AN INVESTIGATION INTO WHETHER TOTAL PRODUCTIVE MAINTENANCE IS EFFECTIVELY APPLIED AT AN AUTOMOTIVE PLANT

By

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DECLARATION

I, **Louis Wentzel 9814281**, hereby declare that the treatise for **Magister in Business Administration** is my own work and that it has not previously been submitted for assessment or completion of any postgraduate qualification to another University or for another qualification.

Louis Wentzel

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ABSTRACT

For many manufacturing companies, equipment is the largest capital investment and effective maintenance of these assets can impact on profitability. It extends equipment life, improves equipment availability and retains equipment in proper condition. Conversely, poorly maintained equipment may lead to more frequent equipment failures, poor utilisation of equipment and delayed production schedules. Malfunctioning equipment may result in scrap or products of poor quality.

Total productive maintenance (TPM) is one of the most popular concepts for improving process dependability (Nakajima 1988). It focuses on increasing the effectiveness of maintenance which is commonly measured by the overall equipment effectiveness (OEE).

Ford Struandale Engine Plant (FSEP) applies lean manufacturing through its Ford Production System (FPS) which consists of twelve elements. One element of FPS is Ford Total Productive Maintenance (FTPM) with the objective to maximise the overall effectiveness of plant facilities, equipment, processes and tooling through the focused efforts of work groups and the elimination of the major losses associated with manufacturing equipment.

The concern for FSEP management was that although FTPM is implemented, the OEE data revealed that equipment availability targets are not achieved. The researcher identified a gap to investigate the reasons for the poor performance. A literature study was conducted to search for relevant information on the subject. A questionnaire was constructed from the theoretical information and a survey was conducted.

After data collection the results were captured and analysed. The researcher made conclusions based on the data and made recommendations. The main findings were that autonomous maintenance is not functioning well, spares management is not good and the Computerised Maintenance Management System is underutilised. The recommendations were that these issues must be addressed.

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ABBREVAITIONS

ANOVA	Analysis of Variance
CBM	Condition-Based Monitoring
CIM	Computer-Integrated Manufacturing
CMMS	Computerised Maintenance Management System
FRACAS	Failure Reporting, Analysis and Corrective Action System
FSEP	Ford Struandale Engine Plant
FTPM	Ford Total Productive Maintenance
HAZMAT	Hazardous Materials
IMF	Industrial Material Flow
IMT	Integrated Manufacturing Team
IS	Information Systems
ISPC	In Station Process Control
JIPM	Japan Institute of Plant Maintenance
ME	Manufacturing Engineering
MP	Maintenance Prevention
OEE	Overall Equipment Effectiveness
PdM	Predictive Maintenance
PM	Preventive Maintenance
P-M	Phenomenon Mechanism
RCM	Reliability-Centred Maintenance
R&M	Reliability and Maintainability
SHARP	Safety and Health Assessment Review Processes
SMED	Single-Minute Exchange of Die
SMF	Synchronised Material Flow
TPM	Total productive maintenance
TQM	Total Quality Management

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CHAPTER ONE
PROBLEM STATEMENT AND DEFINITIONS OF CONCEPTS

1.1 INTRODUCTION

For many manufacturing companies, equipment is the largest capital investment and effective maintenance of these assets can impact on profitability. Swanson (2001) stated that effective maintenance is critical to manufacturing companies. It extends equipment life, improves equipment availability and retains equipment in proper condition. Conversely, poorly maintained equipment may lead to more frequent equipment failures, poor utilisation of equipment and delayed production schedules. Malfunctioning equipment may result in scrap or products of poor quality.

Maintenance is a secondary process in manufacturing that supports production, the primary business process. For most companies, maintenance represents a very significant function within the overall production environment.

Under traditional manufacturing regimes a maintenance system was created which was divorced from the commercial requirements of the factory and treated as a necessary organisational cost. However under current competitive conditions and the general rate of change in industry, the role and importance attached to the maintenance function has drawn increasing levels of interest by senior members of the factory management team. (Rich, 1999)

The changes which create the integration of the production and maintenance departments will necessitate an understanding of the manner in which the production process is managed, as well as promote the benefits of a planned and proactive approach to maintenance. (Rich, 1999)

Total productive maintenance (TPM) is one of the most popular concepts for improving process dependability (Nakajima 1988). It focuses on increasing the effectiveness of maintenance which is commonly measured by the overall equipment effectiveness (OEE). Bacula (2008) states that, to be successful, TPM has to be an integrated part of the business strategy that is driven and monitored by the operations area of the business and embraced and supported by leadership.

Ford Struandale Engine Plant (FSEP) manufactures two engine derivatives; namely, Rocam petrol engine and Puma diesel engine. The Rocam engine has been in production since 2001 and is reaching the end of its programme life. The Puma engine started production in 2011 and this has created a transitional period from Rocam to Puma in the plant. The plant has undergone major restructuring to fulfil the high standards of being a world class manufacturing facility within the Ford Global Community.

Part of the review and restructuring is the maintenance function. Ford Struandale Engine Plant (FSEP) applies lean manufacturing through its Ford Production System (FPS) which consists of twelve elements. One element of FPS is Ford Total Productive Maintenance (FTPM) with the objective to maximise the overall effectiveness of plant facilities, equipment, processes and tooling through the focused efforts of work groups and the elimination of the major losses associated with manufacturing equipment.

1.2 PROBLEM STATEMENT

1.2.1 Main Problem

The availability data for the three Puma production lines; namely, Cylinder Block, Cylinder Head and Cylinder Crank showed that the target of 94 per cent set by the plant, was not achieved at any time for the months of October and November 2011. The average monthly availability achieved across all three lines was 85 per cent as can be seen in the table 1.1 below.

Table 1.1: Monthly Availability 2011

Availability			
Puma Area	**October**	**November**	**Target**
Cylinder Block	81.4%	84.7%	94%
Cylinder Head	84.9%	83.5%	94%
Cylinder Crank	89.2%	86.8%	94%
Average Month	85.2%	85%	94%

Source: Ford Motor Company Struandale Engine Plant

It is evident from the figures in table 1.1 above that SEP did not achieve their target for the two months and it is a concern for the management of SEP.

In a previous study by Qweleka (2009) into OEE performance at FSEP it was found that although the FTPM system is theoretically good, the application lacks fundamentals.

Another study by Koen (2009) into causes of poor OEE at FSEP found that availability was problematic and was negatively affected by factors such as training, autonomy, employee engagement, mutual respect, spares management, communication and supervision.

Based on the statements above, the following problem statement was formulated:
Is Total Productive Maintenance effectively applied at Ford Struandale Engine Plant?

1.2.2 Sub-problems

To address the main problem statement, sub-problems that will be addressed, are:

- What does the literature reveal about TPM, OEE and FTPM?
- Is the FTPM function effectively applied?
- Is autonomous maintenance effectively applied?
- Is there efficient planning for spare availability?
- Is the Computerised Maintenance Management System (CMMS) efficiently utilised?

1.3 DELIMITATION OF THE RESEARCH

Research delimitations explain how the scope of the study is limited to focus on a particular area (Collis and Hussey, 2009).

1.3.1 Geographic Area

The research is limited to the Ford Struandale Engine Plant located in Struandale Port Elizabeth.

1.3.2 Department

The research will focus on the FTPM department of FSEP and common Puma and RoCam production lines. These lines are Cylinder Block, Cylinder Head, Crank and Engine Assembly. The research will not include Manifold and Flywheel line and Plant Facilities.

1.3.3 People

The research will focus on personnel involved with Maintenance and Operations. The groups will be Management; Integrated Manufacturing and Process Engineers as Staff; Production and Technical Team Leaders; FTPM technicians, Electronic Technicians, Electricians, Fitters, Machine Setters as Skilled Workers and Operators.

Personnel in the finance, quality, human resources and logistics departments will not form part of the study.

1.4 METHODOLOGY

1.4.1 Research Paradigms

Collis and Hussey (2009) define a research paradigm as a framework that guides how research should be conducted based on people's philosophies and their assumptions about the world and the nature of knowledge. The first question of this assignment is to discuss the two main research paradigms; namely, positivistic and phenomenological paradigms.

A positivist study originates from the natural sciences where scientist used observation and experimentation to discover theories that can predict the relationship between variables. It is an objective approach and the researcher is focused on measuring something that has happened. Researchers familiarise themselves with concept to be studied and then develop hypotheses to be tested. They use experimental methods and quantitative measures to test hypothetical generalisations.

In a positivist study the data to be analysed can be in numerical form, quantitative, or nominal form, qualitative. The qualitative data is quantified for statistical analysis. In a positivist study a large amount of data is needed for statistical analysis. It is not always possible to collect all the data for analysis and therefore a sample is chosen that is a representative of the population. In a positivist study the data can be collected by experiments and surveys.

A phenomenological (interpretive) paradigm was developed because positivism was inadequate to be used by social scientists. It is a subjective approach because it stems from people's perceptions. The researcher identifies a problem for which there are few or no earlier studies and describes the phenomena. The researcher develops a theory and then tests it.

In a phenomenological study the data are qualitative and it is not the intention to analyse the data statistically, therefore it is not quantified. The data also need not be large and small samples are used. To collect qualitative data, interviews with selected participants are conducted and these could be face-to-face or via the telephone.

1.4.2 Measuring Instruments

The data collection method used was a self-completion questionnaire. According to Collis and Hussey (2009) a questionnaire is a list of carefully structured questions, which have been chosen after considerable testing with a view to eliciting reliable responses from a particular group of people.

Collis and Hussey (2009) explain that the main steps in designing a questionnaire are:

- Design the questions and instructions;
- Determine order of presentation;
- Write accompanying letter/request letter;
- Test questionnaire with a small sample;
- Choose method for distribution and return;
- Plan strategy for dealing with non-responses, and
- Conduct tests for validity and reliability.

A Likert scale is be used to measure the variables. The Likert scale is the sum of responses on several Likert items. A Likert item is a statement which the respondent is asked to evaluate according to any kind of subjective or objective criteria and the level of agreement or disagreement is measured.

A five point Likert scale was used, with high scores reflecting better relations:

1. Strongly Disagree
2. Disagree
3. Undecided
4. Agree
5. Strongly Agree

1.4.3 Sampling

According to Collis and Hussey (2009) the unit of analysis is the phenomenon under study, about which data are collected and analysed, and is closely linked to the research problem and research questions. In business research, a unit of analysis might be a particular organisation, division or department within an organisation or a more general group.

Collis and Hussey (2009) further state that natural sampling is fairly common in business research and occurs when the researcher has little influence on the composition of the sample. For example, only particular employees are involved in the phenomenon being investigated or only certain employees are available at the time of the study. Therefore for this study, natural sampling would be used.

The sample for this study will be selected from persons involved in the maintenance of production equipment at Ford Struandale Engine Plant (FSEP). That will include operators, maintenance personnel, team leaders, salaried staff and management. FSEP is divided into various functional departments and production lines. As mentioned previously there are two engine manufacturing programmes; namely, Puma and Rocam. In turn each programme consists of four production lines namely Cylinder Block, Cylinder Head, Cylinder Crank and Engine Assembly.

Each line has maintenance artisans consisting of electricians, mechanical fitters and machine setters, reporting to a technical team leader who in turn reports to an Integrated Manufacturing Team (IMT) engineer. The production team consists of operators who report to production team leaders, who in turn, also report to the IMT engineer. That is for each shift in a three shift system. The three IMT engineers of each line report to the production manager. The sample will be from these groups.

1.4.4 Data Analysis

The data were captured in Microsoft Excel and the analysis was done with a software programme called Statistica.

Common analysis techniques include Pearson *r*, Spearman rho and other correlation coefficients. The value of the correlation coefficient indicates the strength of the relationship. The Pearson correlation is +1 in the case of a perfect positive (increasing) linear relationship, −1 in the case of a perfect decreasing (negative) linear relationship, indicating the degree of linear dependence between the variables. As it approaches zero there is less of a relationship. The closer the coefficient is to either −1 or 1, the stronger the correlation between the variables.

1.5 TERMINOLOGY

The following terminology requires explanation:

Autonomous maintenance

Operator involvement in regular cleaning, inspection, lubrication and learning about equipment to maintain basic conditions and spot early signs of trouble (The Productivity Development Team, 1999).

Availability

Availability is the rate of equipment effectiveness or operating rate and is based on a ratio of operation time, excluding downtime, to loading time (Nakajima, 1988). The mathematical formula is: Availability = operation time / loading time

= (loading time – downtime) / loading time

FTPM – Ford Total Preventative Maintenance

It is the concept of a never-ending improvement process that is included in maintenance activities with the goal of improving quality of products and productivity (Franz, 2000).

Interpretivism (phenomenological) Paradigm

Interpretivism originated from the belief that social reality is subjective because it is shaped by perceptions. The research involves an inductive process with a view to providing interpretive understanding of social phenomena within a particular context (Collis and Hussey, 2009).

Mean Time Between Failure

Mean time between failure (MTBF) analyses is a technique that is employed to assess the average time intervals between the failures of a machine (Rich, 1999).

Mean Time To Repair

The 'mean time to repair' (MTTR) technique is a measure of the maintainability of an asset and relates the recovery time to the failure (Rich, 1999).

Overall Equipment Effectiveness

Overall equipment effectiveness (OEE) is a measurement used in TPM to indicate how effectively machines are running. OEE is the multiplication of performance, availability and quality, which is expressed as a percentage. (The Productivity Development Team, 1999)

Positivism (positivistic) Paradigm

Positivism originated in the natural sciences. It rest on the assumption that reality is independent and the goal is the discovery of theories based on empirical research (observation and experiment). The research involves a deductive process with a view to providing explanatory theories to understand social phenomena (Collis and Hussey, 2009).

Preventative Maintenance

It is a daily maintenance (cleaning, inspection, oiling and re-tightening), design to retain the healthy condition of equipment and prevent failure through the prevention of deterioration, periodic inspection or equipment condition diagnosis, to measure deterioration (Venkatesh, 2005).

Questionnaire

The word "questionnaire' refers to an ordered arrangement of items (questions, in effect) intended to elicit the evaluations, judgments, comparisons, attitudes, beliefs, or opinions of personnel (Babbitt and Nystrom, 1989)

Total Productive Maintenance

A company wide approach for improving the effectiveness and longevity of machines. It is key to lean manufacturing because it attacks major waste in production operations. The main strategies used in TPM are often referred to as ‘pillars’ that support the smooth operation of the plant. The eight basic pillars of TPM are:

- Focused equipment and process improvement;
- Autonomous maintenance;
- Planned maintenance;
- Quality maintenance;
- Early equipment management;
- Safety;
- Equipment investment and maintenance prevention design, and
- Training and skill building (The Productivity Development Team, 1999).

1.6 OUTLINE OF THE STUDY

The study is divided into five chapters:

Chapter One outlines the scope of the study, the problem statement, delimitation, methodology, the importance of the topic as well as provide a description of the approach and the proposed chapter headings of the research treatise.

Chapter Two will provide a literature overview on the Total Productive Maintenance (TPM) and Ford TPM (FTPM) and OEE measurement.

Chapter Three will outline the research methodology, which includes the research paradigm, sampling design and measuring instruments.

Chapter Four will presents and discuss the empirical results.

Chapter Five will consist of conclusions and recommendations.

1.7 SUMMARY

In Chapter One the research problem was introduced, which is to determine if TPM is effectively applied at Ford Struandale Engine Plant. The company was introduced and background to the problem given. Sub-problems were identified, which will assist in answering the main problem. Delimitations to the research were defined and the research methodology was explained. Key concepts were defined and an outline of the study was given.

In Chapter Two a literature overview of Total Productive Maintenance (TPM), Overall Equipment Effectiveness (OEE) and Ford Total Productive Maintenance (FTPM) will be conducted.

CHAPTER TWO
LITERATURE OVERVIEW

2.1 INTRODUCTION

Smoothly operating equipment is critical for manufacturing today. In an environment that is more competitive than ever, factory machines have to work dependably to supply products when the customer needs them. Yet factories everywhere are plagued with machine problems of one type or another. The companies that are pulling ahead in the production race are those that understand their equipment problems and take steps to eliminate them (The Productivity Development Team, 1999).

One of the most important subsystems of the manufacturing or production system itself is the support service provided by the maintenance function. The maintenance function within the manufacturing business is charged with the responsibility of ensuring that the production system is capable of sustaining high levels of productivity and quality simultaneously as well as providing the engineering competency with which to improve the entire manufacturing system. The competency of the maintenance management and the internal structures, through which managers control the efforts of departmental technicians, forms a key interface between the requirements of customers and the overall effectiveness and efficiency of the conversion process. (Rich, 1999)

The research problem was introduced in Chapter One and in this chapter a literature study will be conducted in order to address the research question. The research problem introduced was to determine if TPM is effectively applied at Ford Struandale Engine Plant. The literature overview will seek to understand what the concept TPM is about. It will also discuss how the metric OEE are used to measure the application of TPM. Finally it will discuss what FTPM is and why it is used in Ford's Struandale Engine Plant.

2.2 TOTAL PRODUCTIVE MAINTENANCE (TPM)

2.2.1 TPM Definition

The origins of TPM can be traced to two distinct sources. The first is a tactical approach to the maintenance of machinery which was initially developed in the

United States (US) for the maintenance of military equipment. This involves a preventative approach to the management of equipment throughout the lifetime of the asset. The birthplace of the modern approach to TPM is Japan (the Denso Corporation) and the origins of this approach can be traced to the rise in popularity of total quality management philosophies and practices in Japanese industry (Rich, 1999).

Following World War II, the Japanese industrial sectors borrowed and modified management and manufacturing skills and techniques from the United States (Nakajima, 1988).

The concept of preventive maintenance was introduced to Japan from the United States in 1951. Before preventive maintenance, companies generally practiced breakdown maintenance which means fixing equipment only after it has broken down. Based on small-group activities, TPM takes preventive maintenance company wide, gaining the support and cooperation of everyone from top management down. It goes beyond the maintenance department to involve the whole company and that is how preventive maintenance became Total Productive Maintenance (TPM) (Shirose, 1992).

During the 1980s, Japanese industry, in response to a changeable competitive environment, started with mass education and the growth of many organisations, such as the Japan Institute of Plant Maintenance (JIPM) and government agencies to support and develop new industrial practices. The maintenance department and its strategies, structure and responsibilities for the maintenance of the equipment began to change and necessitated the integration of all other business departments which affected the ability to maintain the equipment at optimal performance (Rich, 1999).

From the statements above it can be concluded that TPM originated in Japan but it used maintenance management techniques and skills from the United States.

The concept of total productive maintenance has as many definitions as there are companies which adopt the philosophy. A conclusive and accepted definition of TPM does not exist, which in many ways reflects the uniqueness of the application of TPM within each company. The working definition of Total Productive Maintenance (TPM) will be defined as:

> A company-wide approach to the management and operation of all the factory assets, both human and equipment, in such a manner as to achieve the optimisation of the conversion process and the generation of customer 'value' over the economic working lifetime of assets employed (Rich, 1999).

TPM is often defined as "productive maintenance involving total participation." Frequently management misconstrues this to mean workers only and assumes that preventive maintenance (PM) activities are to be carried out autonomously on the floor. To be effective, however, TPM must be implemented on a company-wide basis, including top management (Nakajima, 1988).

The two definitions emphasise that TPM must be practised by all employees in the organisation. The first definition also states that the approach should be to manage all assets, both human and equipment.

A complete definition by Nakajima (1988) of TPM includes the following five elements:

- TPM aims to maximise equipment effectiveness (overall effectiveness).
- TPM establishes a thorough system of preventive maintenance for the equipment's entire life span.
- TPM is implemented by various departments (engineering, operations, and maintenance).
- TPM involves every single employee, from top management to workers on the floor.
- TPM is based on the promotion of preventive maintenance through motivation management: autonomous small group activities.

A definition by Shirose (1992) of TPM contains the following five points:

- It aims at getting the most efficient use of equipment (that is overall efficiency)

- It establishes a total (companywide) preventive maintenance system encompassing maintenance prevention, preventive maintenance and improvement-related maintenance.
- It requires the participation of equipment designers, equipment operators and maintenance department workers.
- It involves every employee from top management down.
- It promotes and implements PM based on autonomous, small group activities.

Nakajima (1988) states that “Total maintenance system” is a concept first introduced during the productive maintenance era. It establishes a maintenance plan for the equipment’s entire lifespan and includes maintenance prevention (MP), maintenance free design, which is pursued during the equipment design stages. Once equipment is assembled a total maintenance system requires preventive maintenance (PM) and maintainability improvement (MI), repairing or modifying equipment to prevent breakdowns and facilitate ease of maintenance. The last feature, “autonomous maintenance by operators” (small group activities), is unique to TPM.

Peng (2005) states that TPM has three major components:

- maintenance prevention,
- preventive maintenance, and
- autonomous maintenance.

Maintenance prevention is defined as an approach to eliminate equipment breakdown through designing or selecting equipment that is maintenance-free. Preventative maintenance, an American approach, is still a key component of the TPM, however, basic maintenance tasks are passed down to machine operators. Autonomous maintenance is the most essential component and the backbone of TPM, which introduces equipment operators to maintenance (Peng, 2005).

The word “total” in “total productive maintenance” has three meanings that describe the principal features of TPM:

- Total effectiveness indicates TPM’s pursuit of economic efficiency or profitability.

- Total maintenance system includes maintenance prevention (MP) and maintainability improvement (MI) as well as preventative maintenance.
- Total participation of all employees includes autonomous maintenance by operators through small group activities (Nakajima, 1988).

The Productivity Development Team (1999) stated that the main strategies used in TPM are often referred to as 'pillars' that support the smooth operation of the plant. The eight basic TPM pillars and the activities are:

- Focused equipment and process improvement: Measurement of equipment- or process-related losses and specific improvement activities to reduce the losses.

- Autonomous maintenance: Operator involvement in regular cleaning, inspection, lubrication and learning about equipment to maintain basic conditions and spot early signs of trouble.

- Planned maintenance: A combination of preventive, predictive and proactive maintenance to avoid losses and planned responses to fix breakdowns quickly.

- Quality maintenance: Activities to manage product quality by maintaining optimal operating conditions.

- Early equipment management: Methods to shorten the lead time for getting new equipment online and making defect free products.

- Safety: Safety training; integration of safety checks, visual controls and mistake-proofing devices in daily work.

- Equipment investment and maintenance prevention design: Purchase and design decisions informed by costs of operation and maintenance during the machine's entire life cycle.

- Training and skill building: A planned programme for developing employee skills and knowledge to support TPM implementation

Shirose (1992) gives a brief description of his five pillars of TPM development:

- Implement improvement activities designed to increase equipment efficiency. This is accomplished mainly by eliminating the “six big losses”.
- Establish a system of autonomous maintenance to be performed by equipment operators. This is set up after they are trained to be “equipment –conscious” and “equipment-skilled”.
- Establish a planned maintenance system. This increases the efficiency of the maintenance department.
- Establish training courses. These help equipment operators raise their skill levels.
- Establish a system for MP design and early equipment management.

Nakajima (1988) states that the dual goal of TPM is zero breakdowns and zero defects. When breakdowns and defects are eliminated, equipment operation rates improve, costs are reduced, inventory can be minimised and as a consequence labour productivity increases.

As both quality and maintenance go hand in hand in a manufacturing set-up, TPM shares many threads of commonality with Total Quality Management (TQM), such as employee involvement, cross functional approach, organisation wide diffusion and continuous improvement. Therefore, TPM has been considered complementary to TQM. Like TQM, TPM also aims at continuous and long-term improvement in performance and therefore it also results in improving financial performance and profitability of organisations (Seth and Tripath, 2006).

2.2.2 TPM Implementation

The practical details and procedures for using TPM to maximise equipment effectiveness must be tailored to the individual company. Each company must develop its own action plan, because needs and problems vary, depending on the company, type of industry, production methods and equipment types and conditions. There are however, some basic conditions for the development of TPM that apply in most situations (Nakajima, 1988).

Generally the successful implementation of TPM requires:

- Elimination of the six big losses to improve equipment effectiveness.
- An autonomous maintenance programme.
- A scheduled maintenance programme for the maintenance department.
- Increased skills of operations and maintenance personnel.
- An initial equipment management programme (Nakajima, 1988).

Results cannot be achieved overnight. Typically it takes an average of three years from introduction of TPM to achieve prize-winning results. The goal of TPM is to effect fundamental improvement within a company by improving worker and equipment utilisation. To eliminate the six big losses people's attitudes must change and their skills increased. Increasing their motivation (yaruki) and competency (yaruude) will maximise equipment effectiveness and operation (Nakajima, 1988).

Work environment (yaruba) is a third important condition for improvement. A work environment must be created that supports the establishment of a systematic programme for implementing TPM. Unless top management takes the lead by seriously tackling this issue, the necessary transformation in attitudes, equipment and the overall corporate constitution will not progress smoothly (Nakajima, 1988).

The development of TPM, as part of a continuously-improving system of maintenance management control, has some fundamental, discernible objectives:

- To maximise the overall equipment effectiveness of individual and natural groups of assets within the factory.

- To establish a thorough system of preventative maintenance for the economic lifetime of the equipment.

- To integrate other business departments with the implementation of TPM including internal customers (production operators) and internal suppliers (industrial engineering, purchasing and engineering).

- To involve every employee from the managing director to the newest apprentice.

- To promote the TPM process and objectives through highly motivated, empowered and autonomous small group activities in the factory (Rich, 199).

TPM development can be grouped in three stages that is Preparation, Implementation and Stabilisation. In the Preparation stage a suitable environment is created by establishing a plan for the introduction of TPM. The Implementation stage is comparable to the production stage for a product. A final inspection completes the manufacturing process and this period is called the Stabilisation stage (Nakajima, 1988).

Nakajima (1988) propose a twelve step TPM development which is group in the three stages:

TPM Preparation stage:

Step 1: Announce top management's decision to introduce TPM

Top management must inform their employees of this decision and communicate enthusiasm for the project.

Step 2: Launch educational campaign

The second step in the TPM development programme is TPM training and promotion, which should begin as soon as possible after the introduction of the programme.

Step 3: Create organisations to promote TPM

The TPM promotional structure is based on an organisational matrix, forming horizontal groups such as committees and project teams at each level of the vertical management organisation. It is important that a TPM promotional headquarters be established and professionally staffed.

Step 4: Establish basic TPM policies and goals

The TPM promotional headquarters staff should begin by establishing basic policies and goals. Although policies may consist of abstract written or verbal statements, the goals should be quantifiable and precise, specifying the target (what), quantity (ho w much) and time frame (when).

Step 5: Formulate a master plan for TPM development

The next responsibility of the TPM promotional headquarters is to establish a master plan for TPM development.

Steps from TPM Implementation to Stabilisation (Nakajima, 1988):

Step 6: Hold TPM "kick-off"

The TPM "kick-off" is the first step in implementation. The individual workers must move away from their traditional daily work routines and begin to practice TPM.

