Improving the overall equipment effectiveness of automated machines in volume driven manufacturing

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ABSTRACT

The study outlines the framework concerning Overall Equipment Effectiveness (OEE) using Total Productive Maintenance in the Lubrichem automated volume driven machinery. This research has been carried out using the data obtained from electronic system called RS-production of October 2016 to March 2017 at Lubrichem Company.

The data were obtained through a tool for Overall Equipment Effectiveness called RS-production. The tool system (RS-production) data was from four sections or department of Lubrichem Company (Automated volume driven machines, Automated maintenance workshop, Automated blending machines and Semi-automated machines) sections. A conceptual framework was designed to determine the effect of OEE on Lubrichem automated volume driven machinery and subsequently measures availability, performance and quality losses in a system or machines.

The research survey was based on the sample of four divisions of Lubrichem industry (Automated volume driven machineries, Maintenance workshop, Automated blending machines and Semi-automated machines), including analysing the outcome of the research using excel.

The objective of the thesis was to identify OEE losses, downtime sources and possible improvement. The availability losses and planning factor were the highest in all four divisions. To get rid of unplanned losses, root cause analysis was performed to lower prolonging of planned change overs and setups that require Single Minutes Exchange of Dies for external (SMED) and internal events.

There is a frailty relationship of the unplanned equipment losses which were grouped into unplanned production breakdowns. The losses which were recorded were identified, analysed and split into two to provide potential solutions. Some of the losses were stated as ‘no reason’ because production teams did not furnish the data or information. This requires awareness, training and educating of production personnel who operate the machines.

Keywords: Single Minutes Exchange of Dies, Overall Equipment Effectiveness and Cause Effect diagram.

ACKNOWLEDGEMENTS

I would like to thank god, my saviour for providing me with the opportunity to embark on this journey of my studies.

This research is dedicated to my colleagues, employer and all other manufacturing industry who intended to have continues improvement by improving overall equipment effectiveness of volume driven manufacturing.

The study of this magnitude requires collaboration and support of different people who deserve to be acknowledged. I would firstly like to thank my wife and kids for their support and inspiration during this research. The grate words as a token of appreciation goes to the following people:

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- Prof Johan Jordaan for his role at the scientific committee.

SOLEMN DECLARATION BY STUDENT

I Ndou Tshifhiwa Tesness declare herewith that the Mini Dissertation Research Proposal (Chapter 1) entitled Improving the overall equipment effectiveness of automated machines in volume driven manufacturing, which I herewith submit to North West University, Potchefstroom Campus, in compliance/ partial compliance with the requirements set for MBA degree is my own work and has not already submitted to any other university.

Signature of the student ________ University number 28024052

Signed at Durban South (Prospecton) this day 15 August 2018

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LIST OF ABBREVIATIONS

FMEA	Failure Mode Effective Analysis.
MP	Maintenance Prevention.
OEE	Overall Equipment Effectiveness.
OEM	Operations Equipment Manufactures.
SOP	Standard Operations Procedure.
SPC	Statistical Process Control.
TBM	Time-Based Maintenance.
TC	Total Count.
TPM	Total Productive Maintenance.
TPM	Total Productive Maintenance.
TQM	Total Quality Management.

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1 CHAPTER 1: CONTEXTUALISATION OF THE STUDY

1.1 Introduction

This study focuses on improving the Overall Equipment Effectiveness (OEE) of high volume driven machines and semi-automated machines using the Total Productive Maintenance (TPM) approach at Lubrichem Company.

The chapter outlines the following: the background, the research problem statement, primary and the secondary objectives, methodology applied, the limitations as well as the overview structure of the research.

1.2 Background

“If you cannot measure it, you cannot improve it.” 67(Kaufman & Reichert, 2018:267).

In today’s business world, companies need to emphasise competitiveness, effectiveness and efficiency in the manufacturing of goods and services. The competitiveness in the business industry is measured by the increasing sales and market share which translates to returns on investments or profits.

During the manufacturing process defects, inefficiencies and unidentified losses need to detected and eradicated. Empirical studies carried out in the manufacturing industry highlighted the need to use measurement techniques correctly to measure performance(De Wilde, 2014:44). When working with performance measurement, the following questions needs to be addressed: how and what to measure.

In manufacturing industries, production machines are critical. They are required to be available for production if the company needs to stay competitive in the market according to (Hill, 2017). Businesses need to optimise and improve their productivity to prevent unplanned production losses and eliminate defects. This improves quality of the product ultimately lowers the manufacturing costs, helps meet customer specifications or demands and to remain competitive in the market (Ross, 2017).

According to Domingo and Aguado (2015:9033), TPM philosophy was launched with metrics of OEE. The OEE is a tool which is used to measure productivity of the machines using three elements which are performance, available and quality. It identifies potential losses and provides corrective actions that could be used to eliminate potential losses. The measurement of OEE can be done on the raw material for used for production, men and machines. The advantages of OEE are as follows:

- It reduces maintenance cost and machines downtime resulting in improved machines life cycle.
- It identifies bottlenecks and improves productivity.
- It reduces defects, scraps and reworks of products resulting in increased quality.
- It increases man power efficiency resulting in increased of productivity.

As stated Ohunakin *et al.* (2012:130), in research in the Nigerian beverage industry, the OEE implementation increased availability, quality and performance by over 50%. This resulted in increased productivity, reduced process waste, scraps, rework and unplanned losses.

1.3 Problem statement

Lubrichem operates over 850 machines to achieve its production targets. These volume driven machines form the backbone of production at Lubrichem. In the past two years, it has been noted that these machines are not operating at their full production capacity (Lubrichem Company, 2018). This is an overall equipment effectiveness problem and it has negatively affected Lubrichem's bottom line.

Management challenge is to decipher and isolate the cause of the problem.

1.4 Objectives

The study comprises of primary and secondary objectives.

1.4.1 Primary Objective.

The main purpose of this study is to determine why operations team are not reaching the production target in all the shifts.

1.4.2 Secondary Objectives.

The secondary objectives are:

- To do literature study that will show how to identify ways to improve overall equipment efficiency of the machines.
- To identify the source of downtimes during production.
- To prescribe solutions to the eliminate downtimes and reach production targets

The scope of the study is briefly outlined below.

1.5 Scope of the study

The study is set in an operations management environment. It involves the principles of efficiency, availability and effectiveness of production machines in a high volume driven manufacturing environment. The research method used for the study is briefly discussed below.

1.6 Research methodology

This research methodology section outlines the methodology that was used to conduct this research. It consists of a literature review and an empirical study. A review of the research design, research instrument, data collection and analysis techniques that were used are also outlined.

1.6.1 Literature Review.

Identifying and eliminating losses improves productivity. Total Productive Maintenance (TPM) is one way of maintaining equipment or machines in collaboration with the Overall Equipment Effectiveness (Jin *et al.*, 2016). The following sources were used to obtain a comprehensive overview of the topic:

- Approved journals.
- Approved articles.

- Internet.
- Textbooks.
- Previous dissertations

The literature study defines Overall Equipment Effectiveness (OEE) as a hierarchy of standard measurement developed to evaluate how high volume driven manufacturing operations can effectively use machines and raw materials in manufacturing operations (Cochran, 2017). It is based on the labour efficiency, availability, performance and quality.

Therefore: OEE = Availability x Performance x Quality

Standard Measurement 1: Availability

Availability (A)= Run time / Total time

Availability is measured based on the percentage machines running time while making the product divided by the total time which the machines was running.

Standard Measurement 2: Performance

Performance (P)= Total parts produced/ Target counter

Performance is measured based on the percentage total parts produced divided by the target production counter. It answers the question how well is the machine running?

Standard Measurement 3: Quality

Quality (Q)= Good count/ Total Count

Quality is measured based on the percentage of good parts out of the total parts produced on the machine divided by total number of goods which the machine has produced.

A brief description of how the empirical study is carried out is discussed below.

1.6.2 Empirical Study.

The empirical study outlines specific techniques, measurement instruments (electronic RS-Production system) used and the activities initiated in conducting the research of qualitative.

1.6.2.1 Research type.

The research type is the quantitative because the research seeks to explore, explain and understand the effectiveness of the machines and employees using OEE (Brannen, 2017).

1.6.2.2 Quantitative method

This method deals with emphasized and generated numerical information. Quantitative method produces good results for the data collected in group sample and comprising of data information from group sample as stated by Darmer and Freytag (1995). It presents good understanding of theory and research. Tezel and Barker (2016), defined it as "explaining phenomena by collecting numerical data that are analysed using mathematically based methods (statistics)".

Table 1.1: below shows understanding of Quantitative methods.

Research phases	**Quantitative data collection**
Sampling	• Reduce sampling by adequate size of sampling • Random sampling
Permissions	• Individual authorising access to site. • Board review • Individual
Data sources	• Check list. • Instrument • Public document

Recording data	• Instruments with valid and reliable scores.
Administer data collection	• Attend to ethical issues • Standard procedure

1.6.2.3 Population and Sample Design.

Lubrichem operates over 867 production machines in different categories as shown in the table below. This is entire machine population. A sample of 192 machines was selected as shown in the same table below. This was deemed representative enough as the machines in each category are the same.

Production machine category	**No of machines**	**No. of machines used as a sample**
Automated volume driven machines	244	23
Automated maintenance workshop	347	69
Blending machines	157	62
Semi-automated machines	119	38
Total	867	192

Table 1.2: Machine sampling for the quantitative study

1.6.2.4 Data collection.

Collection of data refers to the registration of values for a certain variable. Data can be registered manually or automatically, and, in some cases, this can be done simultaneously. Xu and Croft, (2017) suggested that automatic measures used to collect information are probably relevant in the long run.

The researcher used electronic RS-production system as methods of collecting the data. The primary data was collected using RS-Production system to scientifically confirm the management findings. The RS-Production system data is based on these

- Totals time registered
- Set up/changeover times per piece
- Cycle time recorded ranges
- Aggregated stoppage reasons
- Average OEE values for the Lubrichem Company

Statistical data on RS- Production was collected from October 2016 to July 2018.

Throughout the research, discussions and the interviews were made and brainstormed. The research questions were answered using interviews, discussions and analysis and data subsequently transcribed.

The OEE measurements depend on the source of data including how it is collected. The data has to be accurate and not biased according to Taylor (2018). The method used in the collection of data is a vital aspect needed in the calculation of OEE.

Data collection can vary from manual to much automated, as correct input of parameters acquired from the production system is essential for OEE calculations (Xu and Croft, 2017). Manual data collection which mainly happens in low-tech industries consists of a registry, where operators are required to fill in the causes and duration of breakdowns as well as reliable comments about minor stoppages and speed losses.

According to Vogel-Heuser and Rösch (2016), in high-tech industries, an automatic OEE calculation system is governed by sensors linked to the equipment, automatically recording the start time and duration of stoppages while prompting the operator to make available the system with correct information about their specific downtime causes. With automatic method, opportunities are made available for operators to set up lists of potential downtime causes, scheduling the available operating time and constructing an automatic OEE calculation for any specific time period.

As long as the data input are provided in the system, it is not only possible to provide OEE results but makes it easier to retrieve a variety of reports of production performance and visualization of the performance results from the system.

However, too much information in the system can be a waste of time for the operators and they will have to search for each downtime cause. Reluctance against data collection from operators and foremen are some of the major challenges faced by many industries.

Wickens and Holland, (2015) found it necessary to convince operators as some do believe that some disturbances have a major impact on efficiency which later measurements show that to be completely wrong. With automatic data collection, the system is quite expensive, complex and is collected at an aggregated level. On the contrary, manual data collection can be very detailed as losses can be fully examined.

It is necessary to introduce both manual and automatic data collection methods coupled with training of the operators of OEE as a performance measure, and on various parameters affecting the OEE outcome. Main reasons for this would be to qualify the quality of input data in line with an increase in the competence of operators and creating a better involvement of the operators in identifying potential performance loss factors as well as providing system with accurate information.

