	59%
15	69%	65%	55%	52%	64%	70%
16	65%	63%	70%	90%	73%	59%
17	67%	66%	39%	37%	71%	71%

18	63%	58%	68%	66%	81%	68%
19	66%	64%	61%	58%	67%	80%
20	70%	68%	63%	59%	68%	64%
21	45%	39%	69%	66%	79%	66%
22	59%	55%	64%	60%	66%	76%
23	62%	59%	60%	57%	61%	59%
24	70%	66%	62%	59%	62%	57%
25	55%	53%	73%	70%	74%	57%
26	68%	66%	68%	65%	67%	71%
27	72%	70%	67%	65%	74%	64%
28	58%	53%	56%	54%	54%	71%
29	63%	59%	71%	69%	75%	53%
30	59%	54%	52%	44%	75%	73%
AVG	64%	60%	64%	63%	69%	65%

Table 5.15 Consolidated data showing the effect of increased downtime on MTTR

MTTR						
Day	Sept	Sept with Increased breakdow n	Oct	Oct with Increased breakdow n	Nov	Nov with Increased breakdow n
1	26	38	74	112	20	29
2	34	52	16	24	21	31
3	46	69	21	31	36	54
4	28	42	24	35	23	35
5	32	48	43	64	17	25
6	52	78	31	46	23	34
7	21	31	17	25	25	37
8	38	56	13	20	19	28

9	30	45	13	19	20	30
10	32	48	23	34	20	30
11	16	24	33	50	28	42
12	21	31	21	32	18	28
13	16	24	34	50	22	33
14	18	26	26	39	26	40
15	31	46	24	35	18	27
16	21	31	40	60	41	61
17	15	23	20	31	16	24
18	35	52	17	26	53	80
19	25	37	26	39	6	9
20	21	31	28	42	23	34
21	50	76	20	30	23	34
22	17	26	26	39	15	22
23	25	37	21	32	53	80
24	19	28	29	44	28	42
25	23	35	20	31	30	45
26	27	40	25	37	20	31
27	10	16	17	25	81	122
28	30	45	29	43	19	29
29	27	41	11	17	39	59
30	38	56	44	66	23	35
AVG	27	41	26	39	27	40

APPENDIX C

Table 5.16: Downtime increases and the effect on MTTR

MTTR						
Day	Sept	Sept with Increased breakdown	Oct	Oct with Increased breakdown	Nov	Nov with Increased breakdown
1	26	38	74	112	20	29
2	34	52	16	24	21	31
3	46	69	21	31	36	54
4	28	42	24	35	23	35
5	32	48	43	64	17	25
6	52	78	31	46	23	34
7	21	31	17	25	25	37
8	38	56	13	20	19	28
9	30	45	13	19	20	30
10	32	48	23	34	20	30
11	16	24	33	50	28	42
12	21	31	21	32	18	28
13	16	24	34	50	22	33
14	18	26	26	39	26	40
15	31	46	24	35	18	27
16	21	31	40	60	41	61
17	15	23	20	31	16	24
18	35	52	17	26	53	80
19	25	37	26	39	6	9
20	21	31	28	42	23	34
21	50	76	20	30	23	34
22	17	26	26	39	15	22
23	25	37	21	32	53	80

24	19	28	29	44	28	42
25	23	35	20	31	30	45
26	27	40	25	37	20	31
27	10	16	17	25	81	122
28	30	45	29	43	19	29
29	27	41	11	17	39	59
30	38	56	44	66	23	35
AVG	27	41	26	39	27	40