Step 7: Improve equipment effectiveness

TPM is implemented through five basic TPM development activities, the first of which is to improve the effectiveness of each piece of equipment experiencing a loss. Engineering and maintenance staff, line supervisors and small group members are organised into project teams that will make improvements to eliminate losses.

Step 8: Establish an autonomous maintenance programme for operators

Autonomous maintenance by operators is a unique feature of TPM, organising it is central to TPM promotion within the company. The longer a company has been organised, the harder it is to implement autonomous maintenance because operators and maintenance personnel find it difficult to let go of the concept "I operate – you fix."

Each operator must be trained in the skills necessary to perform autonomous maintenance. In most cases the operators just go through the motions without actually making any effort. The daily check sheets they fill out reveal their attitude. Some operators check off items in advance, sometimes important tasks are neglected.

Step 9: Set up a scheduled maintenance programme for the maintenance department

Scheduled maintenance carried out by the maintenance department must be coordinated with the autonomous maintenance activities of the operations department so the two departments can function together.

Step 10: Conduct training to improve operation and maintenance skills

Education and training are investments in people that yield multiple returns. A company implementing TPM must invest in the training that will enable employees to manage their equipment properly. In addition to training in maintenance techniques, operators must also sharpen their conventional operation skills.

Step 11: Develop early equipment management programme

Early equipment management is performed mainly by production engineering and maintenance personnel as part of a comprehensive approach to maintenance prevention and maintenance-free design.

By working together with design engineers during commissioning to eliminate problems at the source and by promoting activities within the individual project teams, the engineering and maintenance staff can absorb and apply knowledge about maintenance prevention design.

Final stage TPM Implementation (Nakajima, 1988):

Step 12: Implement TPM fully and aim for higher goals

The final step in the TPM development programme is to perfect TPM implementation and set even higher goals for the future. During this period everyone works continuously to improve TPM results, so it can be expected to last some time.

2.2.3 TPM Small Group Activities

TPM is productive maintenance carried out by all employees through small group activities. TPM, which organises all employees from top management to production line workers, is a companywide equipment maintenance system that can support sophisticated production facilities. Increased automation and unmanned production will not do away with the need for human labour, only operations have been automated; maintenance still depends heavily on human input (Nakajima, 1988).

What does a “small group” do? Teams called circles or groups, set goals, compatible with the larger goals of the company and achieve them through group cooperation or teamwork. This enhances company business results and promotes activities that satisfy both individual employee needs and the needs of the organisation. Small group activities in the factory should be based on participative management (Nakajima, 1988).

The TPM approach enhances the skills of both the production and maintenance personnel in the factory so that a common approach to problem solving, which is focused on the improvement of productivity, is undertaken. Teams form natural business units within the factory and can focus on the improvement of key measures which affect the performance of that area. The empowerment debate, in terms of how much to bestow on working teams, is a question which is unique to each company and has to be based on the competence of the team in question (Rich, 1999).

One of the key elements of TPM is autonomous maintenance. The main idea in the implementation of autonomous maintenance is that it is the workmen themselves, that is operators of production equipment, who know the facilities best in the normal operation, and they should be able to identify best the differences from the correct operation. Their ability to detect impending problems and the imminent repair after the failure may be increased through the maintenance training (Branska, 2011).

Autonomous maintenance is the result of the skills transfer between the maintenance technicians and the TPM teams of operators in the factory. This process is supported through extensive training and application in the factory under supervision and then through self-management (Rich, 1999).

Rich (1999) states further that autonomous maintenance activities represent a portfolio of skills and techniques that support the preventative maintenance of equipment. There are three levels of autonomous maintenance conducted by teams:

- Equipment cleaning routines;
- Equipment lubrication routines, and
- Equipment-related tightening and inspection routines.

Nakajima developed a seven step approach to autonomous maintenance:
The 5 Ss: seiri, seiton, seiso, seiketsu and shitsuke (roughly organisation, tidiness, purity, cleanliness and discipline) are basic principles of operations management. Most factories apply some of these principles superficially. Management is often more concerned about appearances such as painting the factory interior equipment and neglects internal cleaning of revolving and moving parts (Nakajima, 1988).

Covering up dirt, dust and rust may actually worsen the condition. The Japanese Institute of Preventive Maintenance recommends that companies wishing to avoid superficial autonomous maintenance adopt a seven-step approach that includes progressive mastery of each of the 5Ss (Nakajima, 1988):

- Initial cleaning: Operators develop an interest in and concern for their machines through cleaning them thoroughly. Operators learn that cleaning is inspection. They also learn basic lubricating and bolting techniques and become skilled in detecting equipment problems;
- Countermeasures for the cause and effects of dirt and dust: The more difficult it is for the individual to perform initial cleaning, the stronger will be the desire to keep the equipment clean and thus reduce cleaning time;
- Measures to eliminate the causes of dust and dirt or to limit scattering and adherence (for example by using covers and shields) must be adopted;
- Cleaning and lubricating standards: In the first two steps operators identify the basic conditions that should apply to their equipment. When this has been done the TPM circles can set standards for speedy and effective basic maintenance work to prevent deterioration for example cleaning, lubricating and bolting for each piece of equipment;

- General inspection: In this step an attempt is made to measure deterioration with a general inspection of equipment. Team members work together to target problem areas discovered during general equipment inspection;

- Autonomous inspection: The cleaning and lubricating standards established in the first three steps and the tentative inspection standards are compared and revaluated to eliminate any inconsistencies and to make sure the maintenance activities fit within the established time frames and goals;

- The maintenance department should set up an annual maintenance calendar and maintenance standards. Standards developed by operators and maintenance department must be compared to correct omissions and eliminate overlapping;

- Organisation and tidiness: Seiri or organisation means to identify aspects of the workplace to be managed and set appropriate standards. This is a job for managers and supervisors who must minimise and simplify the objects or conditions to be managed. Seiton or tidiness, means adhering to established standards, is mainly the operators' responsibility.

- Seiri and seiton are thus improvement activities that promote simplification, organisation and adherence to standards, ways of ensuring that standardisation and visual controls are instituted throughout the factory;

- Full implementation of autonomous maintenance: Through circle activities led by supervisors, workers develop greater morale and competence. Ultimately they become independent, skilled and confident workers who can be expected to monitor their own work and implement improvements autonomously (Nakajima, 1988).

Many experts say that the keys to success in small group activities lie in three conditions: motivation, ability and a favourable work environment. Management is responsible for actively promoting these three conditions. Of these three keys, motivation and ability are the workers' responsibility but the creation of a favourable work environment is outside their control. This environment has both physical and psychological components that must be satisfied (Nakajima, 1988).

Fredendall, Patterson, Kennedy and Griffin (1997) state that TPM requires that the operator assumes some ownership of the equipment's performance and thus becomes responsible for routine maintenance. At the same time, the maintenance staff assumes increased responsibility for managing, scheduling, training and equipment redesign. When using TPM, the operator and maintenance staff become partners in seeking to improve equipment performance while the maintenance staff and engineers become partners in designing equipment for enhanced performance. This is a paradigm shift which is accomplished only through creative top management leadership.

2.2.4 Planned Maintenance

Some factory managers have a defeatist attitude and say they cannot prevent breakdowns and minor stoppages. Their factories are already in a critical state, breakdowns and minor stoppages have reduced overall equipment effectiveness and reduced productivity. Pressed by the production schedule these factories do not have the flexibility to implement preventive maintenance. Breakdowns and minor stoppages continue and conditions go from bad to worse (Nakajima, 1988).

At some point however, unfavourable conditions must be stopped. Bad habits and defeatist attitudes can be deeply ingrained in the minds of all the employees, from top management to workers on the floor; they then become part of the company's basic disposition. Middle managers and front line personnel alone cannot change the disposition of the company. Moreover, lukewarm determination will not be enough to change long-standing bad habits. Only when top management is seriously committed to TPM can those habits be discarded and an unfavourable environment altered. Only then is fundamental improvement in a company's disposition possible (Nakajima, 1988).

TPM emphasises prevention above all else and this means taking preventive action and is based on the following three principles:

- Maintenance of normal conditions. To maintain normal operating conditions, operators must prevent deterioration by cleaning, checking, oiling, tightening and precision-checking the equipment on a daily basis;

- Early discovery of abnormalities. Operators must use their senses and measurement tools to detect abnormalities as soon as they appear. Maintenance workers should also conduct periodic diagnostic tests to check for abnormalities using specialised tools;

- Prompt response. Operators and maintenance staff cannot afford to delay responses to abnormalities (Shirose 1992).

It is cheaper to repair the equipment on a preventive basis than to wait until it has completely deteriorated. Factories that fail to implement preventive maintenance are in essence accelerating the deterioration of their equipment. In such factories powdered dust and chips fly in all directions, lubricants and oil drip while equipment and floor are littered with dirt, dust, oil and raw materials (Nakajima, 1988).

When dust and dirt adhere to moving parts and sliding surfaces of the machinery, the surfaces are scratched causing deterioration. And when lubrication is neglected, excessive friction or burning can result, wasting energy.

Maintenance personnel are responsible for periodic inspections and preventive repairs. Thus preventive maintenance decreases the number of breakdowns and inevitably increases equipment life span (Nakajima, 1988).

Preventative maintenance (PM) reduces the incidence of breakdown or failure in plant equipment, extends the useful life of production machinery, reduces the total cost of maintenance (PM avoids more costly repairs), promotes safe working conditions, and improves product quality by keeping equipment properly adjusted, well serviced, and in good operating condition. Poor maintenance can make a company unable to implement a lean production system (Pfeil, Holcomb, Muir and Taj, 2000).

Weinsteina, Vokurkab and Graman (2009) state that maintenance is defined as ‘the activities intended to preserve or promptly restore the safety, performance, reliability, and availability of plant structures, systems and components to ensure superior performance of their intended function when required’. Personnel who perform maintenance in a production environment strive to make capacity available to production in a reliable and stable manner.

Preventive maintenance is a proactive approach that requires an organisation to schedule regular maintenance work in order to reduce repair and lower maintenance costs. Interruptions to the production schedule may include normal wear of production equipment, failures resulting from unperformed inspections and services, and unanticipated stresses to the equipment. Planned service allows an organisation to prevent breakdown by detecting weak points and replacing parts that may be usable but do not meet reliability standards (Weinsteina *et al.*, 2009).

The maintenance departmental goals and objectives to increase the effectiveness and efficiency of the factory-wide maintenance process and the maintenance function itself rely upon an understanding of the duties of the department. The routines that impact on the efficiency and determine where effectiveness improvements are focused include (Rich, 1999):

- Planning the maintenance budgeting process including recording and reporting work;
- Scheduling maintenance efforts including the works order system;
- Developing more sophisticated planned maintenance activities to reinforce the TPM teams and advanced inspection routines;
- Planning the maintenance calendar including the planning of periodic shutdown, overhaul activities and the assignment of work;
- Controlling equipment and procedure documentation including standards;

- The custody of TPM standards and preventative maintenance standards including lubrication registers;
- The determination of the maintenance calendar, asset register maintenance and record updating;
- Managing the equipment replacement parts, spare equipment and consumable item systems;
- The on-going analysis of equipment capabilities, reliability and maintainability;
- Managing equipment upgrades and refurbishments;
- Managing suppliers and sub-contractors;
- Managing the maintenance performance measurement system and analysis of system failure statistics including the analysis and correction of such failures;
- Managing environmental controls, safety audits and the amendment of procedures within the system. (Rich, 1999)

The development of a maintenance system which provides a high level of discipline and control, through preventative maintenance and the creation of internal factory standards, allows the conversion process to be protected from disruptions (Rich, 1999).

Preventive and inspection-based maintenance activities may be production-/run-based or calendar-/interval-based. Run-based maintenance is scheduled according to the equipment's level of usage. As production demands increase, the resources required for maintenance will also increase. Calendar-based maintenance is performed at specified intervals of time, regardless of production volume (Weinsteina *et al.*, 2009).

Emergency maintenance activities are performed when production equipment exhibits signs of failure, or after failure has occurred. Sole reliance on emergency maintenance is a reactive approach that may adversely affect both the integrity of the production plan and the quality of the product.

Rich (1999) state that the focus on the delivery of materials and processing performance in the factory offers additional opportunities for the engagement of maintenance effort and the development of new areas of competence such as condition-based monitoring (CBM) and reliability-centred maintenance (RCM). Both these approaches require a thorough understanding and information processing capability to determine the rate of failure in machine subsystems so that these failure cycles can be established and countermeasures undertaken before failure occurs.

These two approaches include analyses such as ‘mean time between failure’ (MTBF) and also ‘mean time to repair’ (MTTR). The maintenance department contribution is therefore the result of amending the standardised systems in the factory from appraisal to prevention, using reliability as the key motivator for maintenance effort (Rich, 1999).

Mean time between failure analysis is a technique that is employed to assess the average time intervals between the failure of a machine. The purpose of the approach is to assess the frequency of failure occurrences and to stimulate problem-solving activities to correct the source of this frequent loss to the conversion process. The application of MTBF allows the maintenance department to generate an information system that allows the need for technical intervention to be identified and also to inform the planned maintenance process in the factory (Rich, 1999).

The ‘mean time to repair’ technique is a measure of the maintainability of an asset and relates the recovery time to the failure. Therefore by addressing the sources of failure and seeking to minimise the time required to correct abnormalities in the conversion process, the efficiency and effectiveness of the maintenance department improves the delivery of materials within and from the factory (Rich, 1999).

Peng (2005) states that the concept of predictive maintenance (PdM) was added to maintenance management as a new component of TPM. PdM, a condition-based maintenance method, focuses on determining the life expectancy of components in order to replace them or service them at the optimum time.

Lyles (1984) explain that the most important prerequisite of a PM system is that it must be accepted by the maintenance person holding the wrench. It must gain his support and approval by offering these useful and practical features:

- Properly detailed instructions;
- Enhanced job safety;
- Easier data and problem reporting;
- Simplified shift turnover and recordkeeping;
- Fewer fluctuations in manpower needs;
- Maximum flexibility to adjust for unplanned events, and
- Readily determined PM status.

With these practical features, the maintenance person will be more inclined to use the system, thus becoming instrumental in the effort to minimise unplanned equipment outage, make more effective use of available time, and reduce bottom-line maintenance costs.

Another large element of maintenance costs and departmental administrative activities is involved in the management of materials, suppliers and subcontractors. The efficiency and control of the maintenance store is traditionally an area of very low priority for the maintenance department. In the past, stock levels tended to simply materialise in an uncontrolled manner. However, the TPM approach provides a level of consumable item stability and ensures that the amount of spares held by the company is correctly defined (Rich, 1999).

The management of suppliers is also important particularly when machine failures are associated with non stock items or the maintenance store personnel are used to co-ordinate annual shut down activity. The efficiency of the maintenance stores is therefore a function of many detailed issues including:

- The logical location of all fast moving parts at the end racks that are close to the despatch area;

- The creation of a self-service consumable rack that is located outside of the store that contains items such as bolts, washers, gloves, eye protection, etcetera;
- Location of small stores in the factory area, through the use of shadow boards for tooling;
- Determining the safety stock;
- Periodic or on-going cycle counts of stocks, and
- Increased integration with key maintenance suppliers and maintenance projects that lie outside the business. (Rich, 1999).

2.2.5 Computerised Maintenance Management System

Bagadia (2009b) states that adding Computerised Maintenance Management System (CMMS) technology to a facility can enhance efficiency and lead to cost-saving measures. A CMMS can improve workflow and give a facility added flexibility to further improve scheduling. It can assist in workflow improvement by easily allowing employees to initiate and approve work requests and help with planning, scheduling, dispatching, completing and then following up for continuous improvement.

Requesters have convenient access to the status of open and completed requests, which reduces lost productivity from identifying and disposing of duplicate requests.
A unified, standardised system will improve the way it tracks and manages work. Inventory, maintenance and repair information is captured out in the field, not behind a desk. The quality of this information relies entirely on the way workers report data.

Bagadia (2009a) states that the statistics are startling. Up to 80 per cent of CMMS implementations have failed in the past. When considering the costs associated with a CMMS project, an 80 per cent failure rate is a tough number for any company to overcome. But, with simple steps for a well thought-out implementation plan, anyone can harness the full potential that a CMMS can bring to an organisation. The above statements are evident that the SEP maintenance department is part of many organisations which have difficulty implementing CMMS successfully. It is thus not a unique problem to the management of SEP, who could learn from others on how to overcome specific problems.

Idhammar (2004) contends that there are many paradigms and legends surrounding maintenance management in plants. One legend is that CMMS will improve reliability and maintenance performance. It is not unusual to see a maintenance organisation implement a new CMMS with the hopes that this new computer software will improve plant reliability. In truth, new software can be a great help, but it is only a tool. If plant performance improves following a software change, it is not the software itself that contributes the majority of improvements. Improvements will be a synthesis of the implementation and execution of better work processes, behaviour changes, and higher-quality data from the software.

People will blame the software because it cannot talk back, but the real problems are lack of discipline in backlog management, prioritisation issues, and the inability of operations and maintenance to coordinate production and maintenance schedules. From the statements above it is evident that CMMS will not solve maintenance problems on its own, but it can be used by people to solve problems (Idhammar, 2004).

Bagadia (2008) further suggests that maintenance is the backbone of any organisation where equipment must be maintained whether it is a manufacturing plant or a utility company. With a CMMS in place, maintenance can save time and money for a number of industries. CMMS can be used to ensure the high quality of both equipment condition and the output. Not just a means of controlling maintenance, it is one of the primary tools that improves the productivity of maintenance. The benefits of using a CMMS include increased labour productivity, increased equipment availability and longer equipment life.

Of these, one of the most significant is increased labour productivity. If the system provides an employee with a planned job, the procedures, needed parts and tools, the employee will be able to work without interruption. They will also work more safely, since job plans would include all safety procedures (Bagadia, 2008).

The tangible benefits of a CMMS include reduction in overtime, reduction of outside contract work, reduced maintenance backlog, and reduced cost per repair, and improved morale, better service, less paperwork and a reduction in supervisor follow-up (Bagadia, 2008).

Users will also see reduced inventory costs and better documentation of safety and compliance issues. Preventing accidents and injuries as a result of proper procedures, documented by CMMS, can save companies a significant amount of money. CMMS offers a number of benefits, the greatest being that it helps cope with downsizing and increases efficiency up (Bagadia, 2008).

Bagadia (2009a) states that CMMS is a sophisticated application and will require training for all employees using the system. Organisations should not make the mistake of underestimating training requirements. Initial software training from the CMMS vendor will be needed and on-going (or internal) training for employees. Every organisation implements CMMS in a different way, and employees need training on the company's specific CMMS use.

Idhammar (2004) states that in some plants, training is reduced to a minimum and often performed several months before the system is put in use. The result is that, at best, about 30 per cent of the CMMS functionality is used and that only 30 per cent of the people know how to use it effectively. This results in a 9 per cent usage of the system.

Sharma and Yetton (2003) reveal that information systems (IS) innovations are often based on complex technologies that pose a high knowledge burden and are difficult for end users to grasp. In such cases, the ability of end users to learn and use technologies effectively is often critical to successful implementation. End users resist IS innovations when they perceive learning barriers to be too high. End- user training and the development of end-user resource materials can promote end-user learning and overcome such barriers.

IS innovations are often rejected by end users when they do not perceive the benefits from adoption to outweigh the costs involved. Expected improvement in performance is a key factor in end-users' evaluation of the perceived benefits of IS innovation (Sharma and Yetton, 2003).

Pfeil, Holcomb, Muir and Taj (2000) contend that information systems can provide organisations with many opportunities to improve their productivity. In a modern factory, information is already available on a real-time basis. The challenge is to discover how to use information to solve problems in a continuous-improvement environment. As computer-integrated manufacturing (CIM) becomes the norm in plants and experience with CIM adoption increases, an untrained workforce is a serious liability.

Companies can change this situation by giving top priority to investments in talent, education, training, and motivation of people. The goal is to develop knowledgeable workforces that can use information systems properly in day-to-day activities and problem solving. This is most important in pull-production or just-in-time environments. Without knowledgeable work forces, a single production line going down could have a domino effect on other production lines in the plant and could soon halt the operation of other plants in the chain (Pfeil *et al.*, (2000).

2.3 OVERALL EQUIPMENT EFFECTIVENESS

2.3.1 OEE Introduction

The measurement of production and maintenance performance must emphasise an increasing value for the business and the customer. TPM is an approach to the maintenance of the factory which uses measures of performance to focus continuous improvement activities in the factory and to asses the effectiveness of manufacturing. To achieve this TPM strives to maximise output by maintaining ideal operating conditions and running equipment effectively (Rich, 1999).

Overall equipment effectiveness (OEE) is a measure that shows how well the equipment is running. It indicates not just how many products the machine is turning out, but how much of the time it is actually working and what percentage of the output is good quality. Because it reflects these three important things, OEE is an important indicator of the health of the equipment (The Productivity Development Team, 1999).

OEE is key measurement in the improvement approach Total Productive Maintenance (TPM). OEE is used in TPM to indicate how effectively machines are running. The first four TPM pillars, Focused equipment and process improvement, Autonomous maintenance, Planned maintenance and Quality maintenance, can directly influence OEE through daily operations, maintenance or improvement activities (The Productivity Development Team, 1999).

The OEE measure is a broad approach to the manufacturing process and is underpinned by the logic that losses are cumulative and have an inter-relationship which requires the multiplication of the portfolio of loss (Rich, 1999).
Sharing OEE information is critical for reducing equipment related losses. Operators, the people who are closest to the equipment, need to be aware of OEE results. Reporting OEE information on charts in the workplace is key to improving future results (The Productivity Development Team, 1999).

To achieve overall equipment effectiveness TPM works to eliminate the 'six big losses' that are formidable obstacles to equipment effectiveness. They are:

- Equipment failure from breakdowns;
- Setup and adjustment from exchange of die in injection moulding machines, etcetera;
- Idling and minor stoppages due to the abnormal operation of sensors, blockage of work on chutes, etcetera;
- Reduced speed due to discrepancies between designed and actual speed of equipment
- Process defects due to scraps and quality defects to be repaired, and
- Reduced yield from machine start-up to stable production (Nakajima, 1988).

2.3.2 OEE factors

A machine's overall effectiveness includes more than the quantity of parts it can produce in shifts. When measuring overall equipment effectiveness, efficiency is one factor. In addition to performance, however, OEE includes three factors and the factors are:

- Performance: a comparison of the actual output with what the machine should be producing in the same time;
- Availability: a comparison of the potential operating time and the time in which the machine is actually making products, and
- Quality: a comparison of the number of products made and the number of products that meet the customer's specifications (The Productivity Development Team, 1999).

The equipment-related losses that are important for OEE are linked to the three basic elements measured in OEE, availability, performance and quality:
Availability – downtime losses: failures, setup time;
Performance – speed losses: minor stoppages, reduced operating speed, and
Quality – defect losses: scrap, rework and start-up loss.

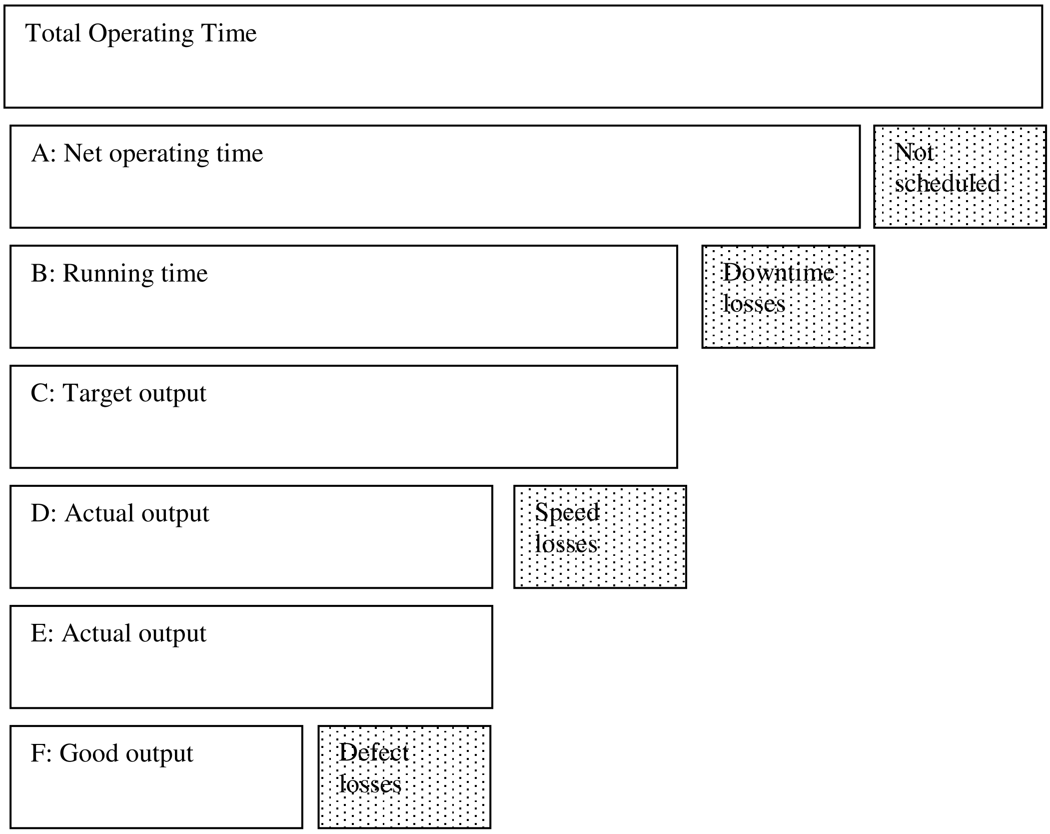
The availability calculation is drawn from the time the equipment was planned to be productive or total time less any planned downtime. This time is also called the loading time and, by subtracting any major production stoppages like equipment changeovers and breakdowns, the operation time can be calculated. Availability is the ratio of operation time against loading time in percentage (Rich, 1999).

The performance efficiency calculation is drawn from the logic that all machines should work at the designed rate for the equipment. An operating rate that is less than the designed speed of the equipment is an apology for poor operations or maintenance. The performance efficiency of the equipment is reduced by such losses as minor stoppages, idling and reductions in speed. Operating speed is the ratio of theoretical cycle time against actual cycle time in percentage (Rich, 1999).

The final element of the OEE trilogy is the rate of quality production that compares the inputs to the process with the outputs achieved (Rich, 1999).

When multiplying performance, availability and quality the result is overall equipment effectiveness which is expressed as a percentage. OEE gives a complete picture of the machine's 'health' not just how fast it can make parts, but how much the potential output was limited due to lost availability or poor quality (The Productivity Development Team, 1999).

Figure 2.1 below depicts a graphical representation of OEE and the losses.
Figure 2.1: Visualising OEE and the losses.



Source: The Productivity Development Team (1999)

OEE = availability x performance x quality = B/A x D/C x F/E x 100

Bars A and B represent availability. Unscheduled time shortens the total operating time, leaving net operating time (A). But the machine is frequently down during some of that time, usually due to breakdowns and setup. Subtracting that downtime leaves the running time (B) in which the machine is making product.