Quantitative measurements for the OEE calculation were collected from a large number of machines in the various industries under a period of three months. Machine downtimes were registered with a use of computer by the help of the operators as suggested by (Ahmad & Gani, 2015).

The researcher used the following instrument to collect data: RS-Production system, voice recorder during interview and skype recording video for interview with night shift employees. The researcher did not have control factors that might influence the behaviour and performance of participant under study thereby reporting the outcome as they are (Dezsö, 2012).

Furthermore, the researcher explained the purpose of study and the objectives to the participants and assured their confidentiality. Interview questions were formulated in

English because it is medium communication language in Durban South (Prospecton) manufacturing industries.

1.6.2.5 Data analysis.

The quantitative was handled through basic statistical analysis.

On one hand, a deductive approach was used to analyses the qualitative data based on the structure predetermined by the researcher. The data was transcribed, and trends deduced.

1.6.2.6 Importance and benefits of the proposed study

The following are the benefits of the current study:

- Identification of possible root causes of poor quality of manufactured products
- Propose quality improvement strategies and solutions to the existing problems
- Propose better methods of improving the quality of products
- Suggest methods of implementing quality awareness culture in the factory
- Identifying necessary skills that can help in improving quality of products in a manufacturing environment and
- Identify factors that will help the company improve its manufacturing performance Heading 3

1.7 Ethical consideration.

Staff members such as operators, artisans and supervisors face ethical challenges when carrying out their duties. According to Harriss, (2013), when employees are used as study participants during investigating research care was exercised because the rights of individuals which need to be protected.

1.7.1 Principles of research ethics.

Research ethics observed in this study are in accordance with those stated by Denzin, (2016) namely the principles of beneficence, respect for human dignity and of justice.

1.7.2 The law of beneficence.

The law of beneficence protects the participants from freedom from being harmed, the risk benefits proportion and freedom from abuse. Participants were informed that they were not obligated to answer question which they were uncomfortable with. Furthermore, they were given liberty to ask questions to eliminate any uncertainty and to make them feel unrestricted. Clarifications were provided to operators concerning their right not to partake in this investigative study.

1.7.3 The law of respect for human dignity.

The law covers the right to self-determination and expose. The right to self-determination was tracked by providing the participants with the right to stop participating if they were uncomfortable or not keen to answer specific questions and not to participate at all if they are not interested. The participants were informed of their right to refuse from participating.

1.7.4 The law of justice

The law of justice covers the right to fair treatment and concealment. The participants' values, belief, life style and habits were respected as part of the right to fair treatment. The participants were interviewed one by one secretly and the data collected were treated with anonymity.

1.7.5 Consent for conducting the survey.

Consent for conducting the survey was obtained from Lubrichem Company Director in Durban. Each participant was completely made aware about the nature of the survey and requested to participate. No compensation was paid, and no participant suffered any mistreatment for declining to participate in the survey. Each participant who concurred to participate signed a form.

1.8 Value-addition and limitations of the study

This study's contribution shows what the degree (extent) of automated machines, employees' engagement is, and the possible link between engagement and the impact it has on the performance of the Overall Equipment Effectiveness of the company. This type of study has never been conducted within this environment, and as such a valuable contribution could be made to more effective performance management within this context.

The use of RS-Production system in the research constitutes a limitation. At best, these relationships were analysed and described, no causality is established. Therefore, the establishment of relationships in the study serves only to set-up certain patterns which can be compared with previous theoretical research regarding the chronological relationships of the different variables being studied (Wohlwill, 2016).

Another limitation is that the study was done using a sample of four division of the Lubrichem Company and might not represent the Petrochemical industry.

The layout of the whole study is summarized below.

1.9 Layout of the study

This study is divided into five chapters:

- Chapter one introduced the content of the paper and explained why the topic was chosen for the research. The chapter presented the problem statement, the research goals, methods and research limitations.
- Chapter two literature review done by other company
- Chapter three reports the research method that was employed to achieve the goals of the research project. Aspects that will be covered include research design, measuring instruments that will be used to gather data and then data analyses techniques will be discussed.
- Chapter four focuses on the results of the study. The results were then discussed by focusing on the implications of the findings.

- Chapter five discusses the conclusion reached resulting from the study as well as any recommendations that can be made to management and recommendations for future studies.

1.10 Chapter summary

Chapter one provided the background and motivation including the problem statement, primary and secondary objectives, scope, research methodology to be utilised, limitations and layout of the study.

2 CHAPTER 2: LITERATURE REVIEW ON OVERALL EQUIPMENT EFFECTIVENESS (OEE)

This chapter outlines the theoretical references used during this study. The theoretical frame work involves Total Productive Maintenance (TPM) method which directly forces machines operators to participate in preventive maintenance of the machines (Poduval *et al.*, 2015:310). TPM is measured using the metric tool called Overall Equipment Effectiveness (OEE). The objectives of TMP are to eliminate machines breakdown, unplanned stoppages, waste, inefficiency of manpower and incidents. OEE identifies losses and categorize them into three factors which are quality, availability and performance.

2.1 Introduction

Stakeholders and company directors expect machines to operate at 100% capacity and at their full capacity with good high quality of production. However, this is somewhat impossible due to process losses which are unplanned as well as planned. According to the Japan Institute of Plant Maintenance (JIPM), Total Productive Maintenance (TPM) is a strategy to increase effectiveness of the machines in operation in the production environment (Jain *et al.*, 2015:506). The OEE values were adopted from the Japanese model.

According to Law, (2015), OEE has the following list of benefits:

- Measurements clarification between results and effort.
- Measurement creates a common language.
- Measurement continuous improvement.
- Measurement for motive of change.
- Measurement simply delegation.
- Measurement for identifying problems.
- Measurements to manage focused management.
- Measurements to benchmark (comparison).

OEE measurement can be used within any manufacturing environment because it can measure the first performance of the manufacturing machines which creates platform to benchmark for continues improvement (Afy-Shararah *et al.*, 2018:2099).

2.2 Total Productive Maintenance (TPM)

The Japanese modified productive maintenance (PM) and preventive maintenance (PM) concept and called it Total Productive Maintenance. According to Szewczak and Piekarczuk (2016:680), the founder of TPM philosophy collected the information of different tasks to optimize efficiency using maintenance with the assistance of the machines operators.

According to Ross (2017), top management and employee empowerment as well as commitment should work as a team to have continuous improvement and to eliminate waste. Machine maintenance team responsibilities are directly reduced as the results of team work (Katzenbach & Smith, 2015). When team members are effective, they don't disturb each other because they are focused on continuous improvement and team work (Goldratt & Cox, 2016). The machine operators feel empowered using TPM and they strive for not having defects and no breakdown.

Total Productive Maintenance is described as follows:

Total, that stands for;

- Involving everyone who works in the organisation and sharing of skills through collaborations.
- Elimination of defects, incidents and breakdowns.

Productive

- Certain task can be performed during production.
- Minimising problems during production.
- Exceed customer's expectations.

Maintenance

- Restoring machines to Original Equipment Manufacturers (OEM) standard.

According to Jain *et al.* (2015:505), Japan Institute of Plant Maintenance (JIPM)'s introduced TPM pillar initiatives to be implemented to improve machines to run smoothly. Below are the eight pillars of TPM.

Development management

- Eradicate problems as much as possible when running new machines.
- Learn from the existing machines.
- Bring new idea to improve maintenance.

Office TPM

- Increase synergy between businesses.
- Empower employee to take decision.
- Solutions to lower the cost.
- Improve housekeeping 5S in the offices.

Safety, health and environment

- Promote safe working conditions and environment.
- Eliminate injuries and incidents.
- Provide Standard Operating Procedures (SOP)

Education and training

- Imparting technical training on new technology.
- Empower employees to perform different task.
- Promote career path and succession plan.
- Evaluate skills and update to be relevant.

Quality maintenance

- No wastes.
- Address machines problem.

Planned maintenance

- Use maintenance planning for the machine.
- Implement check list.
- Improving MTTR and MTBF

Focused improvement

- Identify and eliminate losses.
- Use 2W and FMEA analysis to find the root cause.
- Reach improved machines target.
- Increase OEE on production machines.

Autonomous maintenance

- Empower operator to own the machines.
- Lubricate, clean, adjust, tighten and inspect production machines.

2.3 Introduction to Overall Equipment Effectiveness (OEE)

Overall equipment effectiveness is a metric that uses numbers (quantitative) to measure productivity of the manufacturing machines. This tool measures unknown costs and those costs that are not applicable to the machines (Baumers *et al.*, 2016:198)

In the manufacturing environment machines are expected run 100% with high quality production and at full capacity. It is impossible to achieve 100% availability and quality on the machines due to unforeseen circumstance that are unplanned and sometimes with planned circumstances.

2.4 Definitions of OEE

Overall Equipment Effectiveness (OEE) is part of total productive performance (TPM) philosophy introduced by Seiichi Nakajima in the 1980s'. It is a measurement tool used on TPM

- Machine failure or breakdown.
- Adjustment and set-up.
- Minor stoppages or idling.

- Speed losses or reduced speed.
- Defect.
- Rework

(Bakri *et al.*, 2012)used 85% as the benchmark or OEE value which acceptable worldwide. It was measuring components such as:

- Availability rate at 90%.
- Performance rate at 95%.
- Quality rate at 99%.

After 1988, a lot of research was conducted to find and clarify the best levels of quality, performance and availability for high volume machines. According to Pinto and Goldberg, (2017) OEE value which is more than 50% was acceptable for benchmarking purpose.

On one hand, Domingo and Aguado (2015), stated that an acceptable OEE values should be between 60% and 70% while Singh and Clements (2018) argued that OEE values between 30% and 80% are acceptable for benchmarking.

According to Braglia and Frosolini (2016), a 68% OEE value was acceptable as the average benchmark. However, this was very low as compared to 95% rate as found by Domingo and Aguado (2015). A performance rate of 68% contributed to time losses and idling due to small stoppages and this led to greater losses that were worsened by availability losses.

2.5 The Purpose of OEE

The values of OEE can be used for benchmarking in any manufacturing environment. The initial results of OEE values can be compared with the current obtaining values to measure and propose the possible improvement to be made, as posited by Lee and Bagheri (2015).

The application of OEE values can be used to differentiate performance between machines. According to Maskell and Baggaley (2016), poor performing machines can be separated from high performing one and prescriptive measures applied to remedy the situation.

Furthermore, OEE can be used for practical lean accounting: a proven system for measuring and managing the lean enterprise. In this vein, OEE can be used as the framework to pinpoint and improve certain aspect of the manufacturing machines.

2.6 Chronic and sporadic disturbances

The OEE metric is used to identify machines that are not effective, machines that are not adding value, machines that are wasting the resources and identify losses. These losses, called manufacturing disturbances are divided into two (McDowell & Michaletz 2017) namely;

- Chronic disturbances; and
- Sporadic disturbances.

According to McDowell & Michaletz (2017), chronic disturbances are hidden, small and confusing because they are the results of the sub-cause. They occur repeatedly and have high cost because the machine can't be used all the time due to consistence problem.

Chronic disturbances are latent and difficult to identify because they are 'factory defects' (Original Equipment Manufacture did not see it as well). The characteristics of chronic disturbance should be placed under hidden losses or obvious losses (McDowell & Michaletz, 2017),

Table 2.1: Below is the characteristic of table of chronic disturbance.