Performance is represented by bars C and D. During running time the machine could produce a target output quantity (C) if it ran at its designed speed the whole time. But losses such as minor stoppages and reduced operating speed lower the actual output (D).

Bars E and F represent quality. Of the actual output (E) most of the product is good output (F). But usually some output falls short of the specified quality and must be scrapped or reworked.

2.3.2.1 Availability

Failures and setup losses were the original losses counted as downtime that reduces availability. Cutting tool loss, start-up loss and time not scheduled for production are three other losses tracked as downtime at some plants (The Productivity Development Team, 1999).

Failures

Availability is reduced by equipment failures. Machines used for production generally have lots of moving parts and various subsystems in which things can go wrong. When they do, the machine breaks down until it gets repaired. Many of the causes of machine failure give warnings signs before the machine actually breaks. Autonomous maintenance activities can help spot early trouble signs in time to prevent major breakdowns (The Productivity Development Team, 1999).

Failure and repair time includes all of the downtime until the machine makes the next good product. Some plants lump all breakdowns into one category while other plants may create several categories to distinguish between different types or causes of machine failures. The main thing is to standardise the approach so everyone can measure a failure event the same way (The Productivity Development Team, 1999).

Setup time

Availability is also reduced by the time it takes to set up the machine for a different product. In addition to changing the value-adding parts, a changeover requires some preparation or make-ready. It may involve cleaning and making adjustments to the machine to get stable quality in the next product. Too often it involves running around to find tools, parts or people.

Setup and adjustment time includes the time between the last good piece of product A and the first good piece of product B (The Productivity Development Team, 1999).

Cutting tool loss

Breakage of cutting tools during production causes unplanned downtime while the tool is replaced. Some companies track cutting tool loss separately because of the potential for injury and product defects as well as the cost of tool replacement. Planned maintenance and autonomous maintenance activities help reduce these losses (The Productivity Development Team, 1999).

Start-up loss

Start-up loss is traditionally included as a defect loss since its essence is the production of defective products during start-up. However start-up loss involves lost time until good production can be stabilised (The Productivity Development Team, 1999).

Time not scheduled for production

In some companies when machines are stopped for meetings, preventive maintenance or breaks, the time is considered 'not scheduled' and is not counted in the availability rate. Other companies recognise that even necessary activities like these reduce the available production time. Counting unscheduled time as a loss can encourage creative ideas for reducing the loss without eliminating the activity (The Productivity Development Team, 1999).

2.3.2.2 Performance

Reduced operating speed

Machines often run at speeds slower than they were designed to run. One reason for slower operation is unstable product quality at the designed speed (The Productivity Development Team, 1999).

Minor stoppages

Minor stoppages are events that interrupt the production flow without actually making the machine fail. They often occur on automated lines and add up to big losses at many plants. Minor stoppages last only a few seconds and the time lost is not logged. Instead they are included in performance losses that reduce output (The Productivity Development Team, 1999).

2.3.3 Improving OEE

OEE is measured to monitor the condition of the equipment. By comparing yesterday's or last week's result, it can be seen if the condition has improved or become worse. The point of using the OEE measure is to drive improvement. Standardisation is the first step in improvement. Sustained improvement requires a dedicated approach with management support. There are a few approaches to improve OEE: 5 Why analysis; Autonomous maintenance; Focused equipment and process improvement; Quick Changeover and P-M analysis (The Productivity Development Team, 1999).

5 Why Analysis

Sometimes after repairing a machine problem the same problem happens again after a short time. In such cases the symptoms have been treated but not the real root cause. Until the root cause is addressed the same problem will keep returning.
The 5 Why analysis is a useful tool that brings one closer to the root cause. As its name suggests, 5 Why analysis involves repeatedly asking 'why?' about the problem. It could be more or less than five times, depending on the problem (The Productivity Development Team, 1999).

Autonomous maintenance

Autonomous maintenance refers to activities carried out by shop floor teams in cooperation with maintenance staff to help stabilise basic equipment conditions and spot problems early. In autonomous maintenance, operators learn how to clean the equipment they use everyday and how to inspect for trouble signs as they clean. They may learn basic lubrication routines, simple methods to reduce contamination and keep the equipment cleaner (The Productivity Development Team, 1999).

Autonomous maintenance is, at its heart, a team based activity. Through the steps of autonomous maintenance shop floor, employees work with maintenance technicians and engineers toward a common goal, that is more effective equipment. By sharing what they know, they can catch many of the problems that cause failures, defects or accidents (The Productivity Development Team, 1999).

Focused equipment and process improvement

Focused equipment and process improvement is the TPM pillar that deals most directly with improving equipment-related losses. Autonomous maintenance and planned maintenance improve OEE to a certain level then help maintain basic operating conditions to stabilise OEE. To raise OEE beyond this stabilised level companies apply focused improvement (The Productivity Development Team, 1999).

Focused improvement involves targeted projects to reduce specific losses. These projects are usually carried out by cross-functional teams that include people with various skills or resources an improvement plan might require. Depending on the target, a focused improvement team may include maintenance technicians, engineers, equipment designers, operators, supervisors and managers (The Productivity Development Team, 1999).

Quick Changeover

Setup and adjustment time is an improvement target for OEE since it reduces the time the machine is available to make products. A changeover improvement system, called single-minute exchange of die (SMED), gives a three stage approach for shortening setup (The Productivity Development Team, 1999).

Stage 1: Separate Internal and External setup

The problem at most companies is that internal and external setup operations are mixed together. This means that things that could be done while the machine is running are not done until the machine is stopped. Internal setup: setup operations that can be done only with the equipment stopped. External setup: setup operations that can be done while the machine is working (The Productivity Development Team, 1999).

Stage 2: Convert internal setup to external setup

The next step in the SMED system is to look again at activities done with the machine stopped and find ways to do them while the machine is still active. Typical improvements include:

- Preparing operating conditions in advance
- Standardising functions
- Using devices that automatically position the parts without measurement (The Productivity Development Team, 1999).

Stage 3: Streamline all aspects of setup

This stage attacks remaining setup time and includes these approaches to shorten internal setup:

- Using parallel operations (two or more people working together)
- Using quick-release clamps instead of nuts and bolts
- Using numerical settings to eliminate trial and error adjustments (The Productivity Development Team, 1999).

P-M analysis

P-M analysis is a tool for systematically uncovering and testing all the possible factors that could contribute to chronic problems such as defects or failure. The 'P' in P-M analysis stands for 'phenomenon'; that is the abnormal event and also 'physical' that is the perspective in viewing the phenomenon. 'M' refers to 'mechanism' and the '4Ms' a framework of casual factors to examine that is Machine, Men/ Women/ Operator, Material and Method (The Productivity Development Team, 1999).

The essence of P-M analysis is to look systematically at every detail so no physical phenomena, underlying condition or casual factor are missed. Although product defects and equipment failures are the losses most often addressed, P-M analysis can be applied to any loss that involves equipment abnormality.

P-M analysis involves physically analysing chronic losses according to the principals and natural laws that govern them. The basic steps of P-M analysis are:

- Physically analysing chronic problems according to the machine's operating principles;
- Defining the essential or constituent conditions underlying the abnormal phenomena, and
- Identifying all factors that contribute to the phenomena in terms of the 4M framework (The Productivity Development Team, 1999).

P-M analysis is considered an advanced tool because this level of 'detective work' requires more time, resources and expertise than 5 Why analysis. For these reasons focused improvement teams may save P-M analysis for complex or costly problems (The Productivity Development Team, 1999).

The TPM teams could be directed towards the improvement of the OEE score by addressing issues which affect the speed if it is the lowest single element. The process of problem solving could include:

- A brainstorm of the potential sources of slow speed;
- The development of a cause-and-effect analysis (fishbone chart);
- Creation of a check sheet to capture and collection of data;
- Sorting and ranking of data through histogram and Pareto chart;
- Problem solving the causes with the highest frequency and duration, and
- Establishment of new procedures, error proofing devices or appraisals to eradicate the problem (Rich, 1999).

2.4 FORD TOTAL PRODUCTIVE MAINTENANCE

2.4.1 FPTM Background

Ford Production System (FPS) is a unified system that integrates Ford's worldwide manufacturing, design and development, order to delivery, supply, and management functions. Through the years, Ford has continuously improved by using the "best methods known." Throughout his life and in whatever he did, Henry Ford believed, "true efficiency meant doing work using the best methods known." And that has always been Ford Motor Company's goal (Franz, 2000).

The FPS is a lean, flexible, and disciplined common production system that is defined by a set of principles and processes, and that employs groups of capable and empowered people who are learning and working safely together to produce and deliver products that consistently exceed customers' expectations in quality, cost, and time (Pfeil *et al.*, 2000).

OEE measures performance in areas ("constraints" or "bottlenecks") that prevent products from flowing at desired levels. Ford can improve capacity by working on bottlenecks in production, maintenance and product changeovers (Franz, 2000).

This measurable reinforces attitudes about the importance of consistently maintaining the reliability and efficiency of equipment. Improving capacity planning, designing for manufacturing and reducing complexity in products and processes also can drive this objective.

Within the constraints of a mass production system, Ford's goal is to get as close to this ideal as possible. Ford is continually working to develop processes throughout the company that will:

- Accurately identify the current and projected needs and wants for all markets.
- Shorten the time it takes to design, engineer, order, manufacture and deliver vehicles and components.
- Make full use of available capacity to schedule and build vehicles and components to satisfy the immediate demand for those particular products (Franz, 2000).

The company continually look at the most efficient way to integrate these processes and functions into a smoothly running system that provides the best value to customers and the company. This is the reason for a Ford Production System (FPS) (Franz, 2000).

The Ford Production System is not another name for the Manufacturing function. It is a worldwide, cohesive system that encompasses and integrates Manufacturing processes and interrelated Ford Product Development System, Order-to-Delivery, Supply and Management processes. Its purpose is to develop and institute best practices in the methods used to work with people, equipment and materials so customers receive the greatest value (Franz, 2000).

The Ford Production System Vision is to have a lean, flexible and disciplined common production system that is defined by a set of principles and processes that employs groups of capable and empowered people who are learning and working safely together to produce and deliver products that consistently exceed customers' expectations in quality, cost and time (Franz, 2000).

'Lean' means to eliminate unnecessary duplication and waste in: processes, the way of work and engineering and manufacturing of products. Anything that adds complexity, cost and time that does not add value for the customer must be removed. (Franz, 2000)

FPS consists of 12 elements namely:

- FTPM: Ford Total Preventative Maintenance;
- Training;
- ISPC: In Station Process Control;
- ME: Manufacturing Engineering;
- Environment;
- IMF: Industrial Material Flow;
- SHARP: Safety and Health Assessment Review Processes;
- Natural Work Groups;
- Leadership;
- SMF: Synchronised Material Flow;
- Quality;
- HAZMAT: Hazardous Materials.

FTPM – Ford Total Preventative Maintenance

It is the concept of a never-ending improvement process that is included in maintenance activities with the goal of improving quality of products and productivity.

2.4.2 FTPM defined

FTPM is defined as a work group centred effort to eliminate the major losses in production and manufacturing equipment through the seven steps of TPM. The purpose is to establish a corporate culture to maximise production equipment effectiveness by utilising the seven steps of TPM (Franz, 2000).

This organised method is aimed at preventing losses before they occur throughout the life cycle of the equipment. The goal is to eliminate and drive for zero accidents, breakdowns and defects. It involves every employee, including top management to front-line operators and production employees.

2.4.3 Planned Maintenance

This provides the foundation for FPS by ensuring all activities required to restore and improve facilities, equipment, processes and tooling through routine, periodic and predictive maintenance are in place and effectively used (Franz, 2000). The result is the process explained below:

Maintenance Organisation with supporting Structure

This focus on a formal maintenance organisation to manage the maintenance activities and resources required to restore and improve equipment and processes:

- Defined and documented maintenance processes;
- Defined roles and responsibilities;
- Established vision, goals and objectives;
- Maintenance measurable;
- Training requirements;
- Safety and the environment;
- Communications.

Maintenance Planning and Inspection

This focus on the development of total necessary maintenance work to be scheduled in the plant, with the emphasis on development of PM task schedules prior to equipment failures:

- Identification of all “key” equipment;
- Development of appropriate PM task descriptions and frequencies;
- Identification of appropriate Industrial Materials requirements;
- Establishing a predictive/conditioned maintenance plan;
- Focus on Corporate and governmental regulatory requirements for safety and environmental;
- Work group involvement in the PM process (that is equipment and process checks).

Maintenance Scheduling and Completion

The maintenance scheduling process should complement the facilities maintenance planning process, to ensure that all planned and unplanned maintenance tasks are scheduled and completed in a timely fashion:

- Identify priorities, based on safety, the environment, product quality and throughput, and
- Identify timing, roles and responsibilities and other resource requirements.

Maintenance – Verification and Task Optimization

The purpose is to ensure that all maintenance tasks are performed effectively (that is, safely, timeously, cost-conscious, consistently to a documented standard), through a regular task review process:

- Regularly scheduled task review by an appropriate cross functional work group;
- Defined verification of maintenance task completion process;
- Emphasis on completion and review of safety, environmental and quality tasks, and
- Consideration of effective utilisation of resources, adequacy of tools, cost effectiveness, work group input, increased throughput opportunities, etcetera.

Data Collection, Analysis and Document Control

Effective equipment management is based on current and accurate data and is dependent on a process to collect, report, analyse and archive data:

- Documented data collection and document control process;
- Defined Maintenance Management System (MMS);
- Work group involvement in data collection and analysis;
- Linkage to FRACAS (Failure Reporting, Analysis and Corrective Action System) and R&M (Reliability and Maintainability).

2.4.4 FTPM Autonomous Implementation steps as stated by Franz, (2000).

The official steps:

Step 0

Step 0 is preparation of the organisation including confirmation of constraints and plant leadership commitment to FTPM success. Initial work place organisation, including 5S, is considered a part of step 0.

Step 1 Cleaning Is Inspection

This involves the act of cleaning equipment not just for making the equipment superficially clean but to discover nonconformities in equipment operation utilising the five senses. The initial cleaning is aimed at totally eliminating accumulated dirt and all nonconformities that may cause failures, defects or accidents. Tags are attached to the equipment, a problem summary list is developed and corrective actions are identified to provide permanent resolutions.

The purpose is to discover nonconformities and abnormalities such as leakage, loosening, and damage to equipment. During this cleaning process the equipment is cleaned and "all" dirt is removed from every corner of the equipment. All abnormalities are identified using FTPM tags. Abnormalities are recorded using a problem summary list. Preliminary cleaning standards are developed along with procedures and schedules.

Step 2 Eliminate or Control the Sources of Contamination and Hard to Reach Areas

Workgroup members support activities identified in step one by performing activities that correct the problem summary list by modifying the equipment, processes, work areas or work practices to eliminate, contain or control contaminates. This can include the modification of work areas and of work practices aimed at reducing the time to clean, lubricate or inspect.

Step 3 Cleaning, Lubrication, Inspection and Safety Procedures

Cleaning standards are established to include description, method, cleaning tools, cleaning time and frequency. Machine lubrication should include a lube diagram, lubrication standard, type and amount, method, tools, frequency and pictorials to assist in this step. Safety placards and lockout pictorials must be attached to each machine in accordance with corporate standards. Equipment inspection checks to include daily start-up and shutdown procedures must be considered.

Step 4 General Inspection Training

Overview technical training is provided to workgroup members in the fundamentals of their equipment. This should include hydraulic and pneumatic devices and systems, fasteners, leak prevention and seals, fundamentals of power transmission, fundamentals of spindles and bearings, electrical devices and lubrication. The facility should make maximum use of technical training, single point lessons, sectioned teaching aids and skilled trade subject matter experts.

Step 5 Self Directed Workgroup Inspections and Procedures

Work groups mature and become self-directed. Based on knowledge gained through general inspection training, there is expanded use of checklists, check sheets, and enhancements. Maintenance organisation has improved their standards in performing the required PM and utilisation of predictive technologies.

Step 6 Process Quality Assurance

This is Process Quality Assurance performed on manufacturing processes by Work Groups with support, as required, by skilled trades and other appropriate support activities and is practiced and stabilised in the support areas (for example powerhouse, waste treatment, garage, tool room, maintenance areas, administration building, etcetera) in the facility. This step needs to be reviewed in conjunction with ISPC.

Step 7 Small Group Equipment Management

Workgroups have achieved a high level of autonomy for managing their equipment, this includes managing the manufacturing process, continuously improving their equipment and work area. Improvements in reliability and maintainability and quality have been achieved.

Groups continually analyse production data looking for opportunities to improve overall equipment effectiveness. Workgroups interface with suppliers, customers, support organisations, central maintenance, engineering etcetera.

2.4.5 Maintenance Management System

Ford Struandale Engine Plant has a Computerised Maintenance Management System, called Maximo, which supports continuous improvement in the reliability, maintainability and performance of new and existing facilities, processes, equipment and tooling.

The purpose is to enable and support the following FTPM practices:

- Maintain: conduct planned maintenance;
- Improve: improve equipment effectiveness;
- Measurement of Results and Progress Reporting: trend analysis and historical reporting of equipment failures and maintenance costs;
- Specify: early equipment management /reliability & maintainability;
- Workgroups: empowerment;
- Measurables: total life cycle costs and overall equipment effectiveness (Franz, 2000).

The FTPM and maintenance personnel are the champions of the system supported by plant leadership. The processes followed for Computerised Maintenance Management System (CMMS) implementation are:

Installation and Configuration

Install system database on FPS server and rollout plant-wide infrastructure according to a planned implementation strategy and timeline. Train relevant personnel throughout each stage in the use and administration of the CMMS. Identify and construct equipment, materials, tools, labour and task records in the system.

Planned Maintenance

Use of the CMMS to estimate resources and schedule, assign and track maintenance including but not limited to:

- Preventive Maintenance tasks using a time or meter-based frequency.
- Predictive Maintenance tasks such as Vibration Analysis, Infrared Thermography, Ultrasonic Inspection, Oil Analysis, etcetera
- Corrective Maintenance tasks requiring equipment and work prioritisation.
- Leak Control tasks including tracking the consumption of fluids and leak repairs.
- Lubrication Management tasks requiring identification of product and frequency.
- Project Work involving the coordination of large resources and scheduled downtime.
- Safety Plans and Lock Out/Tag Out Procedures issued in conjunction with appropriate task.
- Assignment of the tasks to qualified maintenance individuals at the scheduled or appropriate time (resources available).
- Upon task completion, report all maintenance and equipment actuals including labour, materials, tools, repair time, downtime and problem, cause and remedy for equipment failure.
- Maintenance of an historical database to be used as a foundation for continuous improvements.

Value stream Integration

The use of the CMMS by work groups and production leadership is central to safety, equipment effectiveness and performance of the seven steps of TPM.

- Request all maintenance through CMMS.
- Report all equipment and facility related safety issues through CMMS.

- Record all equipment related data including downtime and reason for equipment failure in CMMS.
- Schedule cleaning and inspection tasks and record results in CMMS.
- Modify task records in CMMS to support correction, containment or control of identified problems.
- Link relevant diagrams and modify task records in CMMS to support established standards.
- Delegate overall equipment management responsibilities in CMMS to work group members.
- Analyse CMMS data in support of improving overall equipment effectiveness.

Measuring the success of the maintenance management system is determined through the following factors:

- Percentage of CMMS implemented and operating plant-wide.
- Percentage data collection process in place and used by work groups or maintenance personnel for equipment management.
- Percentage of PM tasks that can be performed without interruption of normal manufacturing operating schedules.
- Total maintenance cost per piece.
- Percentage of PM tasks completed to schedule.
- Percentage planned maintenance to crisis.
- Number of breakdowns.
- Number of minor stoppages.
- Availability = (Scheduled time – All unplanned delays) / Scheduled Time.
- Reliability (MTBF: Mean Time Between Failure) = Total operating time or cycles / Number of failures.
- Maintainability (MTTR: Mean Time To Repair) = Total downtime from failures / Number of failures.
- Overall Equipment Effectiveness = Availability x Performance efficiency x Quality rate.

The output of successful maintenance management system implementation will be:

- Proactive versus reactive approach to maintenance.

- Optimised PM tasks based on relevant parameters (history, condition, total cost, etcetera).
- Managed and decreased Total Cost.
- Increased OEE.
- Maintenance as integral to the Value stream.
- Work Group management of equipment.
- Increased safety.
- Improved quality.
- Reduced waste.

2.4.6 Maintenance Measurables

Maintenance Measurables is a defined set of standard maintenance measurables that serve as the base for maintenance activity, work group, engineering and supplier management. These measurables are considered the real state of the plant from which continuous improvement activities are generated (Franz, 2000).

The purpose is for maintenance measurables to drive the business and allow the maintenance performance to be tracked and ensure timely progress to the facility maintenance plan is achieved. This data should be reported to the plant's operating committee during regular business meetings and used by leadership to support continuous improvement.

Twelve key standard measures are collected and trended by the maintenance organisation, year over year. Continuous improvement goals are established and extended five year maintenance plans are developed from these measurables.

The twelve measurables are as follows:

- Percentage of PM tasks completed without interruption to normal production schedules – This measure results in better utilisation of limited maintenance resources required to perform required PM and allows this function to occur safely during production.
- Total Maintenance Cost per Piece - Outstanding measure to be minimised through maintenance task optimisation.

- Process capability CP/CPK - Quality is an indicator that reveals the health of machines and equipment. It can be a significant driver of quality rate if maintained above original design levels.
- Total Maintenance Industrial Materials cost per piece - Cost to be minimised through reduced inventory of spare parts and supplies required to sustain production.
- Percentage of PM task completed to schedule – Should show positive trends in maintenance completion as a result of reduced crisis maintenance. This is an indicator that the maintenance system is effective.
- Percentage Planned maintenance to crisis – Should see an increase in planned maintenance versus crisis.
- Number of Breakdowns – This should be decreasing as a result of the PM and conditioned based maintenance practices.
- MTTR - Mean time to repair should be improving as equipment knowledge increases; this measure will drive improvement in reliability growth.
- MTTF - Mean time to failure should be increasing systematically
- Consumable Utility Usage – This measure includes usage of electricity, oil, natural gas, compressed air, treatment chemicals etcetera. As systems are utilised to reduce usage such as leak tags, energy conservation measures by workgroups, and actions by engineering, the usage of these consumables should be reduced.
- Number of Accidents involving Maintenance Personnel – Indicator of emphases placed on safety related priorities within the facility.

2.5 SUMMARY

In Chapter Two, the literature overview, TPM was defined by different authors and specifically by Nakajima (1988) as "productive maintenance involving total participation." The stages of TPM development were discussed and grouped in three stages; namely, Preparation, Implementation and Stabilisation.

The use of Small Groups in TPM to do autonomous maintenance was explained. Autonomous maintenance was discussed and the three levels of autonomous maintenance; namely, equipment cleaning, equipment lubrication routines and equipment tightening and inspection were outlined.

The importance of the prevention of breakdowns and minor stoppages was explained. Prevention is based on three principles: maintenance of normal conditions, early discovery of abnormalities and prompt response. The importance of planned maintenance was discussed and that routine maintenance helps to prevent breakdowns, increase equipment life span and protect production from disruptions.

The importance of a Computerised Maintenance Management System (CMMS) was discussed. A CMMS can improve workflow, improve scheduling, save time and money. Organisations can also struggle to get the benefits from CMMS if not used correctly, data is not captured accurately and users not properly trained.

Overall equipment effectiveness (OEE) was discussed and is an important indicator of the health of the equipment and a measure that shows how well the equipment is running. OEE is the product of three factors; namely, performance, availability and quality and is expressed as a percentage. There are a few problem solving approaches to improve OEE: 5 Why analysis, Autonomous maintenance, Focused equipment and process improvement, Quick changeover and P-M analysis.

Ford Total Productive Maintenance (FTPM) was discussed and is one of twelve elements of the Ford Production System (FPS). FTPM is the concept of a never-ending improvement process that is included in maintenance activities with the goal of improving quality of products and productivity of work. FTPM is defined as work group centred effort to eliminate the major losses in production and manufacturing equipment through the seven steps of TPM.

Planned maintenance provides the foundation for FTPM by ensuring all activities required to restore and improve equipment and processes through routine and predictive maintenance are in place and effectively used. Ford SEP has a CMMS, called Maximo, which supports continuous improvement in the maintainability and performance of facilities and process. The purpose is to enable and support the following FTPM practices: Maintain, Improve, Report Results and Progress, Specify, Workgroups and Measurables.

The next chapter will discuss the research design, sampling and measuring instruments to analyse if TPM is effectively applied at SEP.

CHAPTER THREE

RESEARCH DESIGN AND METHODOLOGY

3.1 INTRODUCTION

In Chapter Two TPM was defined as total productive maintenance involving all the employees in the company. The importance of small groups doing autonomous maintenance was discussed. The importance of routine or periodic maintenance by maintenance technicians was also discussed. Together this will prevent breakdowns and minor stoppages and improve production performance.

The performance is measured using a metric system called OEE and it consists of three factors; namely, performance, availability and quality. OEE give an indication of the health of the organisation.

In this chapter the research methodology employed for this study will be discussed. The discussion will include aspects such as research design, research paradigms, questionnaire design, question design, sampling size, sampling method, measuring instruments, response rate and data analysis.

3.2 RESEARCH NATURE

Collis and Hussey (2009) define research as a process of enquiry and investigation. It is systematic and methodical and increases knowledge.

Pinsonneault and Kraemer (1992) state that research design is the strategy for answering the questions or testing the hypotheses that stimulated the research in the first place.

Collis and Hussey (2009) classify research according to four criteria, namely:

- Purpose: the reason why it was is conducted;
- Process: the way in which the data were collected and analysed;
- Logic: whether the research logic moves from the general to the specific or vice versa, and
- Outcome: whether the expected outcome is the solution to a particular problem or a more general contribution to knowledge.

Collis and Hussey (2009) further give examples of types of research for each criterion mentioned above:

- Purpose: Exploratory, descriptive, analytical or predictive;
- Process: Quantitative or qualitative;
- Logic: Deductive or inductive, and
- Outcome: Applied or basic research.

Forza (2002) state that what is needed prior to survey research design is theory testing survey research and is a long process which presupposes the pre-existence of a theoretical model (or a conceptual framework). The empirical parallel of the level of reference of the theory is the ``unit of analysis'' issue. The unit of analysis refers to the level of data aggregation during subsequent analysis. The unit of analysis may be individuals, groups, plants, divisions, companies, projects, systems, and etcetera.

3.2.1 Research Purpose

According to Collis and Hussey (2009) exploratory research is conducted on a research problem or issue when there are very few or no earlier studies to which a researcher can refer for information about the issue or problem. Descriptive research is conducted to describe the phenomena as they exist. It is used to identify and obtain information on the characteristics of a particular problem or issue.

Analytical or explanatory research is a continuation of descriptive research. The researcher goes beyond merely describing the characteristics, to analysing and explaining why or how the phenomenon being studied is happening. Predictive research goes further than explanatory research; it forecasts the likelihood of a similar situation occurring elsewhere. Predictive research aims to generalise from the analysis by predicting certain phenomena on the basis of hypothesised, general relationships (Collis and Hussey, 2009).

Pinsonneault and Kraemer (1992) state that survey research can be used for exploration, description, or explanation purposes. The purpose of survey research in exploration is to become more familiar with a topic and to try out preliminary concepts about it. The exploratory survey focuses on determining what concepts to measure and how to measure them best. The exploratory survey also is used to discover and raise new possibilities and dimensions of the population of interest.

The purpose of survey research in description is to find out what situations, events, attitudes or opinions are occurring in a population. The researcher's concern is simply to describe a distribution or to make comparisons between distributions. Analysis stimulated by descriptive questions is meant to ascertain facts, not to test theory (Pinsonneault and Kraemer, 1992).

The purpose of survey research in explanation is to test theory and causal relations. Survey research aimed at explanation asks about the relationships between variables. It does so from theoretically grounded expectations about how and why the variables ought to be related (Pinsonneault and Kraemer, 1992).

3.2.2 Research Process

According to Collis and Hussey (2009) some researchers, to address their research questions, take a quantitative approach. They design a study collecting quantitative data and or qualitative data that can be quantified and analyse them using statistical methods. Others take a qualitative approach to address their research questions. They design a study collecting qualitative data and analyse them using interpretative methods.

Pinsonneault and Kraemer (1992) state that case studies involve examination of a phenomenon in its natural setting. The researcher has no control over the phenomenon, but can control the scope and time of the examination. The researcher may or may not have clearly defined independent and dependent variables. Case studies are most appropriate when the researcher is interested in the relation between context and the phenomenon of interest.

Pinsonneault and Kraemer (1992) state further that survey research involves examination of a phenomenon in a wide variety of natural settings. The researcher has very clearly defined independent and dependent variables and a specific model of the expected relationships which is tested against observations of the phenomenon.

Survey research is most appropriate when:

- The central questions of interest about the phenomena are "what is happening", and "how and why is it happening;"
- Control of the independent and dependent variables is not possible or not desirable;
- The phenomena of interest must be studied in their natural setting.
- The phenomena of interest occur in current time or the recent past (Pinsonneault and Kraemer, 1992).

3.2.3 Research Outcome

According to Collis and Hussey (2009) applied research is a study that has been designed to apply its findings to solving a specific, existing problem. It is the application of existing knowledge to improve management practices and policies.

Basic or pure research is when the problem is of a less specific nature and the research is being conducted primarily to improve understanding of general issues without emphasis on its immediate application.

3.2.4 Research Logic

Collis and Hussey (2009) further explain that deductive research is a study in which a conceptual and theoretical structure is developed and then tested by empirical observation; thus particular instances are deduced from general inferences. For this reason, the deductive method is referred to as moving from the general to the particular.

Inductive research is a study in which theory is developed from the observation of empirical reality; thus general inferences are induced from particular instances. Since it involves moving from individual observation to statements of general patterns or laws, it is referred to as moving from the specific to the general.

3.3 RESEARCH PARADIGMS

A research paradigm is a philosophical framework that guides how scientific research should be conducted. A paradigm reflects the author's basic beliefs, the design of the research, how the data are collected and analysed and even the writing style. The two main paradigms are positivism (positivistic) and interpretivism (phenomenological) paradigms (Collis and Hussey, 2009).

Positivism (positivistic) Paradigm

Positivism originated in the natural sciences. It rests on the assumption that reality is independent and the goal is the discovery of theories based on empirical research (observation and experiment). The research involves a deductive process with a view to providing explanatory theories to understand social phenomena (Collis and Hussey, 2009).

Interpretivism (phenomenological) Paradigm

Interpretivism originated from the belief that social reality is subjective because it is shaped by perceptions. The research involves an inductive process with a view to providing interpretive understanding of social phenomena within a particular context (Collis and Hussey, 2009).

Paradigm Comparison

Table 3.1 below shows a comparison between the two paradigms:

Table 3.1: Paradigm Comparison

Positivism (positivistic)	**Interpretivism (phenomenological)**
Use large samples	Use small samples
Has an artificial location	Has a natural location
Is concerned with hypothesis testing	Is concerned with generating theories
Produces precise, objective, quantitative data	Produces ‘rich’, subjective, qualitative data
Produces results with high reliability but low validity	Produces findings with low reliability but high validity
Allows results to be generalised from the sample to the population	Allows findings to be generalised from one setting to another similar setting

Source: Collis and Hussey (2009)

3.4 DATA COLLECTION

Collis and Hussey (2009) state that there is a wide range of methodologies and methods for collecting research data and it is important to choose those that meet the philosophical assumptions for the appropriate paradigm. Research data can be primary or secondary data. Primary data are data generated from original sources such as the researcher's own experiment, questionnaire surveys, interviews or focus groups. Secondary data are data that have been collected from an existing source such as publications, databases and internal records.

Babbitt and Nystrom (1989) state that there are a number of techniques of data collection that can be used to measure human attributes, attitudes, opinions, and behaviour. Some of the methods of data collection are observation, personal and public records, specific performances, sociometry**,** interviews, questionnaires, rating scales, pictorial techniques, projective techniques, achievement testing, and psychological testing.

Table 3.2 is useful for assessing the availability of data:

Table 3.2: Data availability

Type of data	Source
The literature	Check databases containing academic articles, the library catalogue and internet resources
Official statistics	National jurisdictions, the European Commission and international organisations such as the World Bank
Industry data	Library catalogues, databases and the internet
Company data	Company's website and their annual report and accounts
Internal data	List the information required and get permission/ confirmation of access in writing
People	Establish number of people needed. Communication skills are important. Sufficient funds and time
Surveys	Find a list of relevant organisations and contact details. Interviews and questionnaires. Sufficient funds and time.

Source: Collis and Hussey (2009)

Collis and Hussey (2009) further elaborate that the availability of data is crucial to the successful outcome of research. Many students fail to appreciate the barriers to collecting data. Therefore before deciding on a research project, the researcher must be sure that he or she will be able to get data and other information needed to conduct the research.

According to Collis and Hussey (2009) triangulation is the use of multiple sources of data, different research methods and/ or more than one researcher to investigate the same phenomenon in a study. Four main types of triangulation are:

- Triangulation of theories: a theory is taken from one discipline and used to explain a phenomenon in another discipline;
- Data triangulation: data are collected at different times or from different sources in the study of a phenomenon;
- Investigator triangulation: different researchers independently collect data on the same phenomenon and compare results, and
- Methodological triangulation: more than one method is used to collect and/ or analyse data, but is important to choose from the same paradigm.

3.5 QUESTIONNAIRE

3.5.1 Questionnaire Design

Babbitt and Nystrom (1989) state that the word "questionnaire' refers to an ordered arrangement of items (questions, in effect) intended to elicit the evaluations, judgments, comparisons, attitudes, beliefs, or opinions of personnel.

According to Collis and Hussey (2009) a questionnaire is a list of carefully structured questions, which have been chosen after considerable testing with a view to eliciting reliable responses from a particular group of people. A research instrument is a questionnaire or interview schedule that has been used and tested in a number of different studies.

In addition Collis and Hussey (2009) state the main steps involved in designing a questionnaire or interview schedule are:

- Design the questions and instructions;
- Determine order of presentation;

- Write accompanying letter/ request letter;
- Test questionnaire with a small sample;
- Choose method for distribution and return;
- Plan strategy for dealing with non-responses, and
- Conduct tests for validity and reliability.

Moreover Collis and Hussey (2009) explain that question design is concerned with the type of questions, their wording, the order in which they are presented, the reliability and validity of the responses. An explanatory paragraph or covering letter is needed to explain the purpose of the study since the respondents need to know the context in which the questions are being posed. It is essential to pilot or test the questionnaire as fully as possible to spot problems.

Babbitt and Nystrom (1989) elaborate that the recommended general steps in preparing a questionnaire include preliminary planning, determining the content of questionnaire items, selecting question forms, wording of questions, formulating the questionnaire, and pretesting.

Babbitt and Nystrom (1989) state further that as part of preliminary planning, the information required has to be determined, as do procedures required for administration, sample size, location, frequency of administration, experimental design of the field test, and analyses to be used. The wording of questions is the most critical and most difficult step. Formulating the questionnaire includes formatting, sequencing of questions, consideration of data reduction and analysis techniques, determining basic data needed, and insuring adequate coverage of required field test data.

According to Collis and Hussey (2009), before a researcher can decide what the most appropriate questions will be, he or she must gain a considerable amount of knowledge about the subject to develop a theoretical or conceptual framework and formulate the hypothesis to test. The subject knowledge will come from taught and/ or independent studies and theoretical (conceptual) framework will be drawn from the literature review.

Questions should be presented in a logical order and in a self-completion questionnaire the researcher should give precise instructions. The clarity of the instructions and the ordering and presentation of the questions can do much to encourage and help respondents.

Classification questions collect data about the characteristics of the unit of analysis such as respondent's job title, age, education or geographical region, industry or size of the business. Classification questions collect data that will enable the researchers to describe the sample and examine relationships between subsets of the sample.

Multiple choice questions are those where the participant is asked a closed question and selects his or her answer from a list of predetermined responses or categories.

Another approach is to ask respondents to rank a list of items. Keep the number of items as low as possible, preferably no more than six. In a semantic differential rating scale, two words or phrases are selected to represent two ends of the scale. A second type of rating scale measures intensity of opinion. This allows respondents to give a more discriminating response and indicate if they feel neutral (Collis and Hussey, 2009).

According to Babbitt and Nystrom (1989) rating scale items are a variation of multiple choice items. They are a means of assigning a numerical value to a person's judgment about some object. They call for the assignment of responses either along an unbroken continuum or in ordered categories along the continuum. The end result is the attachment of numbers to those assignments. Ratings may be made concerning almost anything, including people, groups, ourselves, objects, and systems.

Advantages of Rating Scale Items

- When properly constructed, the rating scale reflects both the direction and degree of attitude or opinion, and the results are amenable to analysis using conventional statistical procedures.
- Graphic rating scales allow for as fine a discrimination as the respondent is capable of giving, and the fineness of scoring can be as great as desired.

- Rating scale items usually take less time to answer than do other types of items.
- Rating scale items can be applied to almost anything.
- Continuous scales may at times yield greater discrimination by raters.
- Rating scale items are generally more reliable than dichotomous multiple choice items. They may be more reliable than paired comparison items.
- Manipulation of the anchors does not appear to greatly affect the results. The inadvertent use of mismatching antonyms with partial antonyms to anchor a rating scale may not jeopardise the reliability of the scale (Babbitt and Nystrom, 1989).

Disadvantages of Rating Scale Items

- Rating scale items are more vulnerable to biases and errors than other types of items such as forced choice Items.
- Graphic rating scales are harder to score than other types of items. With a graphic scale item format, the verbal anchors are associated with points on a line, and the respondents indicate their judgment by marking the point on the line which best represents their judgment. Considerable effort and time are required to measure the pencil mark's exact location to the nearest portion of the line.
- The results obtained from the use of graphic rating scale items may imply a degree of precision/accuracy which is unwarranted (Babbitt and Nystrom, 1989).

3.5.2 Reliability and validity

If rating or attitude scales are used in the questions, then the researcher must ensure they will measure the respondents' views consistently. The reliability of the responses received to all questions is an important issue in a positivist study. Reliability is concerned with the findings of the research. The findings can be said to be reliable if the researcher or someone else repeats the research and obtains the same results (Collis and Hussey, 2009).

Reliability indicates dependability, stability, predictability, consistency and accuracy, and refers to the extent to which a measuring procedure yields the same results on repeated trials. Reliability is assessed after data collection (Forza, 2002).

There are three common ways of estimating the reliability of the responses to questions in questionnaires or interviews:

- Test re-test method: the questions are asked of the same people, but on two separate occasions. Responses are correlated and the correlation co-efficient of the two sets of date computed.
- Split-halves method: the questionnaires or interview record sheets are divided into two equal halves. The two halves are then correlated and the correlation co-efficient of the two sets of data computed.
- Internal consistency method: every item is correlated with every other item across the sample and the average inter-item correlation is taken as the index of reliability (Collis and Hussey, 2009).

Validity is concerned with the extent to which the research findings accurately represent what is happening in the situation or whether the data collected represent a true picture of what is being studied. Reasons for doubt could be that the questions contains errors, respondent may become bored, failing to answer questions or not following instructions (Collis and Hussey, 2009).

Of the different properties that can be assessed about a measure, construct validity is the most complex and the most critical to substantive theory testing. A measure has construct validity if the set of items constituting a measure faithfully represents the set of aspects of the theoretical construct measured, and does not contain items which represent aspects not included in the theoretical construct (Forza, 2002).

The empirical assessment of construct validity basically focuses on convergence between measures (or items of a measure) of the same construct (convergent validity) and separation between measures (or items of a measure) of different constructs (discriminant validity). When a test, conducted to assess an aspect of construct validity, does not support the expected result, either the measurement instrument or the theory could be invalid. It is a matter of researcher judgement to interpret adequately the obtained results (Forza, 2002).

Forza (2002) states that content validity of a construct measure can be defined as the degree to which the measure spans the domain of the construct's theoretical definition. It is the extent to which the measure captures the different facets of a construct. Evaluating face validity of a measure can indirectly assess its content validity. Face validity is a matter of judgement and must be assessed before data collection.

Forza (2002) further states that convergent validity is the testing for consistency across measurement items for the same construct. This form of convergent validity is called construct unidimensionality. Some researchers use exploratory factor analysis to check unidimensionality, while others use confirmatory factor analysis. Factor analysis can be performed on items belonging to a single summated scale or items of several summated scales. Factor analysis procedures are well supported by statistical packages

Forza (2002) continues to explain that discriminant validity is the testing for separation across measures of different constructs. It can be assessed through confirmatory factor analysis on items belonging to measures of different constructs. The number of factors and the list of factors which load on each dimension should be specified a priori. Comparing the results of factor analysis with the prespecified factors and loadings, the researcher can obtain an indication of the construct validity.

When an instrument is intended to perform a prediction function, validity depends entirely on how well the instrument correlates with what it is intended to predict (a criterion). Criterion-related validity is established when the measure differentiates individuals on a criterion it is expected to predict. Establishing concurrent validity or predictive validity can do this. Concurrent validity is established when the scale discriminates individuals who are known to be different. Predictive validity is the ability of the measure to differentiate among individuals as to a future criterion (Forza, 2002).

3.5.3 Questionnaire Distribution

Collis and Hussey (2009) show that there are a number of distribution methods, each with different strengths and weaknesses. Cost is often an important factor and the best method for a particular study often depends on the size and the location of the sample.

Examples of distribution methods:

- By post: commonly used method; drawbacks are response rate of 10 per cent or less are not uncommon and sample bias because respondents may not be representative of population;
- By telephone: widely used method; helpful with sensitive and complex questions; achieving the desired number of responses may require a very large sampling frame and costs must be considered; results may be biased towards people who are available and willing to answer;
- On-line: web-based tools allow the researcher to create a survey for free and e-mail it to respondents; obtaining responses may take some time and the results may be biased;
- Face-to-face: questionnaire can be presented to respondents at any convenient place; time-consuming and can be expensive; response rate can be fairly high and comprehensive data collected;
- Group distribution: method is only appropriate where survey is being conducted in a small number of locations or single location; convenient low-cost method and number of usable questionnaires is likely to be high;
- Individual distribution: If the sample is in one location, it may be possible to distribute and collect the questionnaires individually; if properly designed this method can be very precise in targeting the most appropriate sample (Collis and Hussey, 2009).

There are two major problems associated with using questionnaires in a survey. The first is questionnaire fatigue. This refers to the reluctance of many people to respond to questionnaire surveys because they are inundated with unsolicited request. The second problem is with non-response bias which is when some questionnaires are not returned (Collis and Hussey, 2009).

Interviews

Interviews are a method for collecting data in which selected participants are asked questions to find out what they do, think or feel. Interviews can be conducted with individuals or groups using face-to-face, telephone or video conferencing methods.

A positivist approach suggests a structured interview based on a questionnaire or interview schedule. In a structured interview, these questions are likely to be closed questions, each of which has a set of predetermined answers. Structured interviews make it easy to compare answers because each interviewee is asked the same questions (Collis and Hussey, 2009).

3.5.4 Sampling methods

A sample is an unbiased subset that represents the population and a population is a body of people or collection of items under consideration for statistical purposes. If the population is relatively small, the researcher can select the whole population; otherwise select a random sample.

A random sample is one where every member of the population has a chance of being chosen. Therefore the sample is unbiased subset of the population, which allows the results obtained for the sample to be taken to be true for the whole population. The larger the sample, the better it will represent the population. In a questionnaire survey, the expected response rate may be ten percent or less (Collis and Hussey, 2009).

In systematic sampling, the population is divided by the required sample size (n) and the sample chosen by taking every 'nth' subject. Stratified sampling takes account of each identifiable strata of the population; for example in a company, the following strata: senior managers, supervisors and clerical staff (Collis and Hussey, 2009).

Four ways of estimating population variances for sample size determinations:

- take the sample in two steps, and use the results of the first step to determine how many additional responses are needed to attain an appropriate sample size based on the variance observed in the first step data;
- use pilot study results;

- use data from previous studies of the same or a similar population, or
- estimate or guess the structure of the population assisted by some logical mathematical results (Bartlett, Kotrlik, and Higgins, 2001).

Quota sampling involves giving interviewers quotas of different types of people to question. Cluster sampling involves making a random selection from a sample frame listing groups of units rather than individual units. Every individual belonging to the selected groups is then interviewed or examined. Multi-stage sampling is used where the groups selected in a cluster sample are so large that a sub-sample must be selected from each group (Collis and Hussey, 2009).

Pinsonneault and Kraemer (1992) define a survey is a means of "gathering information about the characteristics, actions, or opinions of a large group of people, referred to as a population." As such, there are many data collection and measurement processes that are called surveys: marketing surveys, opinion surveys, and political polls to name some of the most common.

Bartlett, Kotrlik, and Higgins (2001) state that a common goal of survey research is to collect data representative of a population. The researcher uses information gathered from the survey to generalise findings from a drawn sample back to a population, within the limits of random error.

Sills and Song (2002) state that an ideal survey manages to control for error by ensuring that each member of a population has an equal chance of being included in the sample, that sample members are randomly selected in large enough numbers to assure representability, and that everyone who is included in the sample, responds. Sampling error occurs when a subset of a heterogeneous population selected to represent the population as a whole does not truly fit the population.

Pinsonneault and Kraemer (1992) state that surveys conducted for research purposes have three distinct characteristics. First, the purpose of survey is to produce quantitative descriptions of some aspects of the study population. Survey analysis may be primarily concerned either with relationships between variables, or with projecting findings descriptively to a predefined population. Survey research is a quantitative method, requiring standardised information from and/or about the subjects being studied. The subjects studied might be individuals, groups, organisations or communities; they also might be projects, applications, or systems.

Second, the main way of collecting information is by asking people structured and predefined questions. Their answers, which might refer to themselves or some other unit of analysis, constitute the data to be analysed.

Third, information is generally collected about only a fraction of the study population, a sample, but it is collected in such a way as to be able to generalise the findings to the population, like service or manufacturing organisations, line or staff work groups. Usually, the sample is large enough to allow extensive statistical analyses.

3.6 RESEARCH METHODOLOGY OF THIS STUDY

Based on the information in this chapter, the researcher can now classify this study. The purpose of this study is to establish if TPM is effectively applied at an engine plant. The research will attempt to describe the TPM phenomena as they exist therefore the research is descriptive.

The process which used to collect data is a questionnaire; therefore a quantitative approach is used. The data are quantified and analysed using statistical methods.

The outcome of this study will be used to solve the availability of equipment for production in the company; therefore it is applied research.

The research is deductive as a literature review was done and the findings were tested by empirical observation.

3.7 SUMMARY

In Chapter Three the research methodology employed for this study was discussed. The discussion will included aspects such as research design, research paradigms, questionnaire design, question design, sampling size, sampling method, measuring instruments, response rate and data analysis.

The four criteria, purpose, process, logic and outcome, used to classify the research were discussed.

The two main paradigms; positivism (positivistic) and interpretivism (phenomenological) paradigms were discussed and a comparison was made. Positivism research involves a deductive process with a view to providing explanatory theories to understand social phenomena. Interpretivism research involves an inductive process with a view to providing interpretive understanding of social phenomena within a particular context (Collis and Hussey, 2009).

The methodologies and methods for collecting research data were discussed and some of the methods of data collection are observation, interviews and questionnaires. Questionnaire design was discussed and according to Collis and Hussey (2009) a questionnaire is a list of carefully structured questions, which have been chosen after considerable testing with a view to eliciting reliable responses from a particular group of people.

The reliability and validity of research was discussed and established that reliability is concerned with the findings of the research. Validity is concerned with the extent to which the research findings accurately represent what is happening in the situation or whether the data collected represent a true picture of what is being studied.

Sampling was discussed and a sample is an unbiased subset that represents the population and a population is a body of people or collection of items under consideration for statistical purposes.

In the next chapter the results obtained from the survey will be discussed and analysed.

CHAPTER FOUR
EMPIRICAL RESULTS

4.1 INTRODUCTION

In the previous chapter the research methodology was discussed. The information was used to construct a questionnaire to measure the research problem.

The questionnaire was constructed to measure the main problem: Is Total Productive Maintenance effectively applied at Ford Struandale Engine Plant, and sub-problems as stated in Chapter One.

The questions were compiled from the theory in Chapter Two. The method used to construct was explained in Chapter Three. The questionnaire consisted of three sections, first a covering letter, secondly Section A which was classification information and thirdly Section B which were the main questions.

The covering letter was to introduce the researcher to the respondent and to explain the purpose of the research. Permission to conduct the survey was obtained from the plant management; namely, the FPS and Maintenance Manager, the Engineering Manager and the Human Resources Manager.

The classification information in Section A consists of six questions designed to measure the demographics of the sample. The age group, gender, position, years in current position, highest qualification and years experience were requested. This will enable the researcher to create a profile of the respondents.

In the initial design the questions in Section B were grouped in three sections; namely, Total Productive Maintenance (TPM), Overall Equipment Effectiveness (OEE) and Ford Total Productive Maintenance (FTPM). The questions were coded, TPM1, OEE1, FTPM1, etcetera and re-arranged in random order to prevent the respondent from marking in a pattern.

4.2 RESULTS ANALYSIS

4.2.1 General

The survey was conducted at the three Puma component machining lines namely Cylinder Block line, Cylinder Head line and Cylinder Crank line and also the Puma Engine Assembly line.

The respondents were selected on a random basis. The researcher handed the questionnaires to some employees or to the shift team leaders to distribute among their sub-ordinates. A total of 120 questionnaires were distributed and 67 completed ones were returned.

4.2.2 Section A: Classification Information

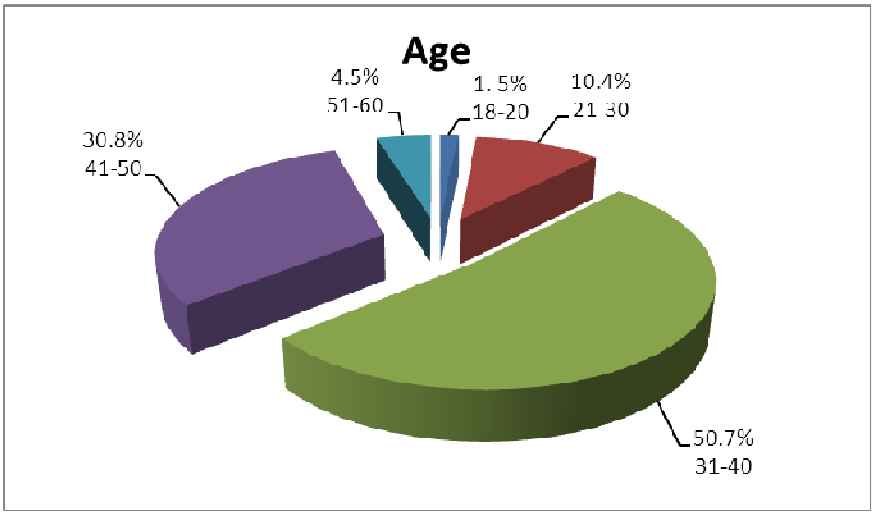
Question one: In what age group are you?

Table 4.1: Age group response

Age		
18-20	1	1.5%
21-30	7	10.4%
31-40	34	50.7%
41-50	22	30.8%
51-60	3	4.5%
61+	0	0

Source: Researcher's own construction from survey data

Figure 4.1: Age group response



Source: Researcher's own construction from survey data

The result shows that about 81.5 percent of the respondents are between 31 and 50 years which indicates a mature sample group.

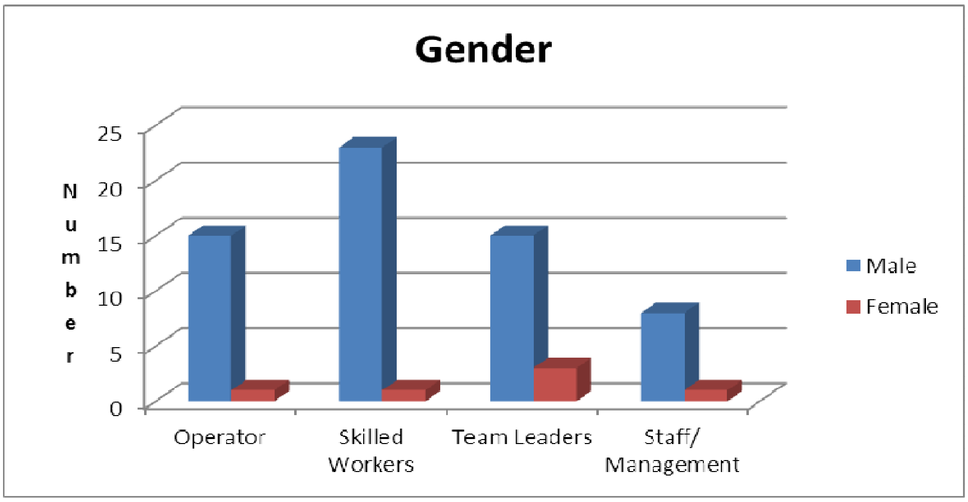
Question two: Gender?

Table 4.2: Gender response

Gender	Total	Operator	Skilled Workers	Team Leaders	Staff/ Management
Male	61	15	23	15	8
Female	6	1	1	3	1
Sub-Total	**67**	**16**	**24**	**18**	**9**

Source: Researcher's own construction from survey data

Figure 4.2: Gender response



Source: Researcher's own construction from survey data

The results show a male dominated sample group but that females are present in each of the categories. This means that there is opportunity for females to work in any position and no position are reserved for males only.