Loses	**Obvious losses**	**Hidden losses**
Sporadic breakdowns	✓	✓

Chronic breakdowns		
Setup and adjustment	✓	✓
Idling and minor stoppages		✓
Speed		✓
Sporadic quality defects Chronic quality defects	✓	✓

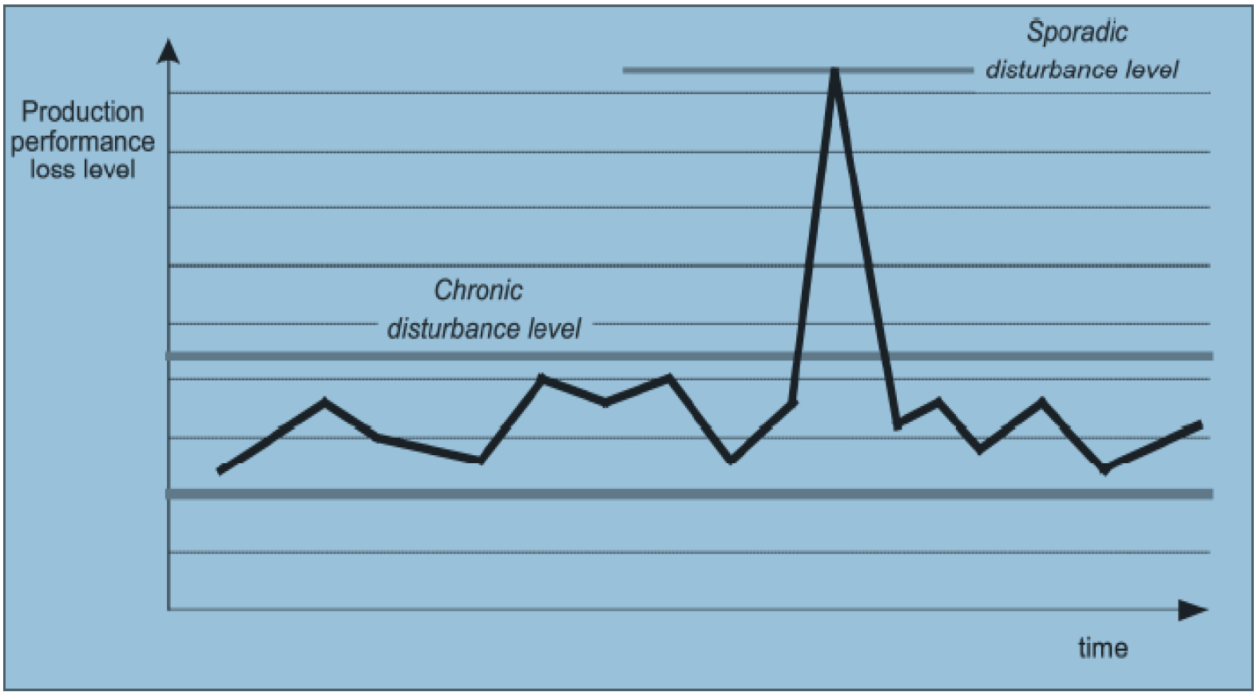


Figure 2.1: Production performance losses because of chronic and sporadic disturbances (Andersson, Bellgran, 2015).

2.7 Six big losses of OEE

According to McDowell and Michaletz (2017), OEE was introduced with an intention to eliminate all defects and breakdowns in the manufacturing industries. The intended benefits were high production, high quality, low inventory cost, increase in manpower efficiency and availability.

McDowell & Michaletz (2017) suggested six big losses which cause unplanned downtime losses and affects machine availability for production.

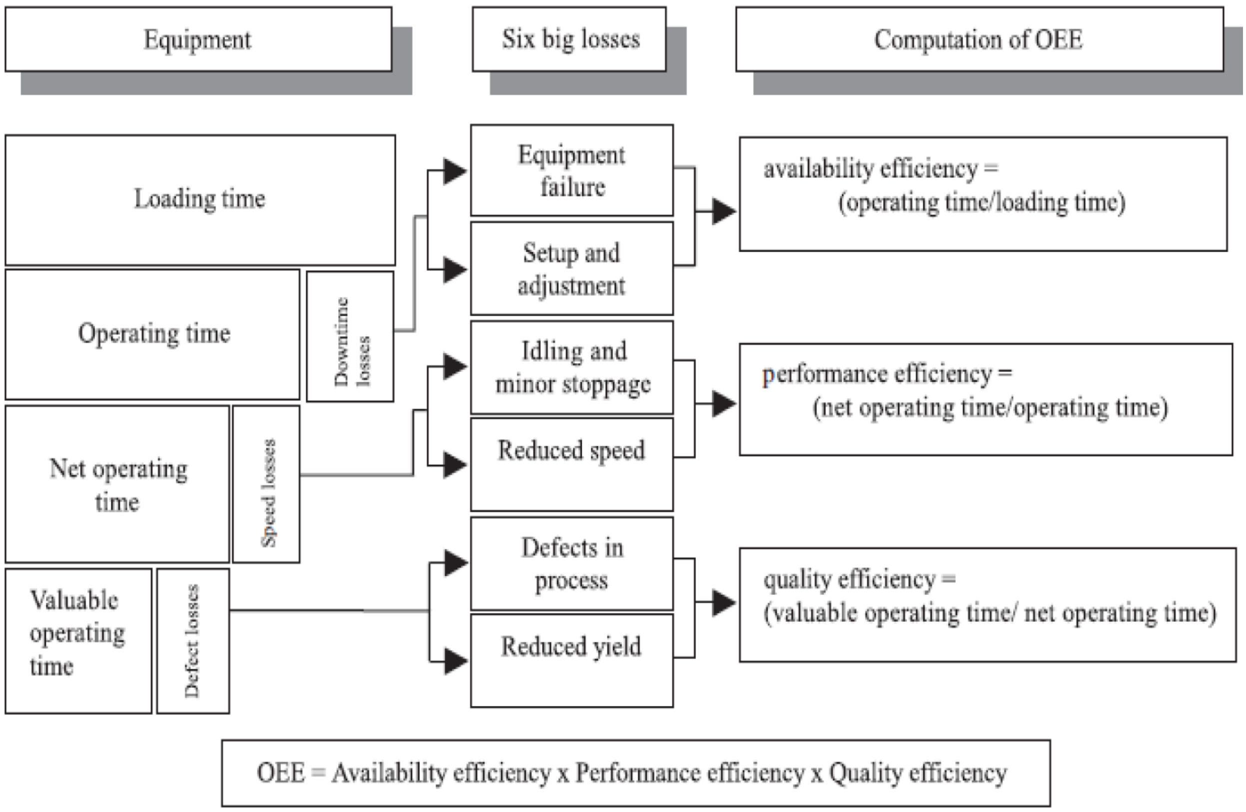


Figure 2.2 Overall equipment effectiveness and Computation procedure (Domingo and Aguado, 2015)

2.8 Evolution of OEE

OEE has been defined by different authors. The first author to define OEE was McDowell & Michaletz (2017). Other authors came with different definitions over the years.

Stange and Etz (2014), stated that the manufacturing industry competitiveness depends on productivity and availability of machines while Jonsson, Stange and Etz (2014), stated that OEE is a tool to measure losses in the manufacturing disturbances which are chronic or sporadic. On one hand, Pai and Srinivas (2016), in their research stated OEE is a quantitative tool to measure productivity in different machines.

2.9 Calculating the OEE of the machines

The process of identifying ways to improve machine OEE systematically requires the calculation of OEE step by step. The following calculation of OEE was done in the Lubrichem manufacturing company which operate 24 hours a day.

Table 2.2 Shift Time Table

Shift	Shift Duration (Time)	Planned stoppages	Downtime Remarks
Shift 1	06:00 to 14:00	Lunch 12.00 ~ 01.30	90min
Shift 2	14:00.30 to 22:00	Lunch 12:00 ~ 13:30	90min
Shift 3	22:00 am to 06:00 am	Lunch 00.00 ~ 01.30	90min

Production Data.

Operating Time= Shift length x 90 min

= 24hous x 60min

= 2160 min/day

Working days in a month.

= 25 x 2160

= 112 320 min/month

Planned down time.

= Cleaning+ Downtime+ Meeting Time

= (30 +270 + 15) min

= 315 min/day

A sample calculation for the bottleneck machine PAAC 06 is given below. The other machines values are calculated and recoded on the table below (refer to Table 2.1)

PAAC-06 Machine:

Planned stoppage time = Setup/changeover + Break time.

= 300 min + 315 min

= 615 min/day

= 615min x 25

= 15375 min/month

Unplanned down time = Mechanical breakdown + Electrical breakdown + Safety device breakdown

= 52.40 Hrs + 18.40 Hrs + 19.40 Hrs = 90.20 x 60

= 5412 min/month

Total Production Parts= 195 600 Nos.

Total Rejection Parts = 21 600 Nos.

Good Parts = Total Production Parts – Total Rejection Parts.

= 1 95 600 – 21 600

= 1 74 000 Nos.

Ideal Run Rate = 12 parts/min

Production time = Operating time – Down time.

= 36000 – 15375

= 20625 min

Operating Time = Planned Production Time – Unplanned Down Time.

= 20625 – 5412

= 15213 min

OEE Factors.

Availability = (18213/ 20625) x 100

= 88.09%

Performance = (195500 / 18213) /12 x 100

= 89.45%

Quality = (173900 / 195500) x 100

= 88.95%

Therefore, OEE=77.09x 89.45x 88.95

= 70.08%

2.10 OEE formulation

According to Nakajima (1988), OEE is has three factors and it is calculated in percentages with the formula below.

(OEE)= Availability (A) x Performance (P) x Quality (Q) x %

The acceptable worldwide value is 85% which is consist of:

- Availability 90.0 %
- Performance 95.0%
- Quality 99.9%
- Planned working hours of EE is calculated as follows:
- Planning factor OEE = Planning factor x (Availability x Performance x
- Quality) rate
- Net operating rate = Number produced x Actual cycle time

- Quality rate = Total number produced – Number Scrapped

2.10 Data collection for OEE

Collection of data refers to the registration of values for a certain variable. According to Wickham (2016), data can be registered manually or automatically, and, in some cases, there can be done simultaneously. Posavac (2015), suggest automatic measures used to collect information are probably relevant in the long run.

The method used in the collection of data is a vital aspect needed in the calculation of OEE. Data collection can vary from manual to much automated, as correct input of parameters acquired from the production system is essential for OEE calculations (Andersson & Bellgran, 2015).

Manual data collection which mainly happens in low-tech industries consists of a registry, where operators are required to fill in the causes and duration of breakdowns as well as reliable comments about minor stoppages and speed losses. In high-tech industries, an automatic OEE calculation system is governed by sensors linked to the equipment, automatically recording the start time and duration of stoppages while prompting the operator to make available the system with correct information about their specific downtime causes. With automatic method, opportunities are made available for operators to set up lists of potential downtime causes, scheduling the available operating time and constructing an automatic OEE calculation for any specific time.

The data inputs are provided in the system. It is not only possible to provide OEE results but makes it easier to retrieve a variety of reports of production performance and visualization of the performance results from the system. However, too much information in the system can be a waste of time for the operators and they will have to search for each downtime cause. Reluctance against data collection from operators and foremen are some of the major challenges faced by many industries.

Gugerty and Karlan (2018) found out that it was necessary to convince operators as some do believe that some disturbances have a major impact on efficiency which later measurements show that to be completely wrong. With automatic data collection, the system is quite expensive, complex and is collected at an aggregated level. On the contrary, manual data collection can be very detailed as losses can be fully examined.

It is necessary to introduce both manual and automatic data collection methods coupled with training of the operators of OEE as a performance measure, and on various parameters affecting the OEE outcome. The main reasons for this would be to qualify the quality of input data in line with an increase in the competence of operators and creating a better involvement of the operators in identifying potential performance loss factors as well as providing system with accurate information. Quantitative measurements for the OEE calculation were collected from many machines in the various industries under a period of three months. Machine stops were registered with a use of computer by the help of the operators as suggested by (Gumus & Topaloglu, 2016).