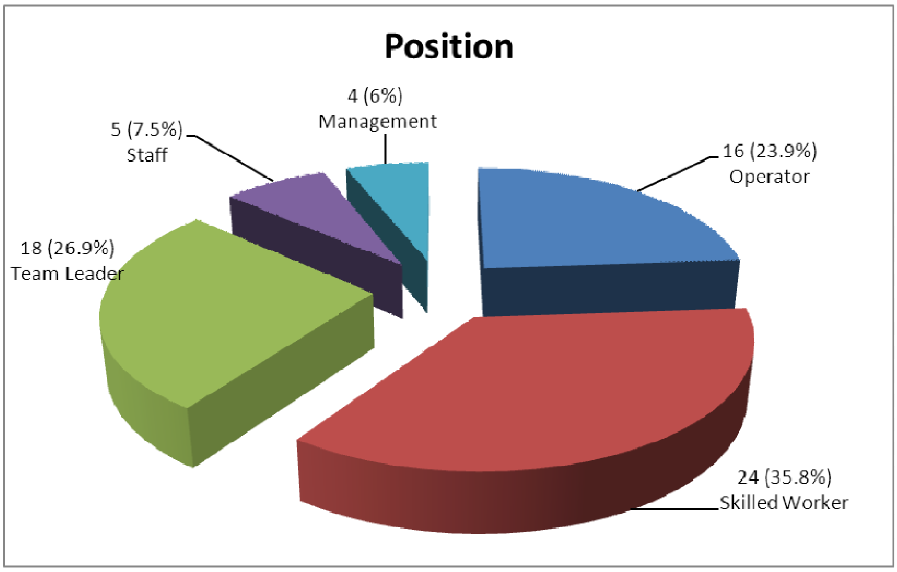
Question three: What is your current position?

Table 4.3: Position response

Position		
Operator	16	23.9%
Skilled Worker	24	35.8%
Team Leader	18	26.9%
Staff	5	7.5%
Management	4	6%

Source: Researcher's own construction from survey data

Figure 4.3: Position response



Source: Researcher's own construction from survey data

The results in table 4.3 show that the Skilled Worker group (38.8 per cent) is the biggest and followed by the team leaders (26.9 per cent) and operators group (23.9 per cent) respectively. These three groups were specifically targeted because they are involved directly with maintenance of the equipment on a daily basis.

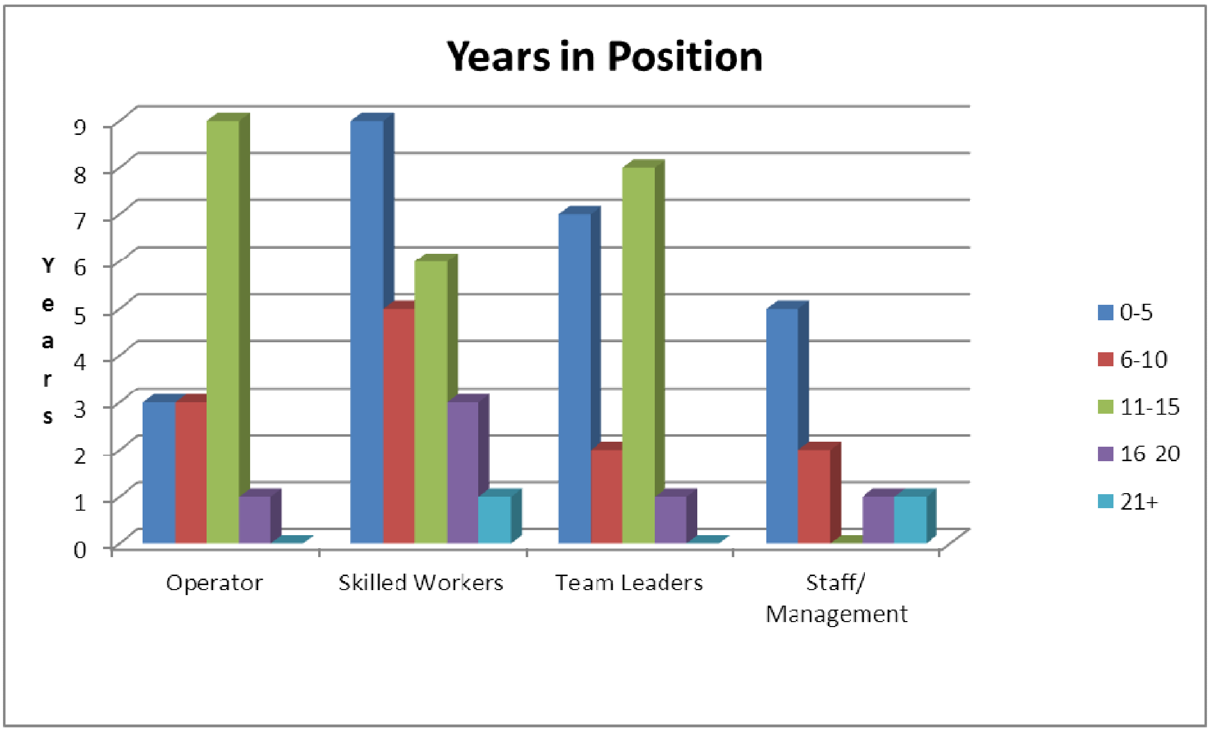
Question four: How many years have you been in the current position?

Table 4.4: Years in current position response

Position	Operator	Skilled Workers	Team Leaders	Staff/ Management
0-5	3	9	7	5
6-10	3	5	2	2
11-15	9	6	8	0
16-20	1	3	1	1
21+	0	1	0	1

Source: Researcher's own construction from survey data

Figure 4.4: Years in current position response



Source: Researcher's own construction from survey data

In the operator group there seems to be stability as many have been working for 11-15 years in the position. In the skilled worker group most have been 0-5 years experience in the position, and this point to newly appointed workers as the age groups in Question 1 showed a mature group.

The team leader group show mixed results as there are two high categories in both 0-5 years and 11-15 years which could indicate newly appointed and experience workers. The staff and management group could be misleading as the result shows mostly 0-5 years but the staff positions were recently restructured from production coordinator to integrated manufacturing team (IMT) engineer.

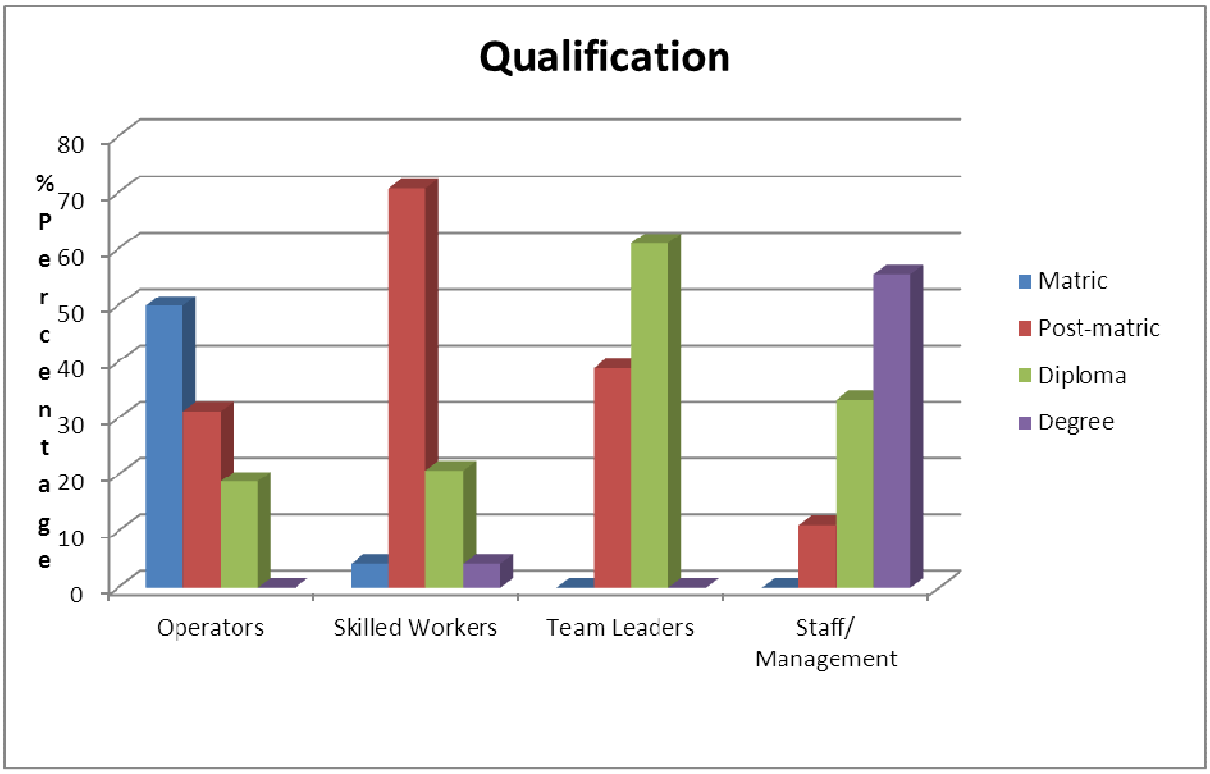
Question five: What is your highest qualification?

Table 4.5: Qualification response

Qualification	Total		Operator		Skilled Workers		Team Leaders		Staff/ Management	
Matric	9	13.4%	8	50%	1	4.2%	0	0	0	0
Post-matric	30	44.8%	5	31.3%	17	70.8%	7	38.9%	1	11.1%
Diploma	22	32.8%	3	18.8%	5	20.8%	11	61.1%	3	33.3%
Degree	6	9%	0	0	1	4.2%	0	0	5	55.6%

Source: Researcher's own construction from survey data

Figure 4.5: Qualification response



Source: Researcher’s own construction from survey data

The results show that for each group there is a dominant qualification which could be a requirement for that specific position. The operator is an entry level position and the minimum qualification needed is a matric certificate; therefore the dominance of the qualification in the group. In the skilled worker group the dominant qualification is post-matric certificate. The educational requirement for maintenance artisans for example is a minimum of an N3 certificate.

The dominant qualification in the team leaders group is a diploma, which indicates a high level of knowledge which is good for the company. This is because the team leaders can use their knowledge to lead their teams. The staff and management groups all have also degrees and diplomas, which indicate a high level of skill.

Question six: How many years work experience do you have since qualification?

Table 4.6: Years work experience response

Years	Operator		Skilled Workers		Team Leaders		Staff/ Management	
0-5	1	6.3%	6	25%	3	16.7%	1	11.1%
6-10	5	31.3%	5	20.8%	4	22.2%	2	22.2%
11-15	8	50.5%	5	20.8%	6	33.3%	3	33.3%
16-20	2	12.5%	5	20.8%	4	22.2%	2	22.2%
21+	0	0	3	12.5%	1	5.6%	1	11.1%

Source: Researcher's own construction from survey data

Figure 4.6: Years work experience response

Source: Researcher's own construction from survey data

These results is similar to question four for years in position. Half of the operator group has between eleven to fifteen years work experience. This indicates an experienced operator group. The skilled worker group show a wide variety of experience varies with a large group of zero to five years experience. The team leader, staff and management groups also shows an experienced group with most respondents between eleven to fifteen years work experience.

4.2.3 Section B: TPM, OEE and FTPM results

The results for Section B were tabled with the positive: strongly agree and agree, and negative selections: disagree and strongly disagree, grouped together for better analysis. A line graph of each group helps to indicate trends and areas of concern.

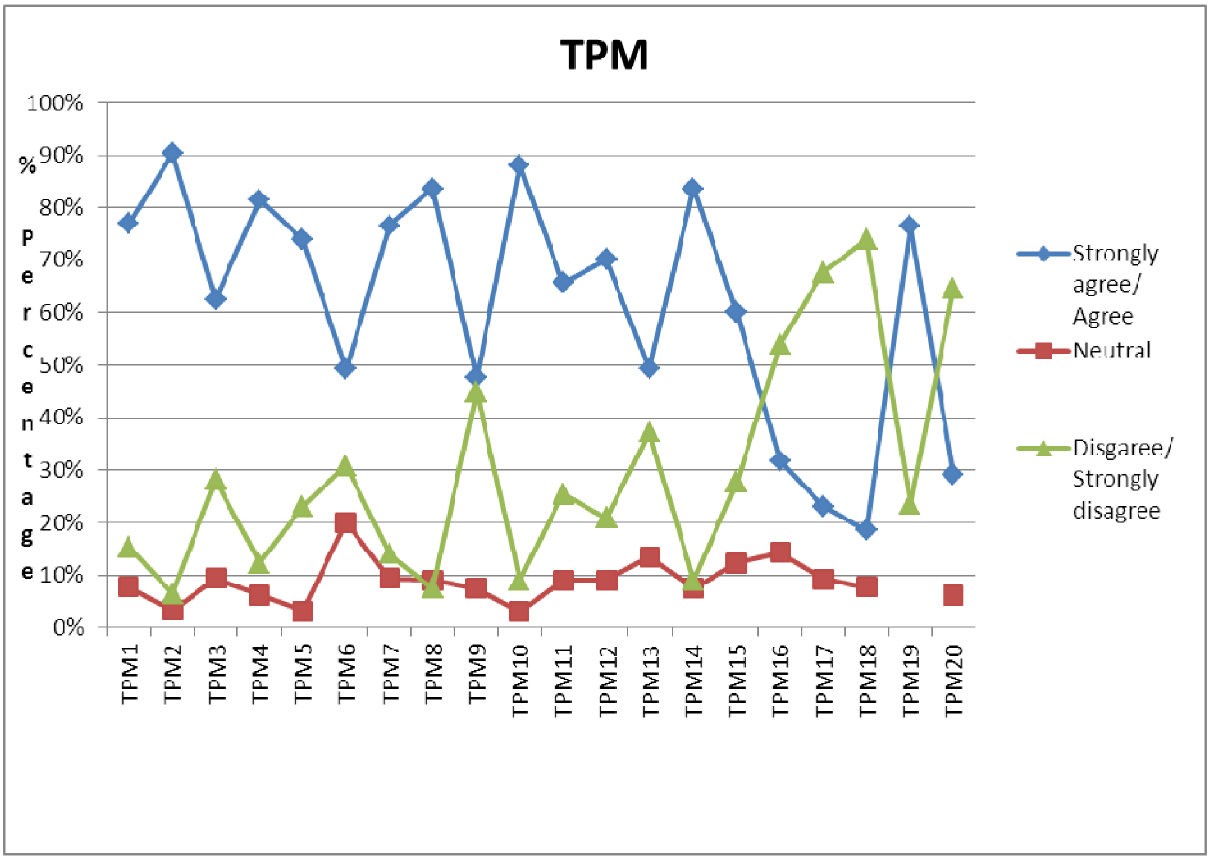
4.2.3.1 Total Productive Maintenance (TPM)

Table 4.7: TPM survey results

No.	Statement	Strongly agree/ Agree	Neutral	Disagree/ Strongly disagree
TPM1	Maintenance is practised by small groups	76.9%	7.7%	15.4%
TPM2	A maintenance system is implemented company wide	90.3%	3.2%	6.5%
TPM3	Maintenance involves all employees	62.5%	9.4%	28.1%
TPM4	Planned preventative maintenance is conducted	81.5%	6.2%	12.3%
TPM5	My team is involved in improvement of equipment condition	73.9%	3.1%	23.1%
TPM6	Daily cleaning, lubrication and inspection of all equipment are conducted	49.2%	20.0%	30.8%
TPM7	Minor stoppages of equipment are recorded	76.6%	9.4%	14.1%
TPM8	All equipment breakdowns are recorded	83.6%	8.9%	7.5%
TPM9	I have access to a computerised maintenance system	47.8%	7.5%	44. 8%
TPM10	Safety information is displayed in my area	88.1%	3.0%	8.9%
TPM11	I received training to increase my skills for my current position	65. 7%	8.9%	25.4%
TPM12	My work environment allows me to perform my daily tasks to the best of my ability	70.1%	9.0%	20.9%
TPM13	I have received training of what TPM is about	49.3%	13.4%	37.3%
TPM14	I am aware what the purpose of autonomous maintenance is	83.6%	7.5%	8.9%
TPM15	My team has access to spares to repair an equipment failure	60.0%	12.3%	27.7%
TPM16	Equipment spare parts are readily available	31.8%	14.3%	53.9%
TPM17	I have received training in the replacement of spare parts	23.1%	9.2%	67.7%
TPM18	I have received training to use the stores management system of spares	18.5%	7.7%	73.8%
TPM19	I have received training in the safety system of equipment	76.6%		23.4%
TPM20	I received training on how to use a computerised maintenance system	29.2%	6.2%	64.6%

Source: Researcher's own construction from survey data

Figure 4.7: TPM survey results



Source: Researcher's own construction from survey data

From the graph in figure 4.7 and table 4.7 it can be seen that ten statements received strongly positive (70 per cent and above) responses. The statements are:

- TPM1: Maintenance is practised by small groups (76.92 per cent);
- TPM2: A maintenance system is implemented company wide (90.33 per cent);
- TPM4: Planned preventative maintenance is conducted (81.54 per cent);
- TPM5: My team is involved in improvement of equipment condition (73.85 per cent);
- TPM7 Minor stoppages of equipment are recorded (76.57 per cent);
- TPM8: All equipment breakdowns are recorded (83.58 per cent);
- TPM10: Safety information is displayed in my area (88.06 per cent);
- TPM12: My work environment allows me to perform my daily tasks to the best of my ability (70.15 per cent)
- TPM14: I am aware what the purpose of autonomous maintenance is (83.58 per cent);

- TPM19: I have received training in the safety system of equipment (76.56 per cent).

TPM1, TPM2 and TPM4 indicate that company management confirms that a maintenance system is implemented plant wide, practised by small groups and planned maintenance is conducted. TPM5, TPM12 and TPM14 indicate that management involves the respondents in equipment improvement, provides a good work environment and informed respondents what autonomous maintenance is about.

TPM7 and TPM8 indicate that all downtime is recorded. This is important in order to improve performance by analysing historical maintenance information. TPM10 and TPM19 indicate that safety is important and that respondents are aware and have been trained to work safe.

Three statements were rated over more than 50 per cent but less than 70 per cent which indicates that although positive, improvement can still be achieved. A significant amount of respondents do not agree with the statements. These statements are:

- TPM3: Maintenance involves all employees;
- TPM11: I received training to increase my skills for my current position;
- TPM15: My team has access to spares to repair an equipment failure.

Most respondents, 62.49 per cent, agree with statement TPM3 that all employees should be involved with maintenance but 28.12 per cent disagree that it is the case. Management still needs to get all employees involved with maintenance of the equipment.

A total of 65.67 per cent respondents agree with statement TPM11 and 25.38 per cent disagrees. This indicates that most respondents have received training to increase their skills but not everyone. Management should make it a priority to ensure all employees are trained to improve their skills.

A total of 60 per cent of respondents agree with statement TPM15 that they have access to spares for repairs but 27.69 per cent disagrees. This could impact on the availability of the equipment if equipment cannot be repaired as quickly as possible due to the unavailability of spares.

There are seven statements statements which received responses below 50 per cent. These statements are:

- TPM6: Daily cleaning, lubrication and inspection of all equipment are conducted;
- TPM9: I have access to a computerised maintenance system;
- TPM13: I have received training of what TPM is about;
- TPM16: Equipment spare parts are readily available;
- TPM17: I have received training in the replacement of spare parts;
- TPM18: I have received training to use the stores management system of spares;
- TPM20: I received training on how to use a computerised maintenance system.

The results of these statements will be analysed individually.

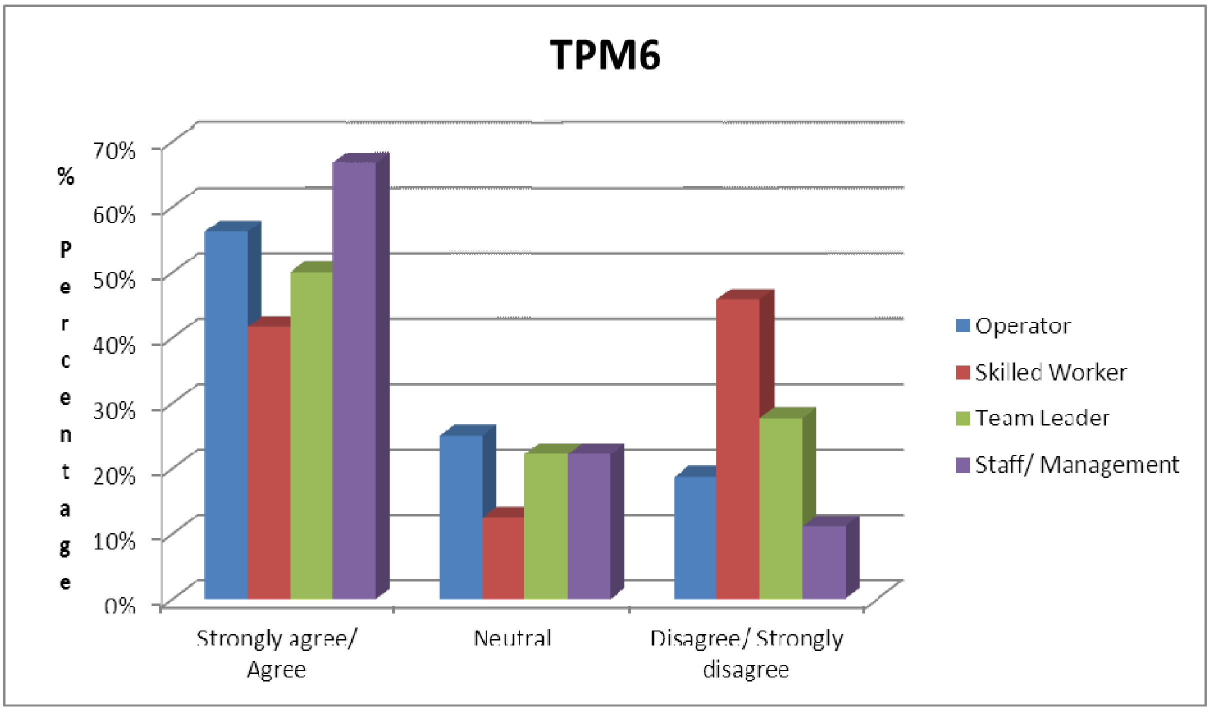
TPM6: Daily cleaning, lubrication and inspection of all equipment are conducted

Table 4.8: TPM6 survey results

TPM6	Strongly agree/ Agree	Neutral	Disagree/ Strongly disagree
Operator	56.3% (9)	25.0% (4)	18.7% (3)
Skilled Worker	41. 7% (10)	12.5% (3)	45.8% (11)
Team Leader	50.0% (9)	22.2% (4)	27.8% (5)
Staff/ Management	66. 7% (6)	22.2% (2)	11.1% (1)

Source: Researcher’s own construction from survey data

Figure 4.8: TPM6 survey results



Source: Researcher's own construction from survey data

The results in table 4.8 and figure 4.8 show the respondents are divided on whether autonomous maintenance is conducted. The previous results in TPM14 indicated that 83.58 per cent of the respondents are aware what the purpose of autonmous maintenance is. This indicate that the respondents are able to recognise if autonomous maintenance are conducted.

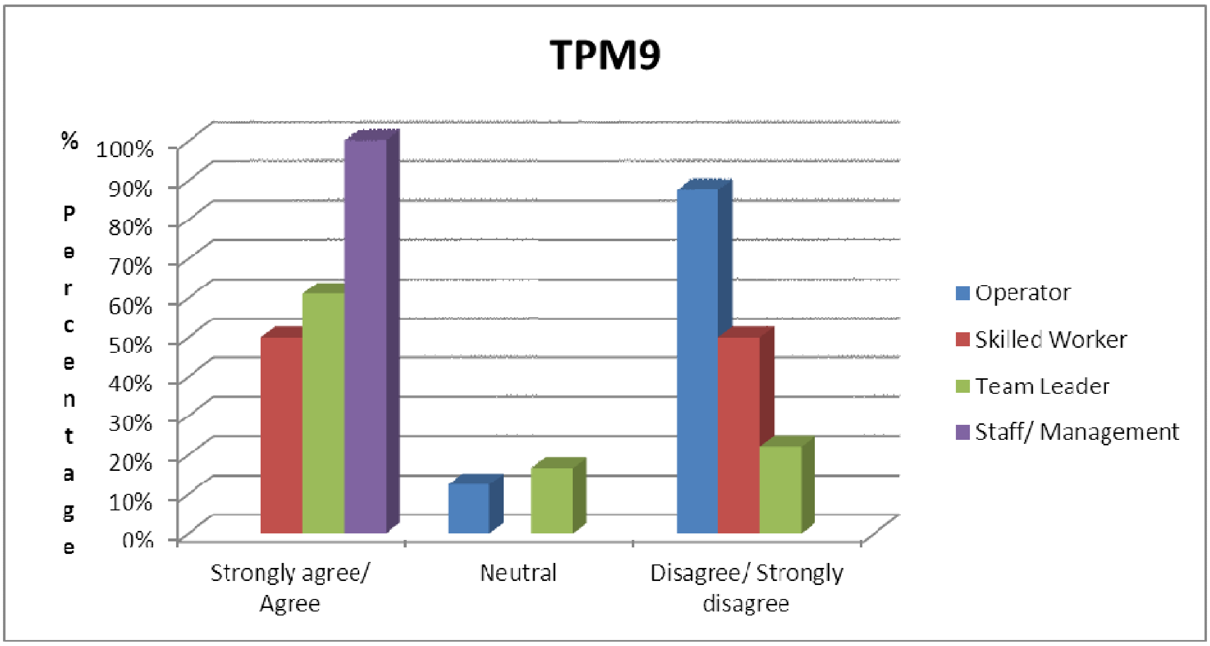
In analysing the results for the individual groups it is evident that the biggest group, the skilled workers, do not entirely believe that autonomous maintenance is conducted. The results show that 41.67 per cent agree and 45.83 per cent disagree. All the other groups showed stronger agreement than the skilled workers.

TPM9: I have access to a computerised maintenance system

Table 4.9: TPM9 survey results

TPM9	Strongly agree/ Agree	Neutral	Disagree/ Strongly disagree
Operator		12.5% (2)	87.5% (14)
Skilled Worker	50.0% (12)		50.0% (12)
Team Leader	61.1% (11)	16. 7% (3)	22.2% (4)
Staff/ Management	100.0% (9)		

Source: Researcher's own construction from survey data
Figure 4.9: TPM9 survey results



Source: Researcher's own construction from survey data

The results in table 4.9 and figure 4.9 indicate that all the operators and half of the skilled workers do not have access to a computerised maintenance system. Most of the team leaders, staff and management have access to a computerised management system. The structure of the company does not allow access to operators to the computerised maintenance system. The operators report all downtime to the team leader who will log it on the maintenance system. It is also not a requirement that the skilled workers should have access to the computerised maintenance system. The skilled workers also report to a technical team leader who will log all maintenance tasks on the system.

What is of concern is that seven of the team leaders do not have access to the computerised maintenance system. It is important that all team leaders must have access to the system. As mentioned before the operator will report breakdowns and maintenance requests to the production team leader who will need to report and raise a work order on the system. The technical team leader will issue a job card to the skilled worker through the system and capture the completion of the job. If the team leaders do not follow this system, important maintenance information would not be captured and stored for analysis and used for improvement.

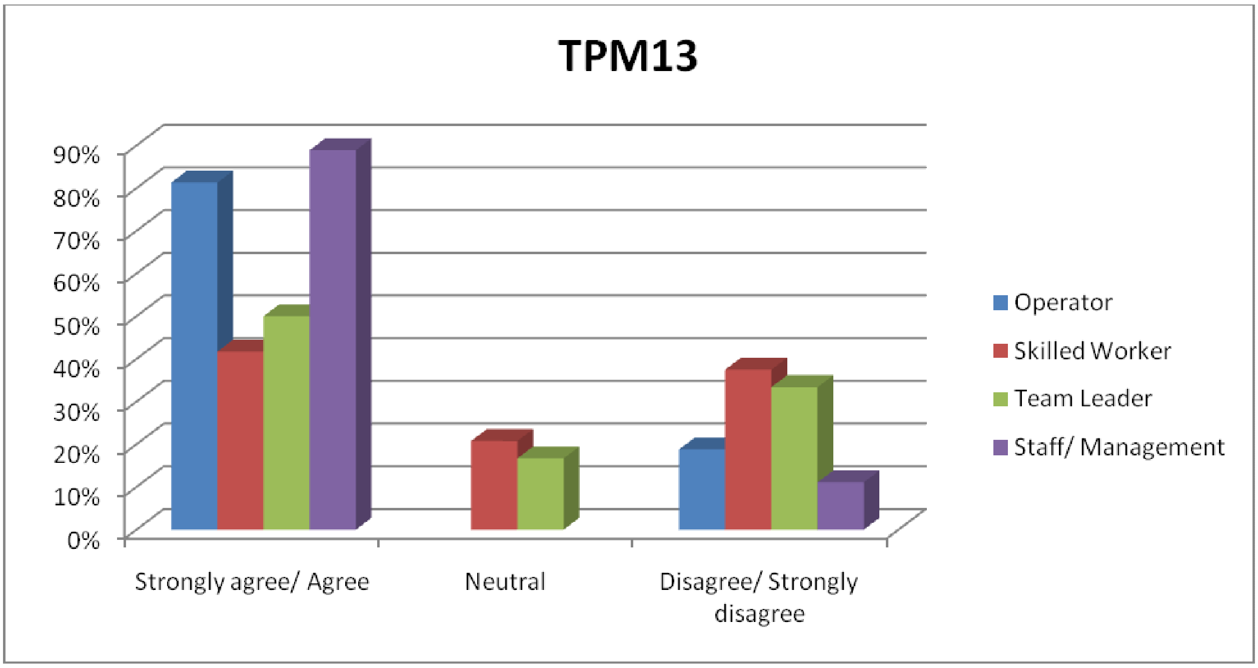
TPM13: I have received training of what TPM is about

Table 4.10: TPM13 survey results

TPM13	Strongly agree/ Agree	Neutral	Disagree/ Strongly disagree
Operator	81.3% (13)		18.8% (3)
Skilled Worker	41.7% (10)	20.8% (5)	37.5% (9)
Team Leader	50.0% (9)	16.7% (3)	33.4% (6)
Staff/ Management	88.9% (8)		11.1% (1)

Source: Researcher's own construction from survey data

Figure 4.10: TPM13 survey results



Source: Researcher's own construction from survey data

The results show that most of the operators (81.3 per cent) and staff/ management (88.9 per cent) have received training of what TPM is about. What is of concern is that a significiant amount of the skilled workers (37.5 per cent) and team leaders (33.4 per cent) have not received training of what TPM is about. In order for them to apply TPM they need to know what it is about. It is therefore important that management ensure that all employees to be trained in TPM.

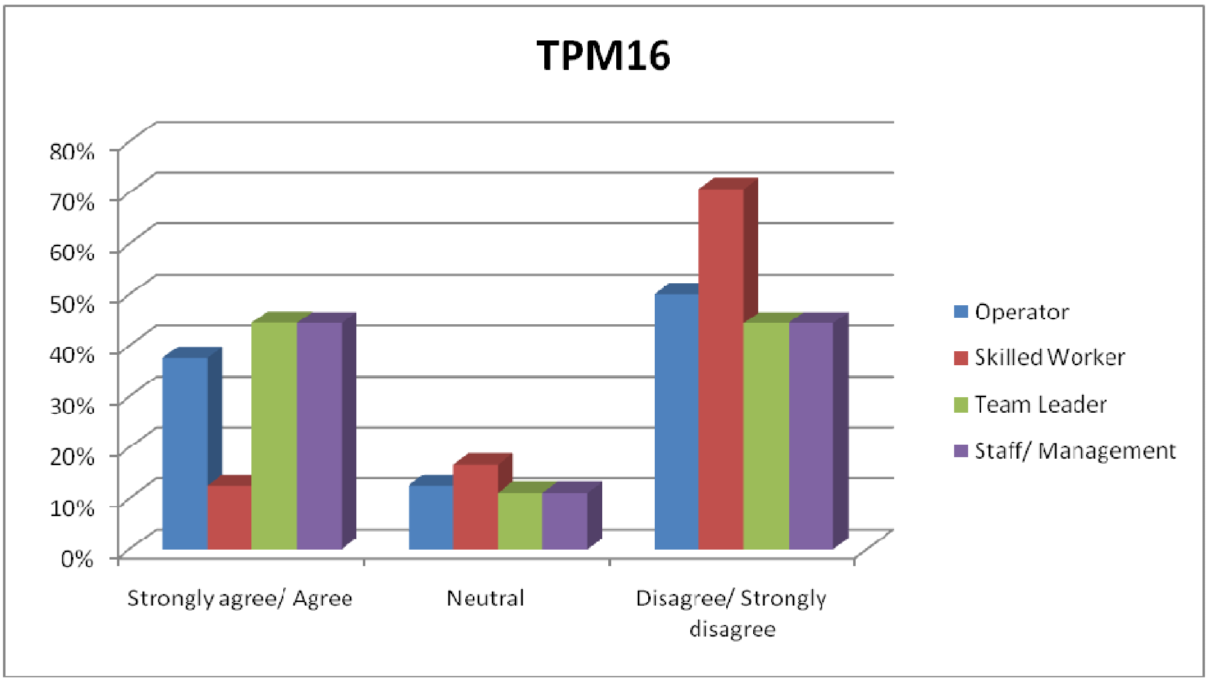
TPM16: Equipment spare parts are readily available

Table 4.11: TPM16 survey results

TPM16	Strongly agree/ Agree	Neutral	Disagree/ Strongly disagree
Operator	37.6% (6)	12.5% (2)	50.1% (8)
Skilled Worker	12.5% (3)	16.7% (4)	70.8% (17)
Team Leader	44.5% (8)	11.1% (2)	44.4% (8)
Staff/ Management	44.4% (4)	11.1% (1)	44.4% (4)

Source: Researcher's own construction from survey data

Figure 4.11: TPM16 survey results



Source: Researcher's own construction from survey data

Most of the respondents indicated that spares are not easily available for equipment repairs. Most significantly about 70 per cent of the group that is mostly involved with the repair of equipment do not agree that spares are available.

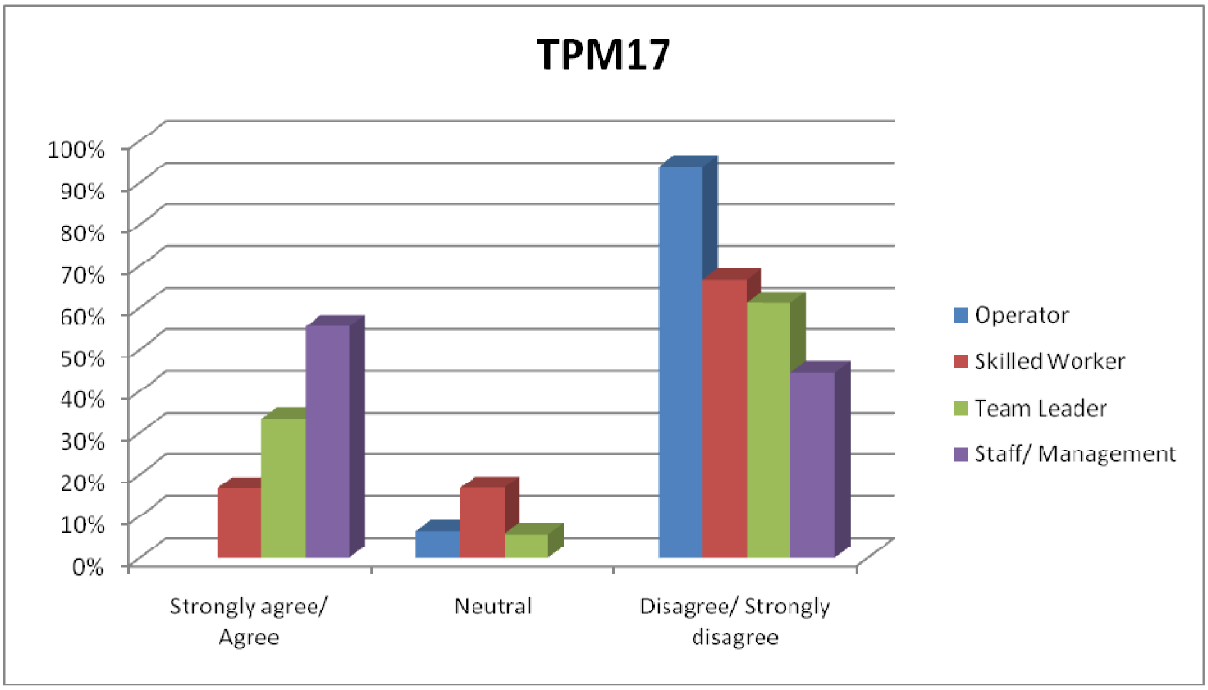
TPM17: I have received training in the replacement of spare parts

Table 4.12: TPM17 survey results

TPM17	Strongly agree/ Agree	Neutral	Disagree/ Strongly disagree
Operator		6.3% (1)	93.8% (15)
Skilled Worker	16.6% (4)	16.7% (4)	66.7% (16)
Team Leader	33.4% (6)	5.6% (1)	61.1% (11)
Staff/ Management	55.5% (5)		44.4% (4)

Source: Researcher's own construction from survey data

Figure 4.12: TPM17 survey results



Source: Researcher's own construction from survey data

Most of the operators, 93.8 per cent, have indicated that they have not received any training in the replacements of spare parts. It is not expected of the operators to repair equipment in the case of equipment failure. Management could train the operators to change spares as part of autonomous maintenance; for example air or oil filters. This will enable the skilled workers to concentrate on the more difficult tasks.

What should be of concern for management is that 66.7 per cent of the skilled workers have indicated that they have not received any training. It is important for repair men to know exactly how to repair equipment quickly to minimise downtime and MTTR.

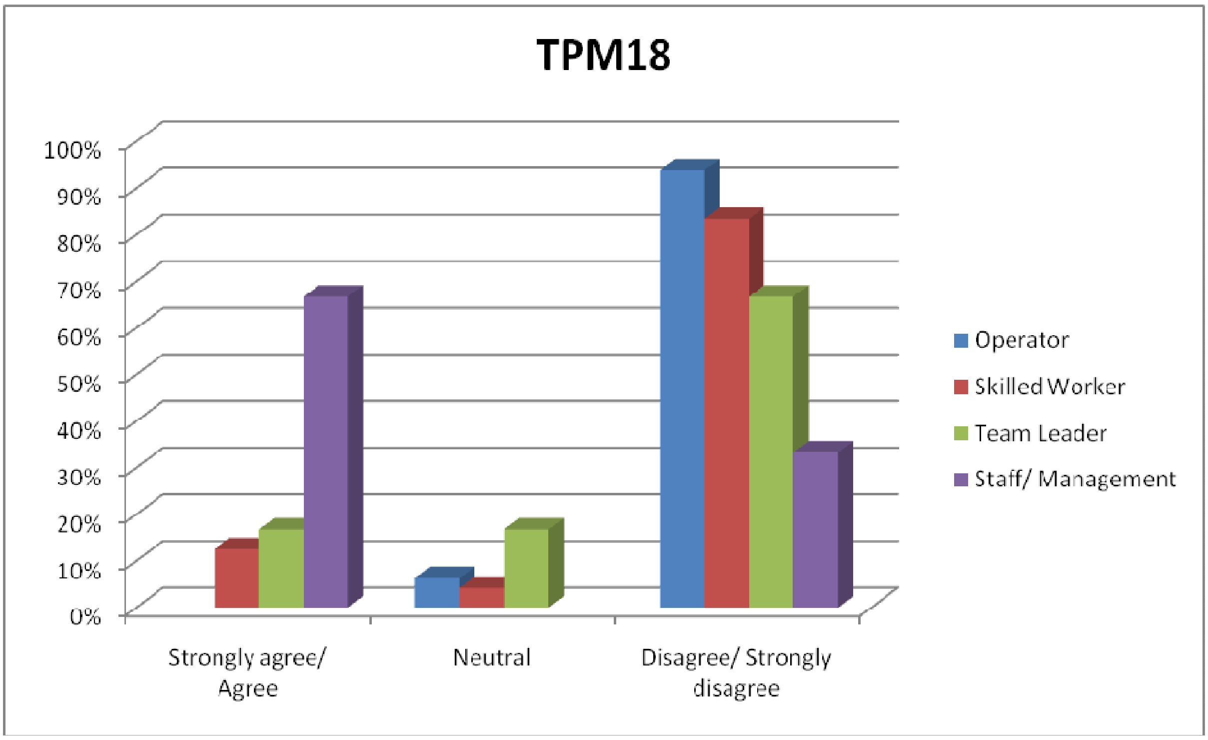
TPM18: I have received training to use the stores management system of spares

Table 4.13: TPM18 survey results

TPM18	Strongly agree/ Agree	Neutral	Disagree/ Strongly disagree
Operator		6.3%	93.8%
Skilled Worker	12.5%	4.2%	83.4%
Team Leader	16.7%	16.7%	66.7%
Staff/ Management	66.7%		33.3%

Source: Researcher's own construction from survey data

Figure 4.13: TPM18 survey results



Source: Researcher's own construction from survey data

Most of the operators, 93.8 per cent, and skilled workers, 83.4 per cent, indicated that they have not received training on how to use the stores management system of spares. It is not a requirement for operators and skilled workers to know how the spare stores system works. The team leaders are required to draw spares for equipment repairs from the store.

The results show that 66.7 per cent of the team leader respondents did not receive any training to use the the stores management system of spares. This should be a concern for management because the inability for team leaders to get spares for equipment repairs could impact on machine availability. Team leaders should be able to draw spares quickly to minimise downtime and MTTR.

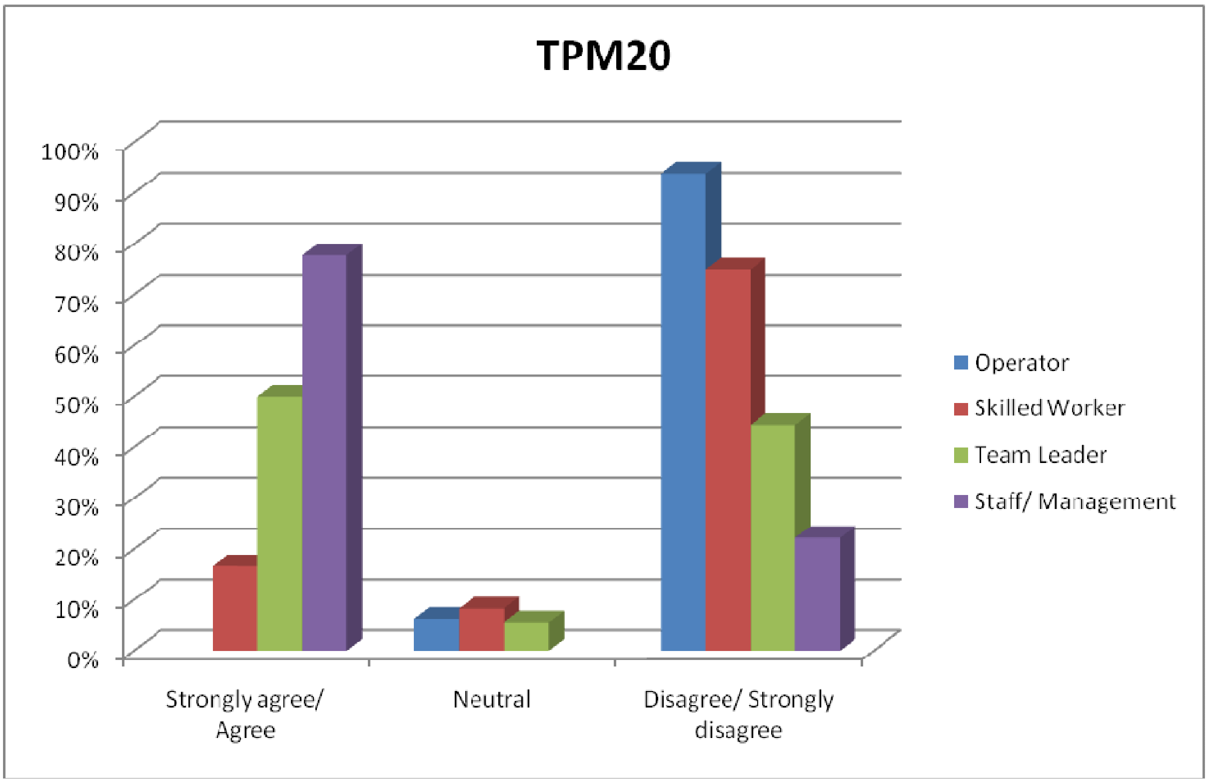
TPM20: I received training how to use a computerised maintenance system

Table 4.14: TPM20 survey results

TPM20	Strongly agree/ Agree	Neutral	Disagree/ Strongly disagree
Operator		6.3%	93.8%
Skilled Worker	16.6%	8.3%	75.0%
Team Leader	50.0%	5.6%	44.4%
Staff/ Management	77.8%		22.2%

Source: Researcher's own construction from survey data

Figure 4.14: TPM20 survey results



Source: Researcher's own construction from survey data

Most of the operators, 93.8 per cent, and skilled workers, 75 per cent, have indicated that they have not received training how to use a computerised maintenance

management system (CMMS). The company does not a require operators and skilled workers to have access and know how the CMMS works.
It is important for team leaders to know how to to use a CMMS in order to capture all maintenance information accurately. The results show that 44.4 per cent of the team leaders did not receive training on how to use a CMMS. Management should ensure that all team leaders know how to use a CMMS to prevent important maintenace information getting lost.

TPM Descriptive Statistics

Evans (2007) states that descriptive statistics refer to a collection of quantative measures and ways of describing data. Measures of central tendency provide estimates of a single value that represents ‘centering’ of data. The most common is the arithmetic mean which is the sum of the observations divided by the number of observations.

Dispersion refers to the degree of variation in the data. Several statistical measures characterise dispersion: the range, variance and standard deviation. The most popular measure of dispersion is the standard deviation which is defined as the square root of the variance. The standard deviation provides an indication of where the majority of data are clustered around the mean.

The results from the statistical analyses confirms the findings in the previous section. In table 4.15, very positive statements, TPM1, TPM2, TPM4, TPM5, TPM7, TPM8, TPM10, TPM12, TPM14 and TPM19, have a high mean that is greater than 3.5. The standard deviation is small and varies between 0.84 and 1.12.

The positive results, TPM3, TPM11 and TPM15, that can still be improved have a mean that is between 3.28 and 3.5. The standard deviation varies between 1.09 and 1.21.

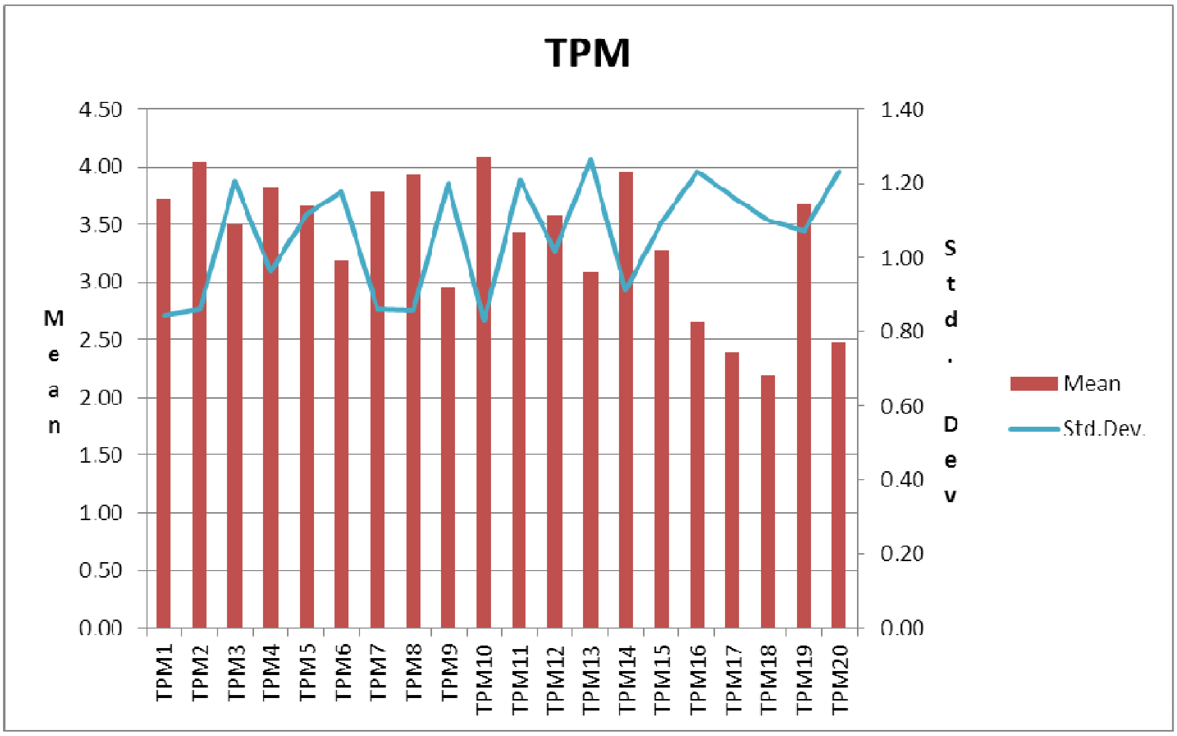
The less positive results, TPM6, TPM9, TPM13, TPM16, TPM17, TPM18 and TPM20, have a low mean, less than 3.18 and as low as 2.18. The standard devation varies between 1.10 and 1.26.

Table 4.15: TPM Descriptive Statistics results

	Valid N	Mean	Minimum	Maximum	Std.Dev.
TPM1	67	3.72	2	5	0.84
TPM2	67	4.05	1	5	0.86
TPM3	67	3.50	1	5	1.21
TPM4	67	3.83	1	5	0.96
TPM5	67	3.66	1	5	1.12
TPM6	67	3.18	1	5	1.18
TPM7	67	3.78	2	5	0.86
TPM8	67	3.93	1	5	0.86
TPM9	67	2.96	1	5	1.20
TPM10	67	4.09	2	5	0.83
TPM11	67	3.43	1	5	1.21
TPM12	67	3.58	1	5	1.02
TPM13	67	3.09	1	5	1.26
TPM14	67	3.96	1	5	0.91
TPM15	67	3.28	1	5	1.09
TPM16	67	2.65	1	5	1.23
TPM17	67	2.40	1	5	1.17
TPM18	67	2.18	1	5	1.10
TPM19	67	3.69	1	5	1.07
TPM20	67	2.48	1	5	1.23

Source: Researcher's own construction from survey data

Figure 4.15: TPM Descriptive Statistics results



Source: Researcher's own construction from survey data

Gliem and Gliem (2003) state that Inter-Item Correlations is descriptive information about the correlation of each item with the sum of all remaining items. A rule-of-thumb is that these values should be at least 0.40. Cronbach's alpha reliability coefficient normally ranges between 0 and 1. The closer Cronbach's alpha coefficient is to 1.0, the greater the internal consistency of the items in the scale. When using Likert-type scales it is imperative to calculate and report Cronbach's alpha coefficient for internal consistency reliability for any scales or subscales one may be using.

Table 4.16: TPM Cronbach's alpha results

Average inter-item corr.: 0.33		
	Itm-Totl	**Alpha if**
	Correl.	**deleted**
TPM1	-0.07	0.91
TPM2	0.53	0.90
TPM3	0.65	0.90
TPM4	0.60	0.90
TPM5	0.74	0.90
TPM6	0.71	0.90
TPM7	0.48	0.90
TPM8	0.59	0.90
TPM9	0.36	0.91
TPM10	0.48	0.90
TPM11	0.56	0.90
TPM12	0.61	0.90
TPM13	0.56	0.90
TPM14	0.62	0.90
TPM15	0.63	0.90
TPM16	0.51	0.90
TPM17	0.60	0.90
TPM18	0.62	0.90
TPM19	0.47	0.90
TPM20	0.58	0.90
Cronbach alpha: 0.91		

Source: Researcher's own construction from survey data

Table 4.16 shows the inter-item correlation value of TPM1 is -0.07. This means that the item is does not correlate well with the scale overall. The item was removed and the Cronbach alpha value improved from 0.9 to 0.91. The Cronbach alpha value of 0.91 indicates that there is a good degree of reliability.

Table 4.17 below depicts the OEE results with groupings: Strongly agree/ Agree; Neutral and Disagree/ Strongly disagree.