2.11 Set-up time

Toyota was unhappy with the waiting period of the cars for customer and they had to introduce lean manufacturing concept on the manufacturing process. According to Gumus and Topaloglu (2016), it is important minimise the cost of machines setup by introducing lean manufacturing because it reduces waiting time.

Lean manufacturing allows the preparations of raw materials to be brought closer to the machines before the actual production start. Certain steps such as testing, inspections, setting and loading of the new tool can be eliminated, the whole process can improve production, reduce waiting time, improve efficiency and effectiveness of the machines to exceed customer expectation. The following are the most common setup delay:

- Program failure
- Tool change
- Waiting for raw material.
- Searching or waiting for missing tool.
- Machine failure.
- Cleaning machines
- Material loading.
- Setup (tools).
- Inspections

According to Maskell and Baggaley (2016), reduction of machine setup time increases the potential to produce more products for the customer and remove bottlenecks on the process.

2.12 Cycle time

Cycle time corresponds to the time required to produce a product under continuous production. According to Luo and Wang (2015), cycle time is the running speed of the machines which is divided into short and long cycle. Good cycle time improves the machines to produce more with continuous improvement.

2.13 Single Minute Exchange of Dies (S.M.E.D)

SMED was introduced by Shigeo Shingo in 1950. There is a high need to exceed customer expectation worldwide especially while manufacturing high volume and small sized products. The process of SMED eliminates waste by improving efficiency and effectiveness in the manufacturing industries by bringing all raw materials close to each which are required to complete the product (Thompson & Moroni, 2016).

The term “single minute” is referred to as spending less time (10min) to start up the machines or to change production. Below are the advantages of applying SMED;

- Lowering cost by preventing defects and unnecessary inventory.
- Rapid change that improve quality instantly.
- Lower the use the machine.
- Lower batch size production
- Improve flexibility, changeover and throughput.

According to Thompson & Moroni, (2016), changeover or setup is post adjustment or preparation done once before or after the changeover. It is divided into:

- Internal setup that take place during shutdown.
- External setup that take place when the machine under operations.

SMED system is implemented in any setup using the following four steps (Thompson & Moroni, 2016).

Step 1: Identifying and separating external and internal.

External set up are more applicable for operators to minimise the chances of making rejects by adjusting and setting the running machines. Internal set is applicable to technicians of the machines to perform maintenance and clean the machine whiles the machine is on shutdown.

Step 2: Converting internal setups to external setups.

Running time of the machines is increase based on the system of converting internal setup time to external setup.

Step 3: Reorganizing all aspects of setup.

5S and good housekeeping is the pillar behind reorganising all aspect setup because everything needs to be its place with less destruction.

Step 4: Performing parallel setup activities.

The components used on the machines need to conform to certain standard that include the raw materials. Set up process needs to be documented in a form of check list or SOP.

2.14 Five (5) WHY’S analysis

Five (5) Why’s analysis is a technique which is used to probe the root cause of the problem with question asking method. According to Dave and Hämäläinen (2015), five (5) whys identify defects or the root cause of the problems. Five (5) whys does not solve the problem as it is an analysis tool to identify the main reason why there is problem and why it originated.

The problem needs to be clearly defined and it can be used by anyone even if they don’t have experience in the department but follow the systematic why of asking the problem. It is effective, simple, engaging, flexible and comprehensive. Below is how to use five (5) why questioning method.

Statement: The overhead crane is always tripping power supply.

Why 1

Why did the overhead crane trip the power supply? Because of damage cable

Why 2

Why is the cable damaged? Because it was loose and touch the crane track.

Why 3

Why did the cable lose? Because it wasn’t fastened inside the cable trunk.

Why 4

Why was it not fastened on the cable trunk? Because the technician did not comply to wiring code.

Why 5 and Root cause

Why did technician not comply to wiring code? Because he COC issues to confirm good workmanship.

2.15 Fishbone (Cause-Effect) Diagram

The Cause-Effect Diagram is also known as Ishikawa diagram. It is used to identify the root cause of a problem. Kauro Ishikawa was accredited for championing this technique in 1960 (Juran). This technique is used to analyse a problem systematically using the cause and effect approach. It provides the relationship link effects and multiple sources of the cause. The process requires the team involvement in brainstorm using the experience of the process but allowing the systematic approach to guide them (Saldaña, 2015).

Cause-Effect diagram is the best tool to qualitative and quantitative approach (Bloomberg and Volpe, 2018). Sub-causes of the main problem are structured on heading such as materials, man, money, machines and methods to identifying the potential causes. Below is the Cause-effect diagram of unscheduled returns identifying causes for spares shortages.

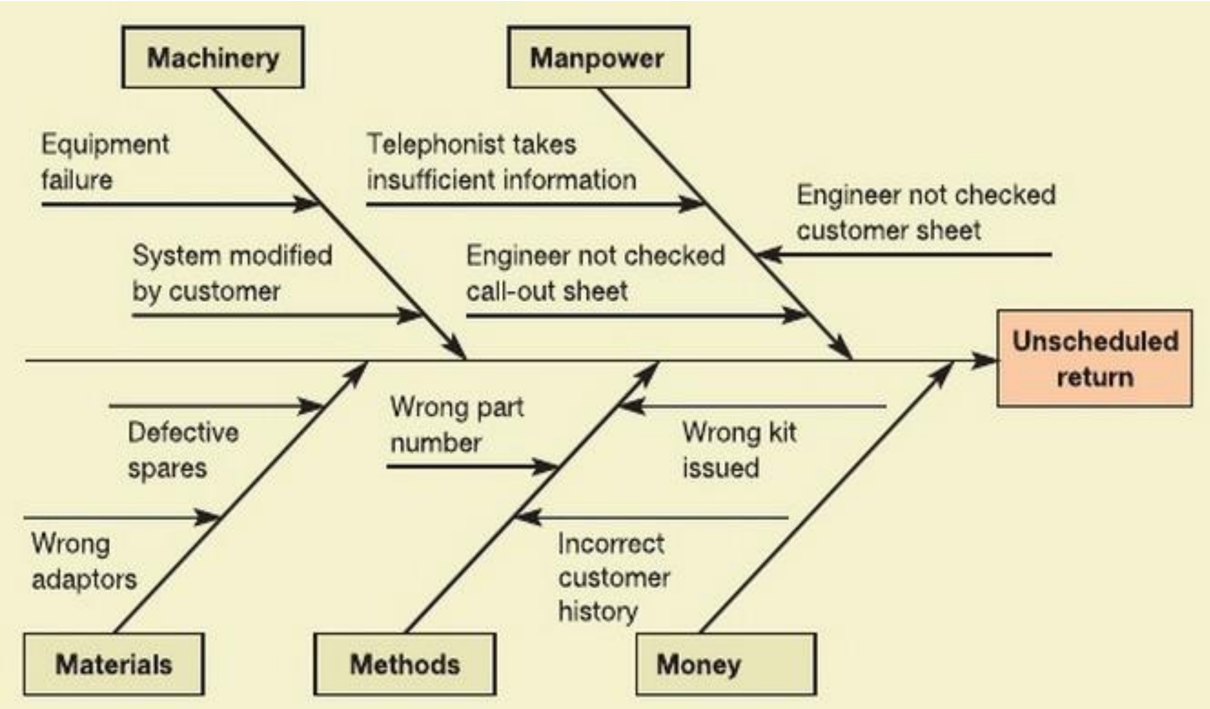


Figure 2.3: Fishbone diagram of unscheduled returns, (Cheh, 2014).

2.16 Chapter Summary

This chapter outlined the history of quality, quality performance, market and financial performance, product quality and TQM practices and quality culture within manufacturing. The following chapter discusses the research methodology used in this study and concludes with a summary.

3 CHAPTER 3 RESEARCH APPROACH

3.1 Introduction

This chapter outlines the how methodology of this study was planned and performed. It discusses the data collection methods.

The approach is a combination of qualitative and quantitative nature. According to Bell and Bryman (2018), it is essential to choose the correct methods of collecting the data of the research. Quantitative and qualitative data collection techniques are the common to be used in scientific research

3.2 Quantitative method

This method deals with emphasized and generated numerical information. Quantitative method produces good results for the data collected in group sample and comprising of data information from group sample as stated by Darmer and Freytag (1995). It presents good understanding of theory and research. Tezel and Barker (2016), defined it as "explaining phenomena by collecting numerical data that are analysed using mathematically based methods (in particular statistics)".

Table 3.1 below shows understanding of Quantitative methods.

Research phases	**Quantitative data collection**
Sampling	• Reduce sampling by adequate size of sampling • Random sampling
Permissions	• Individual authorising access to site. • Board review • Individual
Data sources	• Check list. • Instrument • Public document
Recording data	• Instruments with valid and reliable scores.

Administer data collection	• Attend to ethical issues • Standard procedure

3.3 Population and Sample

Lubrichem operates about 867 production machines as shown in the table below. This is entire machine population. A sample (192) was selected as shown in the same table below.

Production machine category	No of machines	No. of machines used as a sample
Automated volume driven machines	244	23
Automated maintenance workshop	347	69
Blending machines	157	62
Semi-automated machines	119	38
Total	867	192

Table 3.2 Sample of the machines.

The study was conducted in four departments of Lubrichem Company. These departments have these types of machines as shown in table 3.2 above.

- Automated volume driven machine
- Automated maintenance workshop
- Blending machines
- Semi-automated machines

Each machine represented a sample space where data was collated from. Statistical data on RS- Production was collected from October 2016 to July 2018

3.4 Data collection instrument.

Collection of data refers to the registration of values for a certain variable. Data can be registered manually or automatically, and, in some cases, this can be done simultaneously. Xu and Croft, (2017) suggested that automatic measures used to collect information are probably relevant in the long run.

The researcher used electronic RS-production system as methods of collecting the data. The primary data was collected through RS-Production system at Lubrichem Company. This study is a scientific research because it analyses the production data differences and relationships. The RS-Production system data was used to compute the following

- Total time registered
- Set up/changeover times per piece
- Cycle time recorded ranges
- Aggregated stoppage reasons
- Average OEE values for the Lubrichem Company

Throughout the research, discussions and the RS-Production system were populated in the tables and brainstormed. The research questions were answered using RS-Production system figures, discussions and analysis and data subsequently transcribed.

The OEE measurements depend on the source of data including how it is collected. The data has to be accurate and not biased according to Taylor (2018). The method used in the collection of data is a vital aspect needed in the calculation of OEE.

Data collection can vary from manual to much automated, as correct input of parameters acquired from the production system is essential for OEE calculations (Xu and Croft, 2017). Manual data collection which mainly happens in low-tech industries consists of a registry, where operators are required to fill in the causes and duration of breakdowns as well as reliable comments about minor stoppages and speed losses.

According to Vogel-Heuser and Rösch (2016), in high-tech industries, an automatic OEE calculation system is governed by sensors linked to the equipment, automatically recording the start time and duration of stoppages while prompting the operator to make available the system with correct information about their specific downtime causes. With automatic method, opportunities are made available for operators to set up lists of potential downtime causes, scheduling the available operating time and constructing an automatic OEE calculation for any specific time period.

As long as the data input are provided in the system, it is not only possible to provide OEE results but makes it easier to retrieve a variety of reports of production performance and visualization of the performance results from the system.

However, too much information in the system can be a waste of time for the operators and they will have to search for each downtime cause. Reluctance against data collection from operators and foremen are some of the major challenges faced by many industries.

Wickens and Holland, (2015) found it necessary to convince operators as some do believe that some disturbances have a major impact on efficiency which later measurements show that to be completely wrong. With automatic data collection, the system is quite expensive, complex and is collected at an aggregated level. On the contrary, manual data collection can be very detailed as losses can be fully examined.

It is necessary to introduce both manual and automatic data collection methods coupled with training of the operators of OEE as a performance measure, and on various parameters affecting the OEE outcome. Main reasons for this would be to qualify the quality of input data in line with an increase in the competence of operators and creating a better involvement of the operators in identifying potential performance loss factors as well as providing system with accurate information.