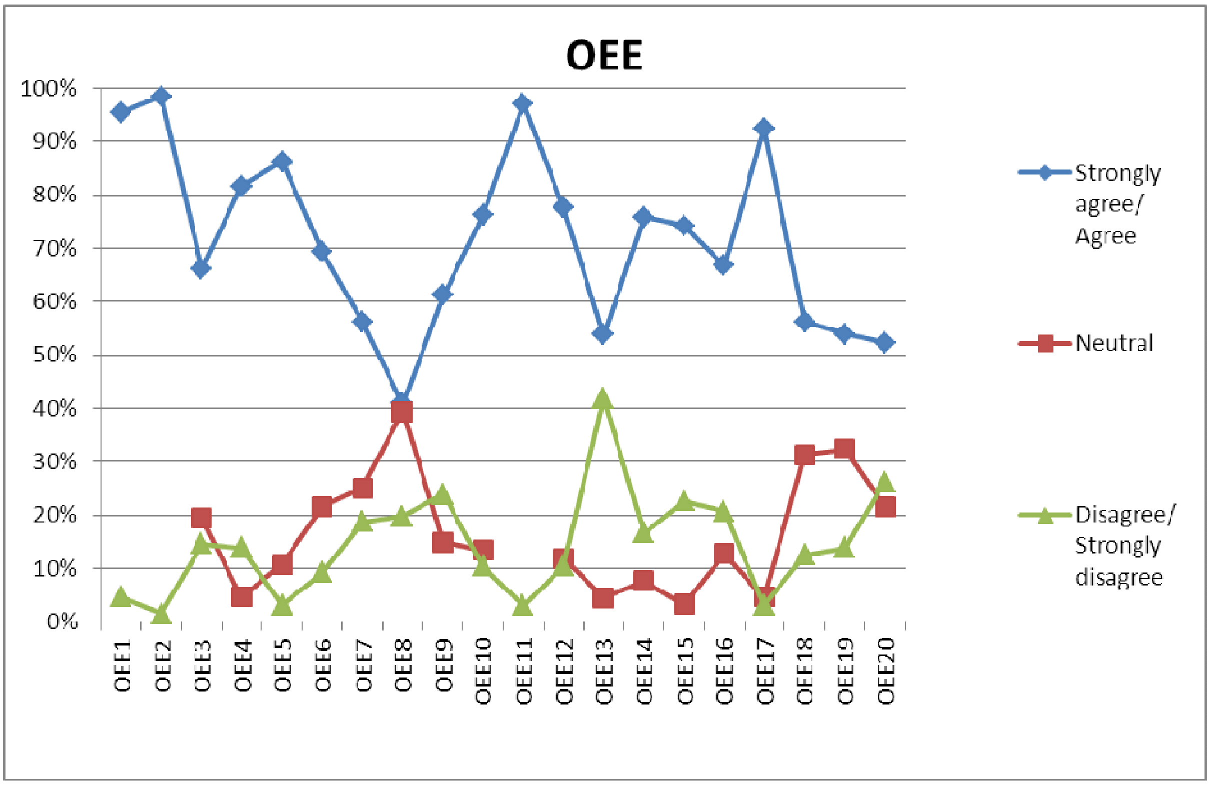
4.2.3.2 Overall Equipment Effectiveness (OEE)

Table 4.17: OEE results

No.	Statement	Strongly agree/ Agree	Neutral	Disagree/ Strongly disagree
OEE1	Production efficiency data are available for my area	95.4%		4.6%
OEE2	Maintenance can improve production efficiency	98.5%		1.5%
OEE3	Setup times are recorded	66.1%	19.4%	14.5%
OEE4	All downtime is recorded	81.5%	4.6%	13.9%
OEE5	All scrap production parts are recorded	86.2%	10.8%	3.1%
OEE6	All tooling losses are recorded	69.2%	21.5%	9.2%
OEE7	Designed operating speeds of equipment are available to view	56.3%	25.0%	18.7%
OEE8	Equipment is operating at less than designed speed	40.9%	39.4%	19.7%
OEE9	All employees have opportunity to give input to equipment efficiency improvement activities	61.2%	14.9%	23.9%
OEE10	Equipment efficiency improvement activities are conducted	76.1%	13.4%	10.5%
OEE11	Production data are displayed in my area	97.0%		3.0%
OEE12	Production equipment availability, performance data and quality rate are separately displayed	77.6%	11.9%	10.5%
OEE13	I have received training to read and analyse production data	53.7%	4.5%	41.8%
OEE14	My team gets regular feedback on production performance	75.8%	7.6%	16.7%
OEE15	My team gives input to improve production performance	74.2%	3.2%	22.6%
OEE16	My team uses problem-solving tools to improvement performance	66. 7%	12.7%	20.6%
OEE17	Autonomous maintenance can help to improve production performance	92.3%	4.6%	3.1%
OEE18	A change over management system is used to change production models	56.3%	31.2%	12.5%
OEE19	Change over times are recorded	53.9%	32.3%	13.8%
OEE20	In my area equipment focused improvement is applied to improve production performance	52.3%	21.5%	26.2%

Source: Researcher’s own construction from survey data

Figure 4.16: OEE results



Source: Researcher's own construction from survey data

The results show that the respondents agreed with ten statements very positively (over 70 per cent). These statements are:

- OEE1: Production efficiency data are available for my area (95.38 per cent);
- OEE2: Maintenance can improve production efficiency (98.46 per cent);
- OEE4: All downtime is recorded (81.54 per cent);
- OEE5: All scrap production parts are recorded (86.16 per cent);
- OEE10: Equipment efficiency improvement activities are conducted (76.12 per cent)
- OEE11: Production data is displayed in my area (97.01 per cent);
- OEE12: Production equipment availability, performance data and quality rate are separately displayed (77.61 per cent);
- OEE14: My team gets regular feedback on production performance (75.76 per cent);
- OEE15: My team gives input to improve production performance (74.19 per cent);
- OEE17: Autonomous maintenance can help to improve production performance (92.31 per cent).

OEE1, OEE11, OEE12 and OEE14 results show that the respondents are able to view their performance and get feedback on how they performed. This will encourage them to continuously improve performance. There are scoreboards on the lines and meeting rooms have performance charts.

OEE2 and OEE17 results show that the respondents believe that maintenance and autonomous maintenance can improve production performance. This shows that there is motivation for maintenance to be conducted.

OEE4 and OEE5 results show that the company records downtime and keep track of quality. This will enable the company to use the information to improve performance.

OEE10 and OEE15 results show that improvement activities are conducted and that the respondents are involved with these activities. Management have implemented improvement projects for all the teams.

Nine statements received responses above 50 per cent but less than 70 per cent which indicates that although positive, improvement can still be achieved. These questions are:

- OEE3: Setup times are recorded
- OEE6: All tooling losses are recorded
- OEE7: Designed operating speeds of equipment are available to view
- OEE9: All employees have opportunity to give input to equipment efficiency improvement activities
- OEE13: I have received training to read and analyse production data
- OEE16: My team uses problem-solving tools to improvement performance
- OEE18: A change over management system is used to change production models
- OEE19: Change over times are recorded
- OEE20: In my area equipment focused improvements are applied to improve production performance

OEE3 (66.13 per cent) and OEE6 (69.23 per cent) results show that respondents agree that setup time and tooling losses are recorded but 33.87 per cent (OEE3) and 31.77 per cent (OEE6) do not know or agree that these items are recorded. Improvement can still be made in the recording of these items for historical analysis.

OEE7 results show that 56.25 per cent agree that they are able to view the designed operating speed of the equipment, 25 per cent do not know and 18.75 per cent do not agree. To be able to view the designed operating speed will enable the employee to compare it with the actual operating speed to detect faults or hidden problems.

The results for OEE13 show that 53.13 per cent agree and 41.79 per cent do not agree with the statement. It is important for employees to be able to do analysis. If they are not able to read and analyse production data they cannot detect problems or improve on their performance.

The results for OEE9, OEE16 and OEE20 show that the respondents are part of production improvement activities and that structured methods are used. However improvement can still be achieved.

The results for OEE18 and OEE19 show that 31.25 per cent and 32.31 per cent of respondents do not know if model change overs are managed and the time recorded. If there is a system in place it is an opportunity for the company to educate all employees.

OEE8 is a negative statement to test if respondents do not follow a pattern in marking the questionnaire. The results show that 39.39 per cent do not know if equipment is operating at less than designed speed. This indicates that either the respondents did not understand the question or genuinely did not know the answer.

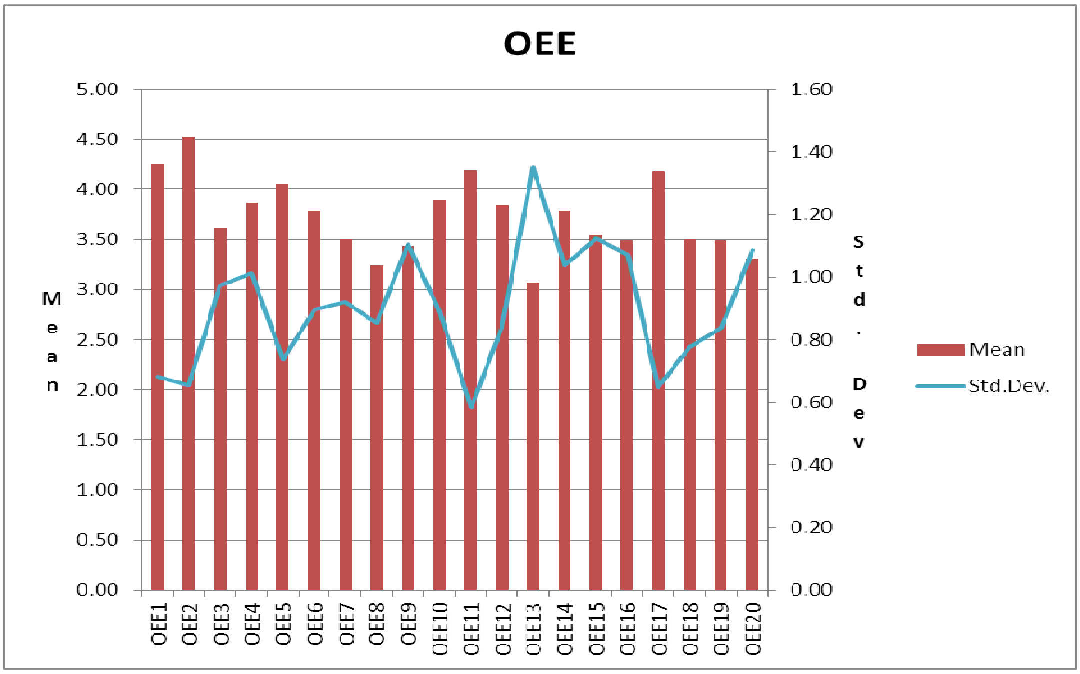
OEE Descriptive statistics

Table 4.18: OEE Descriptive statistics results

	Valid N	Mean	Minimum	Maximum	Std.Dev.
OEE1	67	4.26	2	5	0.68
OEE2	67	4.52	1	5	0.65
OEE3	67	3.61	1	5	0.97
OEE4	67	3.86	1	5	1.01
OEE5	67	4.06	1	5	0.74
OEE6	67	3.78	1	5	0.90
OEE7	67	3.50	2	5	0.92
OEE8	67	3.24	1	5	0.85
OEE9	67	3.43	1	5	1.10
OEE10	67	3.90	2	5	0.89
OEE11	67	4.19	2	5	0.58
OEE12	67	3.85	2	5	0.84
OEE13	67	3.07	1	5	1.35
OEE14	67	3.79	1	5	1.04
OEE15	67	3.55	1	5	1.12
OEE16	67	3.49	1	5	1.07
OEE17	67	4.18	2	5	0.65
OEE18	67	3.50	2	5	0.78
OEE19	67	3.49	2	5	0.84
OEE20	67	3.31	1	5	1.09

Source: Researcher's own construction from survey data

Figure 4.17: OEE Descriptive statistics results



Source: Researcher's own construction from survey data

The results from the statistical analyses confirm the findings in the previous section. The very positive statements, OEE1, OEE2, OEE4, OEE5, OEE6 OEE10, OEE11, OEE12, OEE14, OEE15 and OEE17, have a high mean that is greater than 3.55. The standard deviation is small and varies between 0.58 and 1.12.

The positive results, OEE3, OEE7, OEE9, OEE13, OEE16, OEE18, OEE19 and OEE20, that can still be improved have a mean that is between 3.07 and 3.61. The standard deviation varies between 0.78 and 1.35.

The less positive result, OEE8, has a low mean of 3.24 and the standard devation is 0.85.

Table 4.19: OEE Cronbach's alpha results

Average inter-item corr.: 0.32			
	Itm-Totl	**Alpha if**	
	Correl.	**deleted**	
OEE1	0.60	0.89	
OEE2	0.17	0.90	
OEE3	0.60	0.89	
OEE4	0.61	0.89	
OEE5	0.51	0.90	
OEE6	0.56	0.89	
OEE7	0.50	0.90	
OEE8	0.19	0.90	
OEE9	0.42	0.90	
OEE10	0.67	0.89	
OEE11	0.33	0.90	
OEE12	0.68	0.89	
OEE13	0.56	0.90	
OEE14	0.54	0.89	
OEE15	0.68	0.89	
OEE16	0.76	0.89	
OEE17	0.53	0.89	
OEE18	0.54	0.89	
OEE19	0.44	0.90	
OEE20	0.65	0.89	
Cronbach alpha: 0.90			
Items 2 and 8 deleted: alpha=0.91			

Source: Researcher's own construction from survey data

Table 4.19 showed the inter-item correlation value of OEE2 is 0.17 and OEE8 is 0.19. This means that the items do not correlate well with the scale overall. The items were removed and the Cronbach alpha value improved from 0.89 to 0.91. The Cronbach alpha value of 0.91 indicates that there is a good degree of reliability.

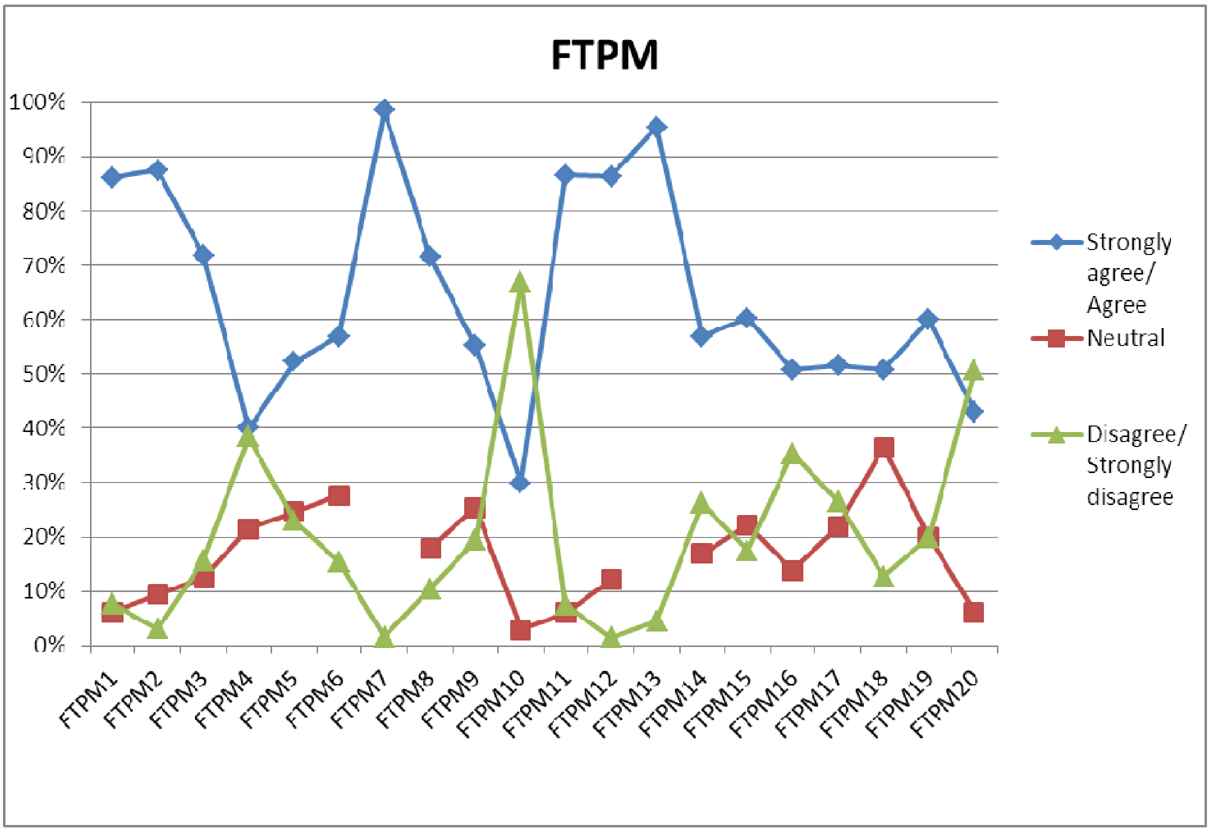
4.2.3.3 Ford Total Productive Maintenance (FTPM)

Table 4.20: FTPM survey results

No.	Statement	Strongly agree/ Agree	Neutral	Disagree/ Strongly disagree
FTPM1	FTPM is a work group effort	86.2%	6.1%	7.7%
FTPM2	Maintenance processes are documented	87.50%	9.4%	3.1%
FTPM3	Work groups are involved in equipment and process checks	71.9%	12.5%	15.6%
FTPM4	Maintenance tasks are scheduled and completed on time	40.0%	21.5%	38.5%
FTPM5	Failure Reporting and Corrective Action (FRACAS) procedures are adhered to.	52.3%	24.6%	23.1%
FTPM6	My team use computerised maintenance system to record safety issues	56.9%	27.7%	15.4%
FTPM7	Safety Notices and Lock Out Placards are visible on all equipment	98.5%		1.5%
FTPM8	All maintenance tasks are recorded	71.6%	17.9%	10. 5%
FTPM9	Autonomous maintenance is recorded in a computerised maintenance system	55.2%	25.4%	19.4%
FTPM10	I have received training on how to use a computerised maintenance system	29.9%	2.9%	67.2%
FTPM11	I am aware of my role and responsibilities in the maintenance of equipment	86.6%	5.9%	7.5%
FTPM12	The company has a predictive maintenance programme such as Vibration Analysis, Infrared Thermography, Oil Analysis	86.4%	12.1%	1.5%
FTPM13	I have received safety and environmental training	95.5%		4.5%
FTPM14	My team collect and analyse maintenance data	56.9%	16.9%	26.2%
FTPM15	All maintenance work is requested through the computerised maintenance system	60.3%	22.2%	17.5%
FTPM16	Maintenance data are displayed in my area	50.8%	13.9%	35.3%
FTPM17	Spare usage is controlled and logged	51.6%	21.9%	26.5%
FTPM18	My team uses historical maintenance data from the computerised maintenance system to improve equipment	50.8%	36.5%	12.7%
FTPM19	Daily autonomous maintenance of all equipment is conducted	60.0%	20.0%	20.0%
FTPM20	I have access to a computerised maintenance system	43.1%	6.2%	50.7%

Source: Researcher's own construction from survey data

Figure 4.18: FTPM survey results



Source: Researcher's own construction from survey data

From figure 4.18 and table 4.20 it can be seen that eight statements received very positive responses (over 70 per cent). The statements are:

- FTPM1: FTPM is a work group effort (86.16 per cent);
- FTPM2: Maintenance processes are documented (87.5 per cent);
- FTPM3: Work groups are involved in equipment and process checks (71.88 per cent);
- FTPM7: Safety Notices and Lock out Placards are visible on all equipment (98.46 per cent);
- FTPM8: All maintenance tasks are recorded (71.64 per cent);
- FTPM11: I am aware of my role and responsibilities in the maintenance of equipment (86.57 per cent);
- FTPM12: The Company has a predictive maintenance programme such as Vibration Analysis, Infrared Thermography, and Oil Analysis (86.36 per cent);
- FTPM13: I have received safety and environmental training (95.46 per cent).

The results for FTPM1 (86.16 per cent) and FTPM3 (71.88 per cent) show that the company uses a work group system for maintenance.

The results for FTPM2 (87.5 per cent) and FTPM8 (71.4 per cent) show that maintenance information is captured. This allows management to use the information for historical analyses.

The results for FTPM7 (98.46 per cent) and FTPM13 (95.46 per cent) show that the safety of employees is important for the company. Safety information is available to view and most of the respondents have received safety training.

The results for FTPM11 (86.57 per cent) show that the respondents understand their role and responsibilities in equipment maintenance. This is important for effective maintenance that there are clear roles and that there is no confusion.

The results for FTPM12 (86.36 per cent) show that there is a predictive maintenance programme in place. This allow for early detection of problems and to prevent downtime.

Nine statements were rated higher than 50 per cent but less than 70 per cent, which indicates that although positive, improvement can still be achieved. These questions are:

- FTPM5: Failure Reporting and Corrective Action (FRACAS) procedures are adhered to.
- FTPM6: My team use computerised maintenance system to record safety issues
- FTPM9: Autonomous maintenance is recorded in a computerised maintenance system
- FTPM14: My team collect and analyse maintenance data
- FTPM15: All maintenance work is requested through the computerised maintenance system
- FTPM16: Maintenance data are displayed in my area
- FTPM17: Spare usage is controlled and logged

- FTPM18: My team uses historical maintenance data from the computerised maintenance system to improve equipment
- FTPM19: Daily autonomous maintenance of all equipment is conducted

The results for FTPM5 and FTPM17 show that 52.31 per cent and 51.56 per cent respectively of the respondents agree that the FRACAS procedure are followed and that spare usage is controlled. Respectively, 23.07 per cent and 26.57 per cent do not agree with the statements. This indicates that not all employees are ensuring that the information of spare usage is recorded. A requirement of the FRACAS procedure is to analyse and record equipment failures.

The results for FTPM6 (56.93 per cent), FTPM9 (55.23 per cent) and FTPM15 (60.32 per cent) show that just more than half of the respondents agree to using a computerised maintenance system for the statements. This indicates that a significant amount of FTPM6 (43.07 per cent), FTPM9 (44.77 per cent) and FTPM15 (39.68 per cent) respondents do not know or do not agree that safety issues, autonomous maintenance and maintenance work are recorded through a computerised maintenance system (CMMS). This indicates that important information could get lost because it is not recorded.

The results for FTPM14 (56.92 per cent), FTPM16 (50.77 per cent) and FTPM18 (50.79 per cent) show that just more than half of the respondents agree that maintenance data are collected, displayed and used for equipment improvement. To get value from the computerised maintenance system, more must be done to record maintenance data and analyse historical data for equipment improvement.

The results for FTPM19 show that 60 per cent of respondents agree that autonomous maintenance is conducted and 20 per cent do not agree. This indicates that although autonomous maintenance is conducted not all employees are doing it.

Three statement results are less positive with less than 50 per cent of respondents agreeing. These statements are:

- FTPM4: Maintenance tasks are scheduled and completed on time;

- FTPM10: I have received training on how to use a computerised maintenance system;
- FTPM20: I have access to a computerised maintenance system.

The results for these statements will be analysed further.

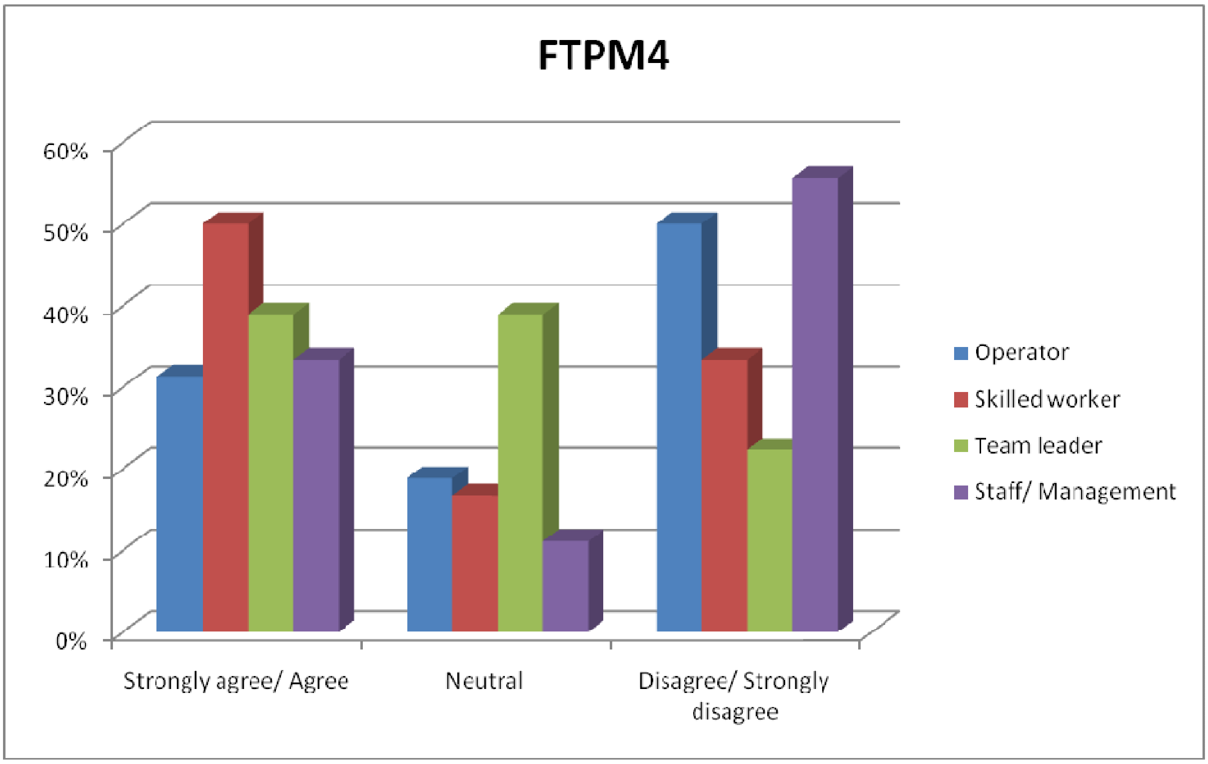
FTPM4: Maintenance tasks are scheduled and completed on time

Table 4.21: FTPM4 survey results

FTPM4	Strongly agree/ Agree	Neutral	Disagree/ Strongly disagree
Operator	31.30%	18.80%	50.00%
Skilled worker	50.00%	16.70%	33.30%
Team leader	38.90%	38.90%	22.30%
Staff/ Management	33.30%	11.10%	55.60%

Source: Researcher's own construction from survey data

Figure 4.19: FTPM4 survey results



Source: Researcher's own construction from survey data

The results for FTPM4 shows that half or more of the operators (50 per cent) and staff/ management (55.6 per cent) respondents do not agree that maintenance tasks are scheduled and completed on time. Half of the skilled worker (50 per cent) respondents agree. This shows that many skilled workers who are primary responsible for maintenance tasks think they complete maintenance tasks on time. Operators, staff and management do not believe it is true.