Quantitative measurements for the OEE calculation were collected from a large number of machines in the various industries under a period of three months. Machine downtimes were registered with a use of computer by the help of the operators as suggested by (Ahmad & Gani, 2015).

The researcher used the following instrument to collect data: RS-Production system, voice recorder during interview and skype recording video for interview with night shift employees. The researcher did not have control factors that might influence the behaviour and performance of participant under study thereby reporting the outcome as they are (Dezsö, 2012).

Furthermore, the researcher explained the purpose of study and the objectives to the participants and assured their confidentiality. Interview questions were formulated in English because it is medium communication language in Durban South (Prospecton) manufacturing industries.

3.5 Case study design

The data was gathered by RS-Production system software after the interview with the employees of Lubrichem Company. The RS-Production was used to collect secondary data because it is a software that record all the stoppages and the alarm or the cause of the downtime. The RS-Production system can collect the data and perform automatic OEE calculations

Figure 3.1 below shows RS-Production connection to the manufacturing process.

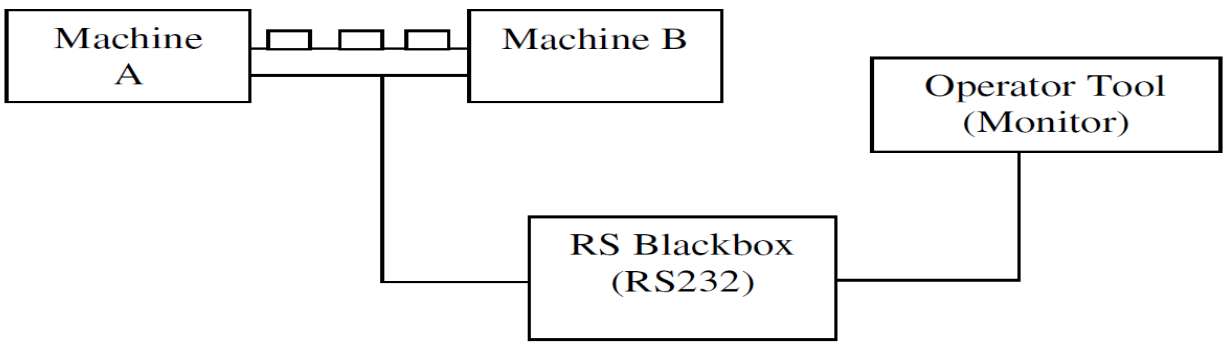


Figure 3.1: RS-Production system connected to the machines.

The figure above shows how the RRS-Production system software is connected to the production machines and how it collects the data. The RS Blackbox is connection to the operator monitor and machine A and B. The Blackbox read all the activities (including, stoppages, alarm, rejects, production figure and availabilities of the machines).

Mechanical signals are used for

- Cycle Signal
- Operating Signal
- Defects Signal
- Processing signal
- Automatic Coding Signal

The operators note the deviations, disturbance and production figures on the monitor. Data collected by RS Blackbox is automatically stored on the server for future reference and record keeping. The server will store the date in the EXCELL spread sheet that has all the formulas to calculate OEE and analysing the results. The system helps Lubrichem Company to improve efficiency and understand their losses.

3.6 Analysis

The quantitative aspect was analysed through statistical approach while the deductive approach was used for the qualitative results. In this study, the qualitative data provided a good background for the problem statement and supported the quantitative approach by making data more understandable (Rubin and Babbie, 2016).

The project took 20 weeks which required lot of planning. The author used the Gantt chart for plotting unplanned and planned meetings to ensure a seamless research.

Table 3.2 Draft table of project planning

Week	Task
1	Intrdoction to project (Lubrichem company)
2 to 3	Meeting with Lubrichem company and project planning
4 to 5	Literature studies
5 to 6	Meeting, data collection and literature studies
7 to 8	Meeting, data collection and literature studies
9 to 14	Meeting and analysis of thesis.
15 to 20	thesis

3.7 Validity and Reliability

According to Graban (2016), validity is framework of improving engagement of communication between all the employee and outline reactions of deviations in the production process. Zimbardo and Boyd (2015) state that the validity as standard of prevent new employees to minimise the chances of making mistakes.

Validity can be achieved in the following ways:

- **Face validity:** experience people are requested to base on their years of knowledge.
- **Concurrent validity:** relevant question to the study.
- **Predictive validity:** new measure of job satisfaction.
- **Construct validity:** deduce hypotheses from the theory that is relevant to the concept.
- **Convergent validity:** measures of the same concept developed through other methods.

According to Streiner and Norman, (2015), reliability is continuing measurement of concept using internal reliability, stability and inter-observer consistency.

- **Internal reliability:** determine whether respondents' scores on any one indicator.
- **Stability:** asking the stability of the measure over time.

Inter-observer consistency: lack of consistency in decision making

According to Weimer and Vining (2017), the interview question needs to be simple and straight forward that lead to limiting the participant from providing the wrong answer.

The following control was in place (data collection, conclusion and interpretation) to ensure validity and reliability achieved in all steps of the research process. Raw data was analysed with descriptive approach to improve transparency when there were setbacks

4 CHAPTER 4 RESULTS, DISCUSSION AND ANALYSIS

4.1 Introduction

This chapter presents the results of the OEE measurements performed in this case study and a discussion on the qualitative interviews.

4.2 Data collection

The study was conducted in four departments of Lubrichem Company mentioned on the table below. The table represents the statistical data that was collected:

Production machine category	**No of machines**	**No. of machines used as a sample**
Automated volume driven machines	244	23 [FB type]
Automated maintenance workshop	347	69 [MW type]
Blending machines	157	62 [AU]
Semi-automated machines	119	38 [308, 184, 149, S3 and E6]
Total	867	192

Table 4.1: Four department of Lubrichem Vs data collected

The data collected was further tabulated and presented, after applying the mathematical formulas presented in the literature, as

- Total time registered (table 4.2)
- Set up/changeover times per piece (table 4.3
- Cycle time recorded ranges (table 4.4)
- Aggregated stoppage reasons (table 4.5)
- Average OEE values for the Lubrichem Company (table 4.6)

Total scheduled production time	357190 hours

Total operation time	170925 hours
Total downtime	186265 hours

Table 4.2: Total time registered

Types of set-up (Changeover) time	Number of pieces
Single set-up time	Less than 5 pieces
Short set-up time	5-25 pieces
Medium set-up time	25-200 pieces
Long set-up time	Greater than 200 pieces

Table 4.3: Setup/Changeover times per piece.

Types of cycle times	Time
Single cycle time	Less than 2 seconds
Short cycle time	2-60 seconds
Medium cycle time	1-5 minutes
Long cycle time	Greater than 5 minutes

Table 4.4: Cycle time recorded ranges

Total Availability	47,9%
Average Availability	49% without considering Total schedule production time
Average OEE	43,5% without considering Total schedule

Table 4.5 Total Availability and OEE for all four departments.

The results of downtime losses and stoppage reasons for all four departments are summarised in the table 4.5 below. This same data is shown in the graph in figure 4.1.

Downtime losses (Aggregate Stoppage Reasons)	**Time**	**Percentages of Losses**
Step/Changeovers	17591 hours	28.4%
Machines/Techniques	9354 hours	15.1%
No reason code	/	/
Shift changes and breaks	3641 hours	5.9%
Unplanned production	13669 hours	22.1%
Planned service/Maintenance	4277 hours	6.9%
Other planned stops	1946 hours	3.1%
Lack of accessories	549 hours	0.9%
Lack of personnel	4631 hours	7.5%
Micro stoppage	2985 hour	4.8%
Personal time	82 hours	0.1%
Problem with internal materials	1535 hours	2.5%
Problem with external materials	1041	1.7%
Quality issues/rework	634 hours	1.0%
Total	61933 hours	100%

Table 4.5: Aggregated stoppage reasons and time of downtime losses.

The OEE values were calculated as follows:

Production machine category	**Average EE**

Automated volume driven machines	49,9%
Automated maintenance workshop	49,8%
Blending machines	38,7%
Semi-automated machines	43,3%

Table 4.6: Average OEE values for the Lubrichem Company.

The table 4.7 below shows the quality values compared with the other OEE parameters.

Production machine category	**Average availability**	**Average performance**	**Average quality**
Volume driven machines	58,76%	82,60%	100%
Maintenance workshop	55,98%	89%	100%
Blending machines	44,70%	89,70%	95,9%
Semi-automated machines	44,90%	96,20%	99,8%

Table 4.7: Highest average OEE parameter for the four departments

The results show that low availability negatively affects the OEE values.

Production machine category	**Average availability**	**Average performance**	**Average quality**
Volume driven machines	58,76%	82,60%	100%
Maintenance workshop	55,98%	89%	100%
Blending machines	44,70%	89,70%	95,9%
Semi-automated machines	44,90%	96,20%	99,8%

Table 4.8: Lowest average OEE parameter for the Lubrichem Company

4.3 OEE of results and discussion for all four departments

The general response from the 16 respondents concurred that the machines cannot run for 24hours without breakdowns or unplanned stoppages. Annexure A gives a tabular summary of the questions and the responses.

The data from the RS Production was summarised in figure 4.1 below.

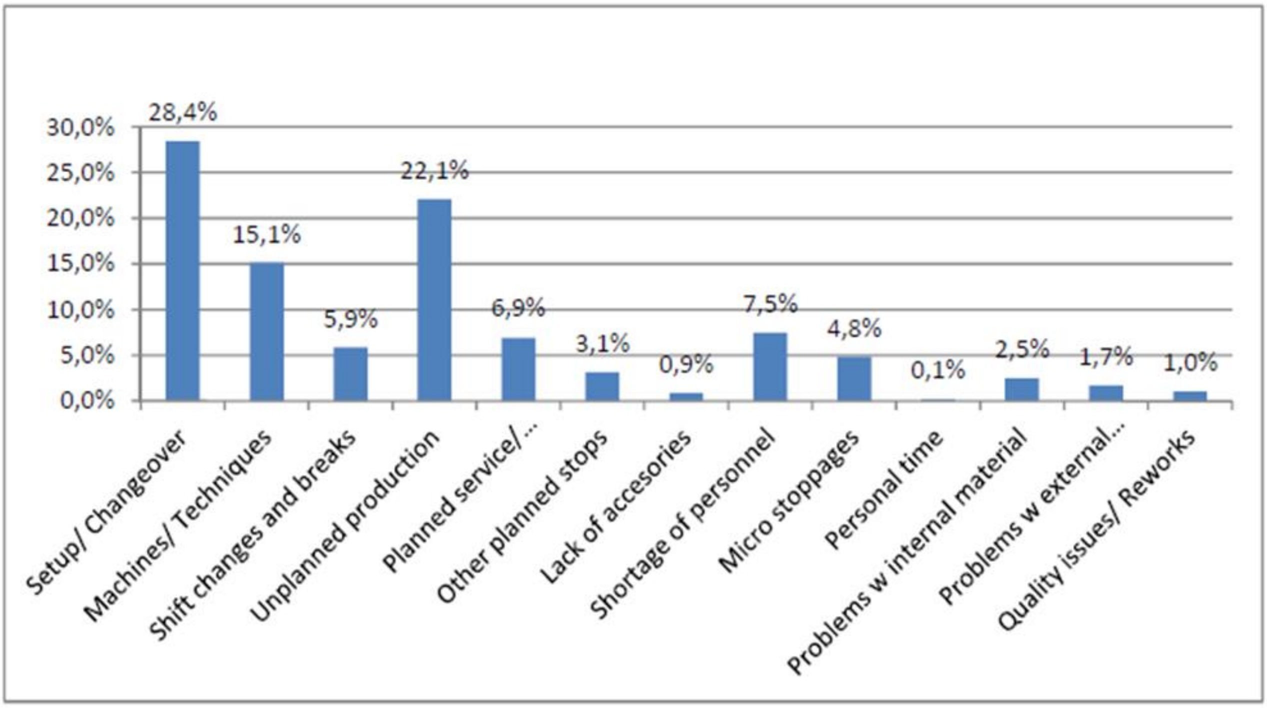


Figure 4.1: Percentage loses within all the machines.

The above diagram shows the downtime reasons and the contribution of each reason in section of the plant.

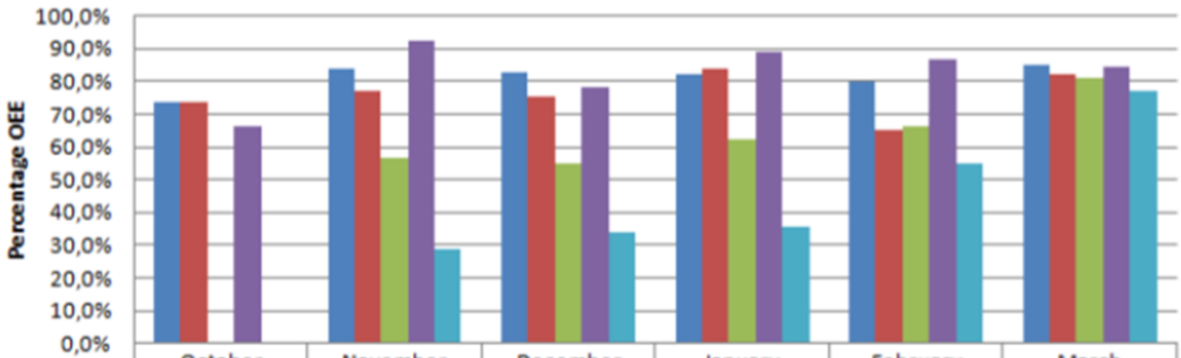
Changeover/Setup stoppages was the biggest contributor with 28.4%, followed by unplanned production at 22.1%. These two reasons accounted for over 50.5% of the stoppage time.

The third reason was losses due to techniques or machines which were at 15,1%, shortage of operations and maintenance personnel was at 7.5%. Therefore, the six reasons accounting for 80% of all stoppages were

- Changeover/Setup stoppages
- unplanned production
- techniques or machines
- Shortage of maintenance personnel
- Planned maintenance and service
- Shift changes and breaks

4.4 OEE results and discussion of automated volume driven machines.

The mean OEE results on the automated volume driven machines (FB14, FB15, FB44, FB40 and FB46) are shown in figure 4.2.



	October	November	December	January	February	March
FB 14	73,5%	83,7%	82,7%	82,3%	80,1%	85,1%
FB 15	73,6%	76,8%	75,3%	83,9%	65,3%	82,1%
FB 44	0	56,8%	54,6%	62,4%	66,2%	81,0%
FB 40	66,3%	92,3%	78,0%	88,8%	86,7%	84,3%
FB 46	0	29,0%	34,0%	35,7%	54,8%	76,8%

Figure 4.2: OEE results of different automated volume driven machines.

The Overall Equipment Effectiveness analysis of different automated volume driven machines between the month of October 2016 and March 2017 shows a huge increase in average Overall Equipment Effectiveness values on the machines FB (14, 15, 44, 40 and 46).

Two specific machines (44 and 46) had a significant increase of OEE results from 0% during the month of October to 81% and 76% respectively. The values of OEE variance were the results of availability, performance, planned factor and quality losses. Quality and performance had the highest Overall Equipment Effectiveness values in the automated volume driven machines.

The losses in the automated volume driven machines department were also collated. The table below shows the percentage of all the losses with the different factors of the OEE on the machines. Planned losses was 24% which were caused by techniques/machines, break (lunch and tea time), shift changes, planned maintenance/service, internal and external material, other planned stops.

Factors	Losses	Stoppage reasons	Percentages
Availability	Planned Losses	Machines/Techniques	10%
		Shift changes and breakdowns	1%
		Planned serviced/Maintenance	5%
		Other planned stops	2%
		Lack of accessories	0%
		Stoppage of personnel	2%
		Personal time	0%
		Problem with internal materials	4%
		Problem with external materials	0%

Factor	Losses	Stoppage reasons	Percentage(s)
Availability	Planned Losses	Machines/Techniques	10%
		Shift changes and breaks	1%
		Planned service/Maintenance	5%
		Other planned stops	2%
		Lack of accessories	0%
		Shortage of personnel	2%
		Personal time	0%
		Problems with internal material	4%
		Problems with external material	0%
Total			**24%**
Availability	Unplanned Losses	Equipment breakdown/ Unplanned production	24%
		Setup/Changeover	14%
Total			**38%**
Performance	Minor idling losses	Micro stoppage	2%
Quality	Defect and rework	Quality issues/Reworks	0%
No reason code	Unknown losses	Unknown	36 %

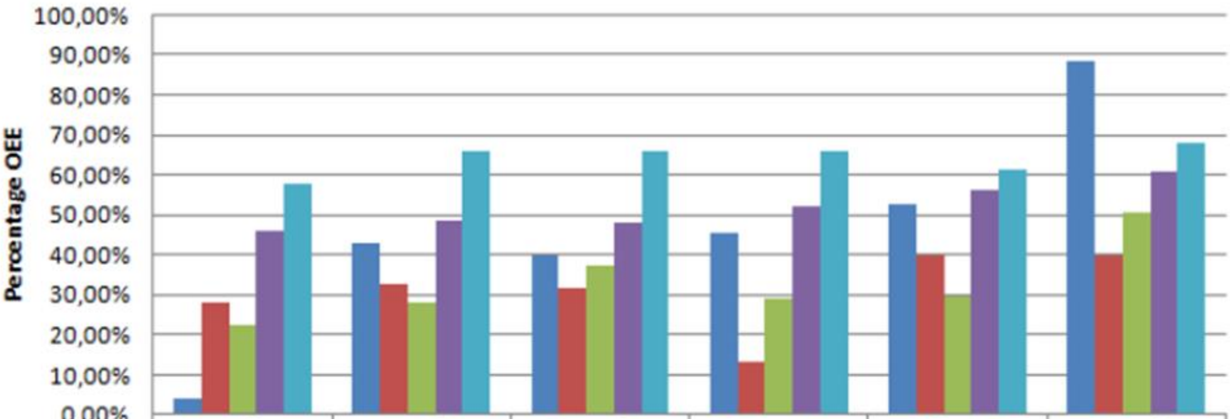
Table 4.9: Average downtime losses for automated volume driven machines.

The availability losses on the machines from the above table were caused by the unplanned production/ breakdown, production changeover and machines set up. These losses contributed 24% and 14% respectively, summing up to a total of 38%.

4.5 OEE results and discussion of Automated Maintenance workshop.

All respondents raised the concern that they were unable to reach the production targets because of the unavailability of the machines, continuous breakdown and poor product quality. The RSP production data on the graph below shows that there were low OEEs for the month of October 2016. However, since the implementation of Total Maintenance Planning (TPM) in November 2016, the productivity, quality and availability values have improved.

The table below shows the average downtime for automated maintenance workshop for machines MW6, MW40, MW39, MW21 and MW29.



	October	November	December	January	February	March
MW 6	3,90%	43,10%	39,70%	45,50%	52,70%	88,30%
MW 40	28,2%	32,6%	31,6%	13,1%	39,8%	40,0%
MW 39	22,4%	27,9%	37,3%	29,0%	29,7%	50,7%
MW 21	45,8%	48,8%	47,8%	52,2%	56,0%	60,8%
MW 29	57,6%	66,0%	65,7%	66,0%	61,3%	67,8%

Figure 4.3: OEE results over time for Maintenance workshop for automated machines

The maintenance workshops machines increased the Overall equipment effectiveness values (quality, performance and availability) after implementing maintenance planning within some of their machines. Among the machines sampled, the result of Overall Equipment Effectiveness values on machines MW (6, 40, 39, 21 and 29) continuously improved.

The machine MW 6 had the highest increase in Overall Equipment Effectiveness value from 3.9% during October 2016 to 88.3% in March 2017. This was followed MW 39 whose value increased from 22.4% to 50.7% respectively.

The highest Overall Equipment Effectiveness value was 88.3% in October for MW 29 machine, highest values was different from months to months while maintenance planning was gaining the effectiveness. The losses of Maintenance workshop machines are classified and defined as planned maintenance.

The total of planned related losses was 25% which were caused by techniques/machines, breaks (lunch, and tea time) while attending to the machines, shift handover, planned maintenance/service, planned stoppages, lack of accessories like spares and tools and shortage of staff/personnel.

The table below show the results Automated Maintenance workshop losses

Factor	Losses	Stoppage reasons	Percentage(s)
Availability	Planned Losses	Machines/Techniques	9%
		Shift changes and breaks	6%
		Planned service/Maintenance	4%
		Other planned stops	1%
		Lack of accessories	1%
		Shortage of personnel	2%
		Personal time	0%
		Problems with internal material	1%
		Problems with external material	1%
Total			**25%**
Availability	Unplanned Losses	Equipment breakdown/ Unplanned production	3%
		Setup/Changeover	13%
Total			**16%**
Performance	Minor idling losses	Micro stoppage	5%
Quality	Defect and rework	Quality issues/Reworks	2%
No reason code	Unknown losses	Unknown	52%

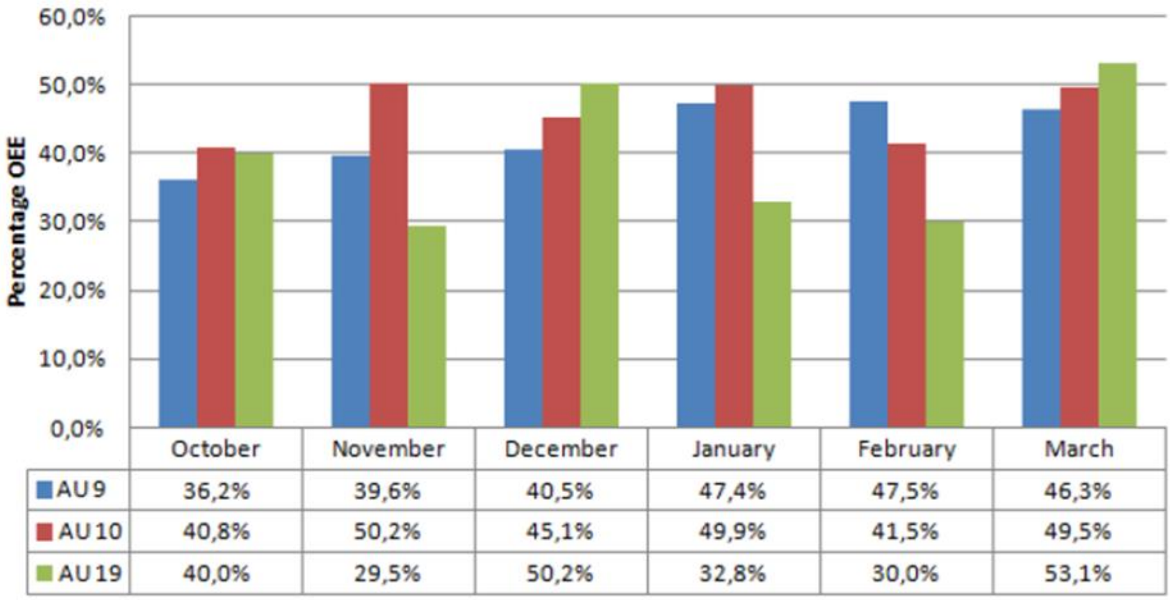
Table 4.10 Downtime losses for Automated Maintenance workshop.

The table above shows average Maintenance workshop losses which were availability (planned and unplanned losses), performance and quality losses. The cause of availability losses was unplanned/breakdowns, machines changeover/setup and production changeover.

Furthermore, these losses were up to 16% of which 3% was directly caused by breakdowns and 13% of machines set ups and production change overs. Performance or micro losses were 5% while quality issues or reworks were 2%. The unknown losses accounted to 52% of the downtimes.

4.6 OEE results and discussion of Automated Blending production machines

The mean OEE results on Blending automated production machines (AU 9, AU10, AU19)



	October	November	December	January	February	March
AU9	36,2%	39,6%	40,5%	47,4%	47,5%	46,3%
AU10	40,8%	50,2%	45,1%	49,9%	41,5%	49,5%
AU19	40,0%	29,5%	50,2%	32,8%	30,0%	53,1%

Figure 4.3: OEE results for Blending automated production machines

The OEE results of Blending automated production machines between October 2016 and March 2017 were recorded. There was a huge increase in average OEE values on machines AU (9, 10 and 19).

The figure above shows Overall equipment effectiveness results of the machine AU (19 and 10) significantly improved to 50 %. Machine AU 9's Overall equipment effectiveness values increased to 46.3% in March 2017 as compared to October 2016.

The result of each of the three machines losses within the Blending automated production machines were caused largely by techniques/machines, breakdowns, shift handover and shift changes. Furthermore, issues like planned maintenance/service, planned stoppages, shortage of operations personnel, problems with internal and external material, machines unplanned breakdown, unplanned production, changeover/setups also contributed to the performance stoppages.

Factor	Losses	Stoppage reasons	Percentage(s)
Availability	Planned Losses	Machines/Techniques	12%
		Shift changes and breaks	4%
		Planned service/Maintenance	6%
		Other planned stops	4%
		Lack of accessories	0%
		Shortage of personnel	10%
		Personal time	0%
		Problems with internal material	0%
		Problems with external material	1%
Total			**37%**
Availability	Unplanned Losses	Equipment breakdown/ Unplanned production	5%
		Setup/Changeover	21%
Total			**26%**
Performance	Minor idling losses	Micro stoppage	3%
Quality	Defect and rework	Quality issues/Reworks	0%
No reason code	Unknown losses	Unknown	34%

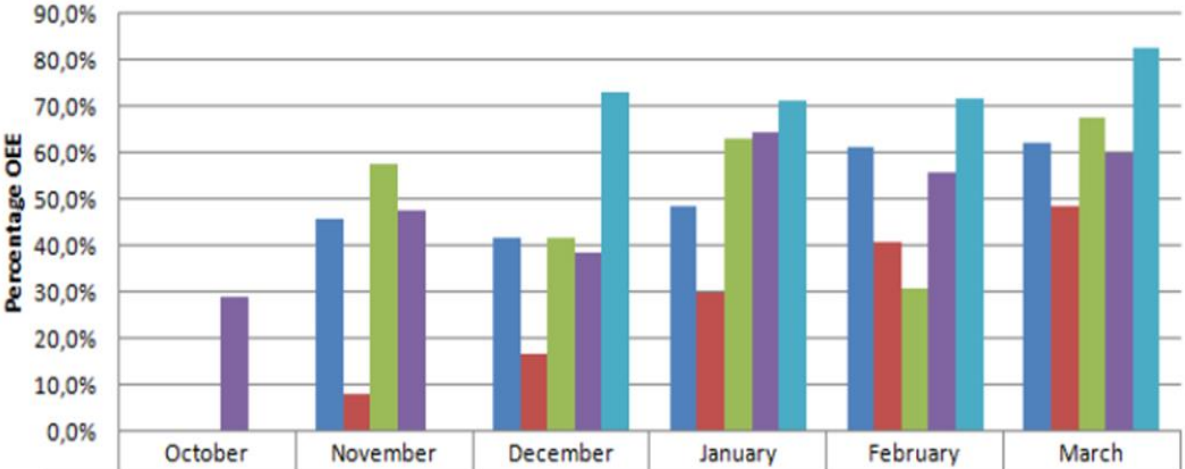
Table 4.11: Downtime losses for other Automated Blending production machines

Planned losses accounted for 37% while availability losses were 26% and machines breakdown contributed 5%. In addition, production changeovers /setups resulted in 21% stoppage time while performance losses were 3%.

However, quality was good because there were no were losses associated with it. There was 34% of unknown losses.

4.7 OEE results and discussion of Semi-automated production machines

The mean OEE results on Semi-automated production machines (308, 184, 149, S3 and E6) are presented below in figure 4.4



	October	November	December	January	February	March
308	0	45,9%	41,6%	48,5%	61,3%	61,9%
184	0	8,0%	16,7%	30,1%	40,8%	48,7%
149	0	57,5%	41,6%	63,2%	31,0%	67,5%
S3	29,1%	47,5%	38,3%	64,2%	55,8%	59,8%
E6	0,3%	0	72,8%	71,0%	71,7%	82,7%

Figure 4.4: OEE results for Semi-automated production machines

In the semi-automated production machines, a total of 35 machines were used on this research. Out of 35 machines E 6, S3, 184, 308 and 149 had a slight increase of Overall equipment effectiveness values as from October 2016 until March 2017.

The value "0" indicates that there were no values of overall equipment effectiveness recorded. The machines increase Overall equipment effectiveness as follows: 308, S3 and 149 was above 50%, machine 184 was below 50%, E6 was 0.3% during October 2016 and increase to 7% during March 2017.

The planned losses identified has negatively affecting Overall equipment effectiveness amounting to 11% were caused by planned maintenance/service planned stoppages, shortage of operations personnel and internal and external issues. The availability losses were unplanned caused by machines unplanned production, breakdown, setting up of the machines and production changeover.

In addition, machine breakdowns were 13%, setting up of the machines was 11%. Quality and performance losses were 0% while unknown losses were 65%.

Factor	Losses	Stoppage reasons	Percentage(s)
Availability	Planned Losses	Machines/Techniques	4%
		Shift changes and breaks	0%
		Planned service/Maintenance	1%
		Other planned stops	1%
		Lack of accessories	0%
		Shortage of personnel	4%
		Personal time	0%
		Problems with internal material	0%
		Problems with external material	1%
Total			**11%**
Availability	Unplanned Losses	Equipment breakdown/ Unplanned production	13%
		Setup/Changeover	11%
Total			**24%**
Performance	Minor idling losses	Micro stoppage	0%
Quality	Defect and rework	Quality issues/Reworks	0%
No reason code	Unknown losses	Unknown	65%

Table 4.12: Downtime losses Semi-automated production machines.

4.8 Analysis and Discussion of the results

Overall equipment effectiveness results can be improved by focusing on the major losses and ways to eliminate them. Unknown losses accounted for a significant amount in all the types of production machines as shown in the table 4.13 below.

Production machine category	Unknown losses %
Automated volume driven machines	36%
Automated maintenance workshop	52%
Blending machines	65%
Semi-automated machines	34%

Table 4.13: Major losses all four-different section.

These major losses could have had a major influence on the results because it is excluded during the calculation of the Overall equipment values in all four sections.

According to Maskell and Baggaley (2016), different measures should be included during calculation of OEE because it makes it difficult to understand right measures in the correct way. The unknown losses of semi-automated machines are lowest as compared to the other sections.

Unknown losses can affect overall equipment effectiveness drastically because it is unpredictable.

4.8.1 Analysis of Automated volume driven machines

The OEE value for the Automated volume driven machines was found to be 49. 9%. This is directly influenced by the performance and availability rates of 58%, 60%, 76% and 82% were as quality is 100%.

Some of the machines were affected by planned losses of 24%. Only a few individual machines had good OEE results. The rest were affected by planned losses up to a total of 24%. The following are losses that can be eliminated:

- Maintenance/Planned service can be eliminated with 5% by scheduling production running time.

- Shortage operations personnel can be eliminated with 2% by improving poor planning.
- Problems with external and internal material can be eliminated with 4% by pre-testing and verification before running production.

In the automated blending machines, unknown losses were 36%. This is a big concern because it has major potential to affect the results of OEE in different ways as it is not linked to the Overall equipment effectiveness factors.

Operators gave the reasons that they were not sure what attributed or system failure or they forgot giving reasons due to reluctance, negligence and overloaded by work. Training and development is required for employees because most of them thy have basic qualification which results on lack on hands on and scientific knowledge of problem solving the problem.

Availability losses in table 4.8 are the highest and it directly contributes negatively to the Overall equipment effectiveness results. Availability losses were 38% which were caused by breakdown and unplanned production on the machines, setting up and the machine and changeover of production was 24% and 14% respectively.

Machines breakdown and unplanned production should have been separated to know the exact contributing factor. Single Minute Exchange of Dies (S.M.E.D) method could help to reduce changeover and set up losses. Cause-effect diagram can be utilized to help identify breakdown causes and eliminate/reduce the 24% of machines breakdown losses. Five (5) whys root cause analysis can be used to identify and list the reasons for each loss.

4.8.2 Analysis Maintenance workshop for automated machines.

The Overall equipment effectiveness values were 49% and it is equivalent to that of automated volume driven machines. It is influenced by the performance, availability and losses rate of 98%, 55% and 89% respectively while quality is 100%. Planned losses affected most of the machines by 25%. Planned losses can be eliminated using the following methods:

- Good planning can eliminate break, lunch and shift changes losses with 6%.
- Scheduling production time can eliminate maintenance or service losses with 4%.
- Good planning can eliminate shortage of operations personnel with 2%.

Unknown losses were 52% and it was the highest. Table 4.10 shows unknown loss as highest after the Blending automated machines. The operators need to attend training and development to address the issue. Planned losses were 25% from the automated volume driven maintenance workshop. 5 whys root cause analysis can be used to identify and list the reasons for each loss. Single Minute Exchange of Dies (S.M.E.D) method could help to reduce changeover and set up losses. Cause-effect diagram can be utilized to help identify breakdown

4.8.3 Automated blending machines.

The Overall equipment effectiveness values for the Automated blending machines was 43.3%. The OEE values were influenced by availability, performance and quality rate at 44%, 96% and 99.8%.

The OEE rate of individual machines was good but affected by planned losses of 37%. Planned losses from automated blending machines are high as compared to other sections. The following planned losses can be eliminated as follows:

- Scheduling production time can eliminate maintenance or service losses with 6%.
- Good planning can eliminate shortage of operations personnel with 10%.

Unknown losses were 34% and it was the lowest. If these losses were eliminated, it would have enhanced the results positively. Planned losses were 37% from the automated volume driven maintenance workshop. Five (5) whys root cause analysis can be used to identify and list the reasons for each loss. Single Minute Exchange of Dies (S.M.E.D) method could

4.8.4 Semi-automated machines.

The Overall equipment effectiveness value of 33.7% was the lowest value compared to the semi-automated machines. The losses are influenced by performance and availability rates with 89.7%, 44% and 70% respectively while quality is at 95.9%. Planned losses affected the other machines by 11%. Good planning could eliminate shortage of operations personnel with 2%.

The highest losses were under automated blending plant at 65%. This is highest on all the four sections. Planned losses are the lowest in all four different sections with only 11% of the losses. Improvement could be done to reduce planned losses due to shortage of operations personnel by (4%), Availability losses with the machines breakdown by 13% and changeover and machines setting by 11%. 5 whys root cause analysis can be used to identify and list the reasons for each loss. The performance factor was 0% and best as compared to other four sections.

5 CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

This study was conducted to analyse of overall equipment effectiveness within four departments namely:

- Automated volume driven machines,
- Automated maintenance workshop,
- Automated blending machines and
- Semi-automated machines by identifying all the losses.

Operations Equipment Effectiveness provided the full version of how different processes can be efficient and improve performance within the four departments. This study provided the data of with the main cause of the stoppages and therefore the decision maker can make informed decision to confront all manufacturing process.

5.2 Conclusions

The objectives of Overall Equipment Effectiveness are to improve business competitiveness in the manufacturing industry by reducing waste, improving availability, performance and quality to have continues return on investment (ROI) and producing increased productivity.

The worldwide values of Overall Equipment Effectiveness are 85% where the availability is expected to be 90%, performance 95% and quality 99.9%. These values reduce the chances of the potential losses since they are acceptable standards in world class countries: difference between ideal and actual states.

According to Williamson (2006), there is no world class value which is based on the empirical study conducted in the different sectors of Lubrichem or Petrochemical industry.

Adjustment and setup time increases all the time when the company run different types of production and it will affect the Overall Equipment Effectiveness value. The only OEE parameter that suits this value is the average quality factor. The average Overall Equipment Effectiveness values are affected by the quality rate, performance and availability rates.

Lubrichem automated blending is the one with highest and best Overall Equipment Effectiveness parameter than other three departments. The quality and performance rates were 96.2% and 99.8 % respectively. Generally, the lowest or worst Overall Equipment Effectiveness parameter is the availability in all four departments of Lubrichem Company. This is affected by the highly overwhelming losses or based on limitations of on the unknown losses that were not recorded.

This study had three main objectives which were answered with help of research questions. The objectives of the study are mentioned below including how they are met.

5.3 Identify the source of down time

Sources of down time was identified using RS-Production system (refer to Table 4.1) and they are mentioned below.

- Machines service/maintenance caused by poor planning.
- Setup/changeover caused by poor production planning.
- Breakdown caused by lack of maintenance planning.
- Quality issues/rework caused by lack quality management tool (check list, histographs, bar chart, pie chart and SPC).
- Shortage of personnel due to poor planning.
- Micro stoppages caused by chronic disturbance.
- Cleaning (housekeeping) of the machines is done during operating hours leading to production delays.
- Time is lost during loading and setting of job on machines resulting in setup delay.
- Production changeover consumes time from one job to another due to the actual set up of the machines during operating time.
- Machines have break downs due to improper cleaning and lubrication of parts which results in the unavailability of the machines for production.
- No planned maintenance schedule for machines which results in performance loss.

- Tools break frequently due to operator inefficiency resulting in performance loss.

5.4 Identify ways to improve Overall Equipment Efficiency of the machines

Overall Equipment Efficiency was improved after implementing TPM on this study (refer to table 4.2, machines FB 44 and FB 46).

Machines OEE was improved from 0% during the month of October to 81% and 76.8% respectively in March. The following factors were improved:

- Availability of the machines (planned maintenance to prevent breakdowns).
- Quality on the product and raw material. (using check list, SPC and graphs).
- Performance of the machines (setting the machine prior running production)

5.5 Identify actual performance improvement opportunities for the plant, based on information obtained through the literature study.

- All four department of Lubrichem Company should continuously use maintenance planning to reduce breakdown of the machines.
- Production planning will improve production and reduce the time to set the machine and changeover. Raw material can be brought closer to the machine, production testing and be done before actual running time.
- The company can use Statistical Process Control (SPC) to manage production quality. SPC will stop the machine automatically if it is making defects and run again after the problem is addressed.
- Continuously implementing TPM will improve the performance above 90%. The machines will always be available for production and producing quality.

According to Hutchins (2016), the measurement is important because it helps in decision making and invariably plays an important role for benchmark for potential continues improvements.

There is prominent level of needs to determine why some of the stoppages reasons were not recorded or recorded as unknown. The OEE of all four departments were poor. This indicates and verifies that they are working manual recording as per respondents of the interview and they are not using the OEE concepts and implement the fundamental principles theory of the OEE. The potential reasons for this problem from the interviews are

- That they guess they have a better machines efficiency than what they don't see, they need to evaluate their process.
- New operators do not understand how machines work.
- Machines are difficult for operators to operate them.
- Operators prone to procrastination.
- Operators think they can measure their performance.
- Machines don't work properly.
- Nobody cares about the machines.
- Data is not relevant.
- Change procedure and management.
- Misused and misunderstood.
- No future improvement.

Plant communication needs to be improved and cascaded to all levels to prevent resistance to change especially on those who run the machines on the daily basis.

Effective communication can improve performance and gain momentum to sustainable competitiveness. The tools known as Cause-Effect diagram and five (5) whys are for any simple or complex systems and can be used to find the root cause of problems related to losses of the OEE on the machines, process, man, methods and materials.

The process of running automated machines requires lots investment on the employees so that they can understand the machines.

The benefits of OEE are:

- Accurate data collection.

- Effective and efficiency usage of the machines.
- Able to make informed decision (clear and visible reporting).
- Quality monitoring machines and energy efficiency.

In all four departments, availability related losses were big and played a role for low OEE especially in October, November and December. Changeovers and setups were the major loss which called for the implementation of SMED.

According to Tekin and Arslandere, (2018), the introduction of SMED will minimise the cost of inventory as well as exceeding customer expectations. Overall Equipment Effectiveness at Lubrichem Company will increase the speed, quality and availability because it the ratio related to the equipment and it can be measured.

5.6 Recommendations

Future recommendation would be informing all the operators and personnel before any of these solutions are implemented. Since people are sometimes resistant to change, the need to be motivated as well as providing a clear reason for these changes should first be brought forward.

Secondly, training and empowering the staff creates awareness and promotes a sense of responsibility on their part. A system should also be designed to fit the specific process in any industry.

Qualitative research can be carried out in gathering data based on interviews (through phone or face-to-face), through questionnaires addressed to operators and the entire management teams. Data from a build cross-functional team work could help create a more reliable and valuable data.

Further unplanned measures due to breakdowns of machines might require preventive maintenance, or vibration analysis. Future research may be done to explore:

- Operation and production design.

- The dynamics of translating equipment effectiveness or loss of effectiveness in terms of cost.
- Machine design or mechanical design.
- Frequency studies on man hours (Human OEE).

5.7 Further research

One important aspect that could further improve the work already carried out in this thesis would be quantitative research. Some of the difficulties encountered during this work were;

- Unavailability of data from some machines limiting the research.
- Incomplete data from some machines.

Since this research had a short time frame, it is recommended that a quantitative research should be applied to as to gather more quantitative data. This can be done in the form of questionnaires either open-ended, closed-ended or a combination of both.

Contact methods may gather information through mail, telephone or personal interview. Questionnaire consists of a set of questions presented to the various industries so as to get their own interpretation (answers). This will help answer some of the questions that might help solve the OEE problem in return. High quality can be established due to effectiveness and efficiency due to effort put by man, machine, method and material.

Future recommendation would be informing all the operators and personnel before any of these solutions are implemented. Since people are sometimes resistant to change, the need to motivate as well as providing a clear reason for these changes should first be brought forward.

Training and empowering the staff creates awareness and promotes a sense of responsibility on their part. A system should also be designed in other to fit the specific process in any industry. Qualitative research can be carried out in gathering data based on interviews (through phone or face-to-face), through questionnaires addressed to operators and the entire management teams. Data from a build cross-functional team work could help create a more reliable and valuable data.

Further unplanned measures due to breakdowns of machines might require preventive maintenance, or vibration analysis. Future research may be done to explore;

- Operation and production design.
- The dynamics of translating equipment effectiveness or loss of effectiveness in terms of cost.
- Machine design or mechanical design.
- Frequency studies on man hours (Human OEE).

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6 ANNEXURE

6.1 Annexure: B, Machines Samples

Semi-automated machines	Average OEE
AU 11	27,6%
AU 12	41,5%
AU 13	27,9%
AU 1	28,5%
AU 22	28,2%
AU 14	21,2%
AU 15	48,3%
AU 16	49,2%
AU 17	53,7%
AU 2	73,6%
AU 3	13,1%
AU 4	65,5%
AU 18	47,6%
AU 8	59,5%
AU 9	42,9%

AU 10	46,2%
AU 5	36,1%
AU 6	27,6%
AU 7	29,4%
AU 19	39,3%
AU 20	5,7%
AU 21	22,8%
Total	38,0%

Average OEE for Mechanical workshop machines

MW 5	36,0%
MW 21	51,9%
MW 6	45,5%
MW 7	37,0%
MW 20	45,9%
MW 12	80,9%
MW 13	78,2%
MW 36	28,5%
MW 10	58,0%
MW 30	43,9%

MW 31	68,1%
MW 42	65,5%
MW 43	28,6%
MW 32	53,1%
MW 11	42,8%
MW 37	30,1%
MW 44	15,2%
MW 66	18,4%
MW 34	63,8%
MW 33	63,3%
MW 8	71,1%
MW 14	48,0%
MW 15	66,8%
MW 45	61,5%
MW 22	85,3%
MW 23	72,7%
MW 24	71,5%
MW 47	42,8%
MW 48	51,0%
MW 49	48,0%

MW 50	50,8%
MW 51	38,2%
MW 52	20,8%
MW 53	37,0%
MW 54	44,8%
MW 46	29,6%
MW 9	21,2%
MW 1	38,1%
MW 2	20,0%
MW 3	34,3%
MW 38	15,7%
MW 55	12,9%
MW 56	30,1%
MW 39	32,8%
MW 25	76,0%
MW 16	71,5%
MW 40	30,9%
MW 41	24,2%
MW 57	23,1%
MW 58	22,5%

MW 17	51,2%
MW 59	62,5%
MW 60	53,7%
MW 61	58,4%
MW 62	63,6%
MW 63	52,4%
MW 26	74,2%
MW 27	79,3%
MW 28	64,1%
MW 29	70,3%
MW 64	52,4%
MW 35	63,0%
MW 65	2,1%
MW 18	40,7%
MW 4	58,5%
MW 19	73,4%
MW 66	66,6%
Total	48,3%

9.4. Average OEE for food and beverage machines

Food and beverages (Machines)	Average OEE
FB 47	31,8%
FB 34	59,6%
FB 35	74,4%
FB 36	80,6%
FB 37	91,6%
FB 38	92,1%
FB 2	51,5%
FB 29	51,0%
FB 1	37,3%
FB 48	28,1%
FB 49	32,2%
FB 3	43,2%
FB 4	49,4%
FB 50	27,1%
FB 50	29,9%
FB 6	40,1%
FB 7	60,5%
FB 8	49,0%
FB 9	40,0%

FB 10	51,0%
FB 51	27,7%
FB 11	61,6%
FB 52	30,7%
FB 12	49,1%
FB 53	47,9%
FB 54	45,7%
FB 12	44,0%
FB 13	59,5%
FB 14	81,2%
FB 15	76,2%
FB 16	68,8%
FB 17	29,7%
FB 18	73,1%
FB 19	65,6%
FB 39	73,2%
FB 40	82,7%
FB 41	92,3%
FB 42	81,8%
FB 43	90,2%

FB 30	71,7%
FB 31	64,3%
FB 32	70,1%
FB 33	47,2%
FB 20	13,5%
FB 21	22,6%
FB 22	25,5%
FB 23	34,4%
FB 24	17,6%
FB 25	28,8%
FB 55	16,8%
FB 56	13,7%
FB 26	21,0%
FB 56	14,8%
FB 57	16,5%
FB 58	1,6%
FB 27	30,6%
FB 28	35,6%
FB 44	59,2%
FB 45	41,6%

FB 46	46,0%
Total	48,2%

9.5. OEE results for Semi-automated production machines:

17	54,3%
139	43,9%
140	56,6%
148	42,9%
149	52,2%
150	56,9%
154	63,8%
155	37,0%
161	56,2%
162	20,3%
164	52,5%
166	42,2%
167	37,1%
168	27,7%
169	61,3%
170	26,9%

171	65,0%
173	80,2%
176	18,5%
178	31,0%
179	45,5%
183	85,0%
184	28,8%
189	47,4%
190	22,3%
195	34,6%
308	51,8%
309	11,9%
577	12,2%
E6	59,7%
S1	26,9%
S12	52,0%
S14	49,2%
S3	49,1%
S4	42,7%
Total	44,2%

Ornery

brat