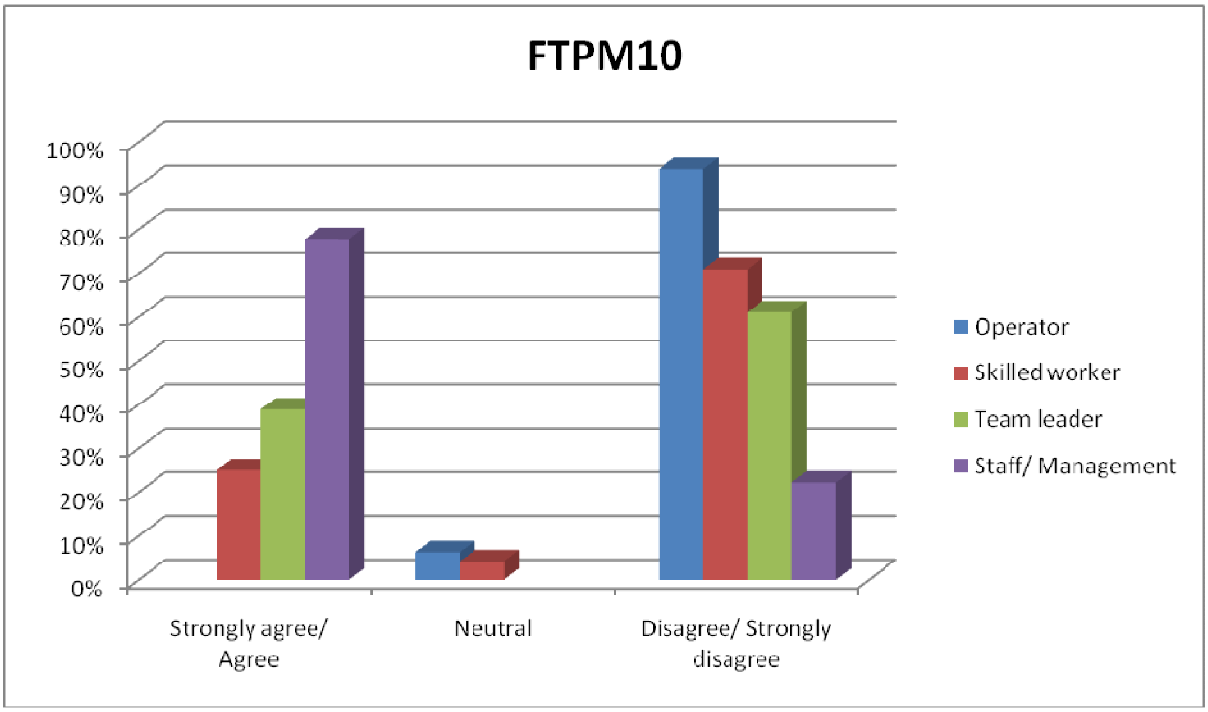
FTPM10: I have received training on how to use a computerised maintenance system

Table 4.22: FTPM10 survey results

FTPM10	Strongly agree/ Agree	Neutral	Disagree/ Strongly disagree
Operator		6.30%	93.80%
Skilled worker	25.00%	4.20%	70.90%
Team leader	38.90%		61.10%
Staff/ Management	77.80%		22.20%

Source: Researcher's own construction from survey data

Figure 4.20: FTPM10 survey results



Source: Researcher's own construction from survey data

The results show that the majority of the operators (93.8 per cent) and skilled workers (70.9 per cent) did not receive training on how to use a computerised maintenance system (CMMS). It is, however, not required for them to use a CMMS.

It is important for the team leader group to know how to use a CMMS. The team leaders have to record all maintenance information. The results show that 61.1 per cent of team leader respondents do not agree with the statement that they have received training. This is a concern, as if they cannot use CMMS, they cannot do the required recording.

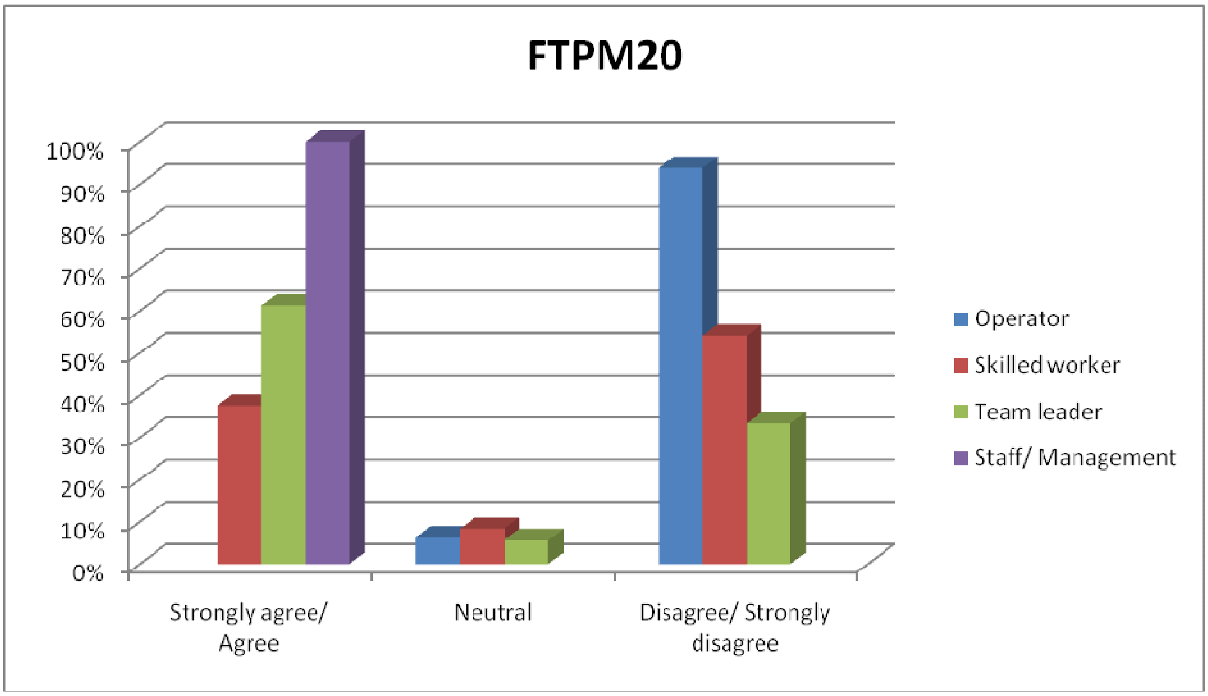
FTPM20: I have access to a computerised maintenance system

Table 4.23: FTPM20 survey results

FTPM20	Strongly agree/ Agree	Neutral	Disagree/ Strongly disagree
Operator		6.30%	93.80%
Skilled worker	37.50%	8.30%	54.10%
Team leader	61.20%	5.60%	33.30%
Staff/ Management	100.00%		

Source: Researcher's own construction from survey data

Figure 4.21: FTPM20 survey results



Source: Researcher's own construction from survey data

The results are similar to that of statement FTPM10 and shows that the majority of the operators (93.8 per cent) and skilled workers (54.1 per cent) do not have access to a computerised maintenance system (CMMS). It is, however, not required for them to have access to a CMMS.

As mentioned before it is important for the team leader group to have access to a CMMS. The team leaders have to record all maintenance information. The results show that 33.3 per cent of respondents do not agree with the statement.

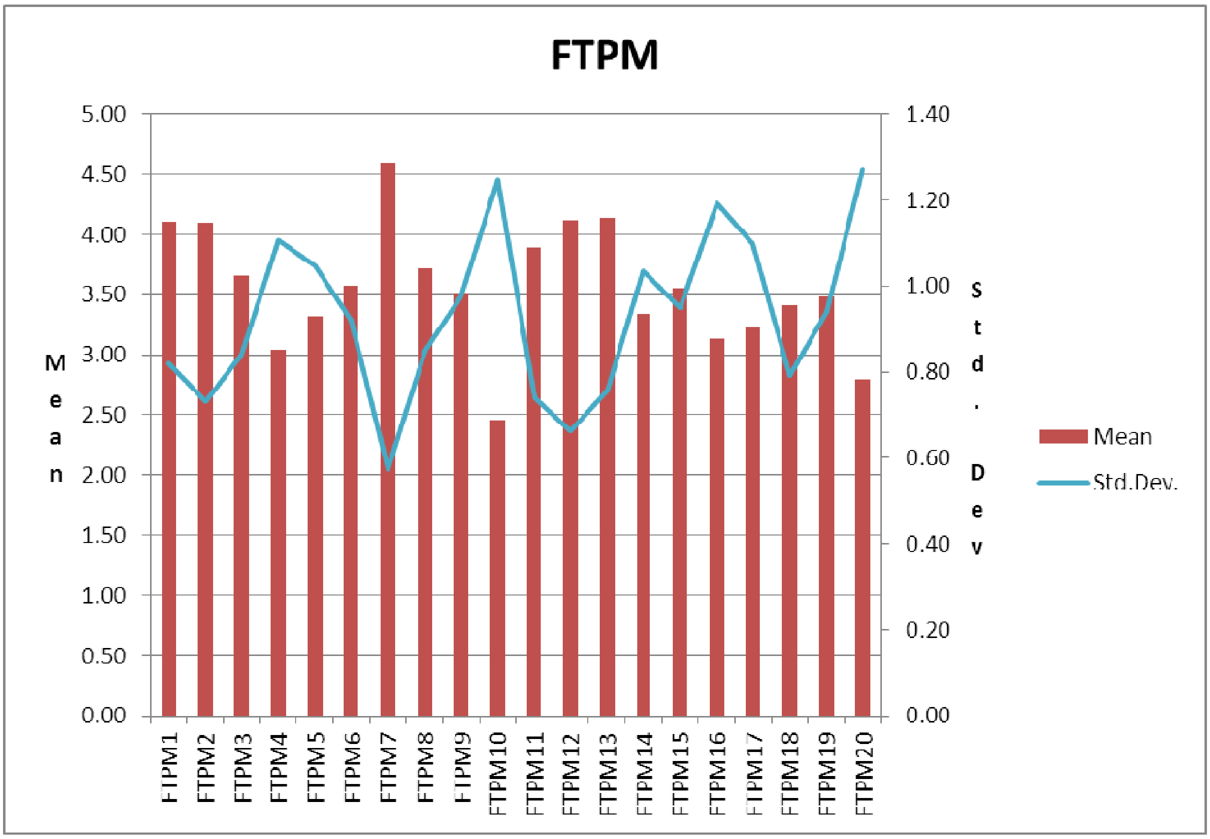
FTPM Descriptive Statistics

Table 4.24: FTPM Descriptive Statistics results

	Valid N	Mean	Minimum	Maximum	Std.Dev.
FTPM1	67	4.11	2	5	0.82
FTPM2	67	4.09	1	5	0.73
FTPM3	67	3.66	2	5	0.84
FTPM4	67	3.05	1	5	1.11
FTPM5	67	3.32	1	5	1.05
FTPM6	67	3.57	2	5	0.92
FTPM7	67	4.58	2	5	0.57
FTPM8	67	3.72	1	5	0.85
FTPM9	67	3.51	2	5	0.98
FTPM10	67	2.46	1	5	1.25
FTPM11	67	3.90	1	5	0.74
FTPM12	67	4.12	2	5	0.66
FTPM13	67	4.14	1	5	0.76
FTPM14	67	3.34	1	5	1.03
FTPM15	67	3.56	1	5	0.95
FTPM16	67	3.14	1	5	1.19
FTPM17	67	3.23	1	5	1.10
FTPM18	67	3.41	1	5	0.79
FTPM19	67	3.48	1	5	0.94
FTPM20	67	2.80	1	5	1.27

Source: Researcher's own construction from survey data

Figure 4.22: FTPM Descriptive Statistics results



Source: Researcher's own construction from survey data

The results from the statistical analyses confirms the findings in the previous section. The very positive statements, FTPM1, FTPM2, FTPM3, FTPM7, FTPM8 FTPM11, FTPM12 and FTPM13, have a high mean that is greater than 3.66. The standard deviation is small and varies between 0.57 and 0.85.

The positive results, FTPM5, FTPM6, FTPM9, FTPM14, FTPM15, FTPM16, FTPM17, FTPM18 and FTPM19, that can still be improved have a mean that is between 3.14 and 3.57. The standard deviation varies between 0.79 and 1.19.

The less positive results, FTPM4, FTPM10 and FTPM20, have a low mean, less than 3.05 and as low as 2.46. The standard devation varies between 1.11 and 1.27.

Table 4.25: FTPM Cronbach alhha results

Average inter-item corr.: 0.27		
	Itm-Totl	**Alpha if**
	Correl.	**deleted**
FTPM1	0.47	0.87
FTPM2	0.51	0.87
FTPM3	0.65	0.86
FTPM4	0.56	0.87
FTPM5	0.63	0.86
FTPM6	0.69	0.86
FTPM7	0.23	0.88
FTPM8	0.59	0.87
FTPM9	0.48	0.87
FTPM10	0.45	0.87
FTPM11	0.49	0.87
FTPM12	0.35	0.87
FTPM13	0.32	0.87
FTPM14	0.44	0.87
FTPM15	0.50	0.87
FTPM16	0.45	0.87
FTPM17	0.39	0.87
FTPM18	0.45	0.87
FTPM19	0.51	0.87
FTPM20	0.42	0.87
Cronbach alpha: 0.87		

Source: Researcher's own construction from survey data

Table 4.25 show the inter-item correlation value of FTPM7 is 0.23. This means that the item does not correlate well with the scale overall. The item was removed and the Cronbach alpha value did not change. The Cronbach alpha value of 0.87 indicates that there is a reasonable degree of reliability.

4.2.4 Combined Analysis

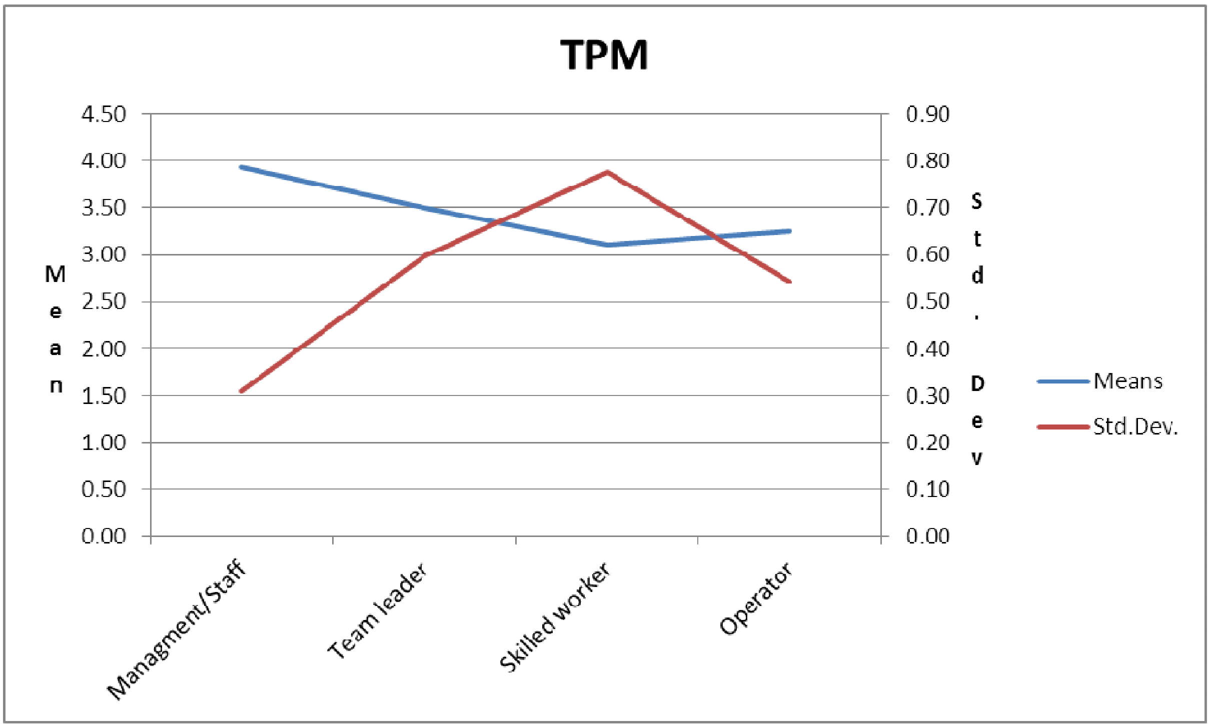
4.2.4.1 Descriptive Statistics

Table 4.26: TPM Breakdown of Descriptive Statistics

Position	**TPM score**	**TPM score**	**TPM score**
	Means	N	Std.Dev.
Management/Staff	3.93	9	0.31
Team leader	3.49	18	0.60
Skilled worker	3.10	24	0.78
Operator	3.25	16	0.54
All Groups	**3.35**	**67**	**0.68**

Source: Researcher's own construction from survey data

Figure 4.23: TPM Breakdown of Descriptive Statistics



Source: Researcher's own construction from survey data

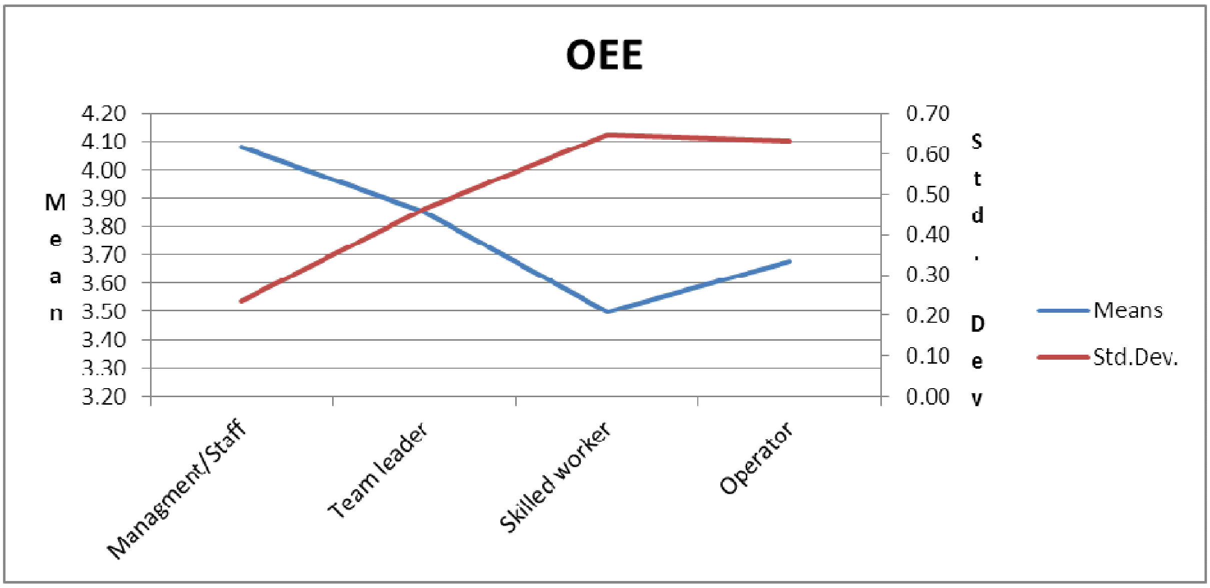
The TPM results of each group of respondents in table 4.23 show the mean, number of responses and the standard deviation. The staff/ management group have the highest mean and lowest standard deviation. This means they have answered most of the questions positively. The skilled worker group have the lowest mean and the higest deviation. This indicates they have answered most of the questions negatively.

Table 4.27: OEE Breakdown of Descriptive Statistics

Position	OEE score	OEE score	OEE score
	Means	N	Std.Dev.
Management/Staff	4.08	9	0.24
Team leader	3.85	18	0.46
Skilled worker	3.50	24	0.65
Operator	3.68	16	0.63
All Groups	**3.71**	**67**	**0.58**

Source: Researcher's own construction from survey data

Figure 4.24: OEE Breakdown of Descriptive Statistics



Source: Researcher's own construction from survey data

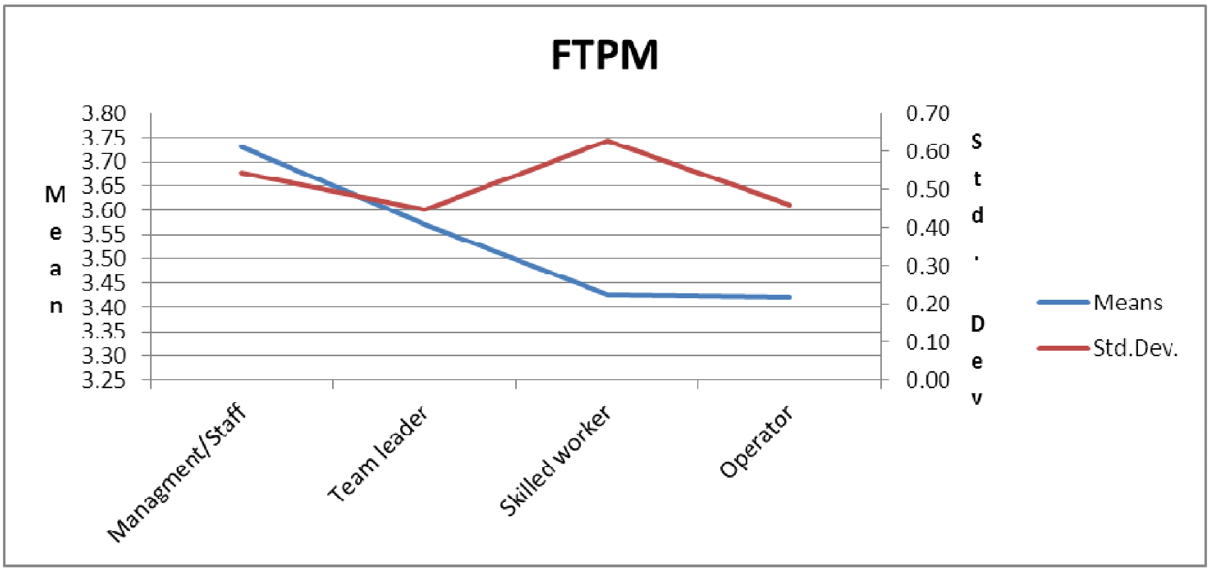
The OEE results show that again the staff/ management group have the highest mean and lowest standard deviation. This means they have answered most of the questions positively. The skilled worker group again have the lowest mean and the higest deviation. This indicates they have answered most of the questions negatively.

Table 4.28: FTPM Breakdown of Descriptive Statistics

Position	FTPM score	FTPM score	FTPM score
	Means	N	Std.Dev.
Management/Staff	3.73	9	0.54
Team leader	3.57	18	0.45
Skilled worker	3.43	24	0.63
Operator	3.42	16	0.46
All Groups	**3.50**	**67**	**0.53**

Source: Researcher's own construction from survey data

Figure 4.25: FTPM Breakdown of Descriptive Statistics



Source: Researcher's own construction from survey data

The FTPM results show that again the staff/ management group have the highest mean and a low but not the lowest standard deviation. This means they have answered most of the questions positively. The skilled worker group have a low but not lowest mean and the higest deviation. This indicates they have answered most of the questions negatively.

The results from the three tables and graphs show a trend between staff/ management and skilled worker respondents. The staff management group responded most positively while the skilled worker group were the most negative.

4.2.4.2 Exploratory Analysis

Pohlmann (2004) states that factor analysis is a collection of statistical methods used to:

- Analyse patterns in a correlation matrix;
- Reduce large numbers of variables to a smaller number of components or factors;
- Simplify analyses of highly correlated independent variables;
- Explore observed data for the presence of theoretical variables, and
- Test hypotheses about theoretical variables.

Exploratory factor analysis is used to gain insight into the structure or underlying processes that explain a collection of variables. The term structure describes the relationships between latent variables and measured variables.

Evans (2007) states that analysis of variance (ANOVA) examines the variation among and within groups or factor levels.

Forza (2002) explains that analysis of variance (ANOVA) is to see whether there are significant mean differences among more than two groups, to see where the difference lies. Tests like Sheffe's test, Duncan Multiple Range test, Tukey's test, and student-Newman-Keul's test are available.

A two-way ANOVA was conducted, that examined the effect of TPM, OEE and FTPM on whether TPM is effectively applied at the company. The results are displayed in table 4.29.

Table 4.29: Overall Score ANOVA analysis results

Analysis of Variance								
Marked effects are significant at p < .05000								
	SS	**df**	**MS**	**SS**	**df**	**MS**	**F**	**p**
	Effect	**Effect**	**Effect**	**Error**	**Error**	**Error**		
TPM score	5.05	3	1.68	25.16	63	0.40	4.22	0.0088
OEE score	2.71	3	0.90	19.72	63	0.31	2.89	0.0426
FTPM score	0.80	3	0.27	18.00	63	0.29	0.94	0.4283

Source: Researcher's own construction from survey data

The result from table 4.29 show that there is significantly interaction between the effects of TPM ($p = 0.0088 < 0.0500$) and OEE ($p = 0.0426 < 0.0500$) on whether TPM is effectively applied. The interaction of FTPM ($p = 0.4283 > 0.0500$) on whether TPM is effectively applied is not significant.

To analyse the effects of TPM and OEE further, a Scheffe test was conducted for each to see if the interaction between groups has an effect on whether TPM is effectively applied. The results are displayed in tables 4.30 and 4.31.

Table 4.30: TPM Scheffe test results

Scheffe Test; Variable: TPM score				
Marked differences are significant at p < .05000				
	Management/Staff {1}	Team leader {2}	Skilled worker {3}	Operator {4}
	M=3.9301	M=3.4950	M=3.1026	M=3.2456
Management/Staff {1}				
Team leader {2}	0.42276			
Skilled worker {3}	0.01539	0.27518		
Operator {4}	0.09085	0.72542	0.92029	

Source: Researcher's own construction from survey data

Table 4.31: OEE Scheffe test results

Scheffe Test; Variable: OEE score				
Marked differences are significant at p < .05000				
	Management/Staff {1}	Team leader {2}	Skilled worker {3}	Operator {4}
	M=4.0802	M=3.8519	M=3.4962	M=3.6775
Management/Staff {1}				
Team leader {2}	0.80132			
Skilled worker {3}	0.07819	0.25534		
Operator {4}	0.40096	0.84361	0.79943	

Source: Researcher's own construction from survey data

The only significant result can be seen in table 4.30 in the interaction between staff/ management group and skilled workers where $p = 0.01539 < 0.0500$. This indicates that the interaction between staff/ management and the skilled workers on TPM will have a significant effect whether TPM is effectively applied in the company.

4.3 SUMMARY

A questionnaire survey was conducted and the responses were entered in Excel. The results from Excel and Statistica were compiled.

The questionnaire consisted of three sections: first a covering letter, secondly Section A which was classification information and thirdly Section B which contained the main questions. The classification information in Section A consisted of six questions designed to measure the demographics of the sample. Section B was grouped in three sections namely: Total Productive Maintenance (TPM), Overall Equipment Effectiveness (OEE) and Ford Total Productive Maintenance (FTPM).

The survey was conducted at the three Puma component machining lines; namely, Cylinder Block line, Cylinder Head line and Cylinder Crank line and also the Puma Engine Assembly line.

The results were tabled and graphically displayed for analysis. Descriptive statistics and exploratory analysis were used.

In the next chapter the empirical results will be used to draw conclusions and make recommendations.

CHAPTER FIVE
CONCLUSIONS AND RECOMMENDATIONS

5.1 INTRODUCTION

In the previous chapter the results of the empirical study was discussed and analysed. In this chapter the literature review and empirical results will be used to draw conclusions of the main problem and the sub-problems and to make recommendations.

In Chapter One the main problem was: **If Total Productive Maintenance (TPM) was effectively applied at an automotive engine plant**. To address the main problem statement, sub-problems addressed were:

- What the literature reveals about TPM, OEE and FTPM;
- If the FTPM function is effectively applied;
- If Autonomous maintenance is effectively applied;
- If there is efficient planning for spare availability; and
- If the Computerised Maintenance Management System (CMMS) is efficiently utilised.

Each of these sub-problems will be discussed in this chapter to answer the main problem.

5.2 LITERATURE REVIEW

The literature study was conducted in Chapter Two discussing three concepts TPM, OEE and FTPM. These three concepts were identified in the sub-problems that address the main problem.

The TPM literature revealed the background and various definitions of TPM. The definition that best addressed this study was by Shirose (1992):

- It aims at getting the most efficient use of equipment (that is overall efficiency)

- It establishes a total (companywide) preventive maintenance system encompassing maintenance prevention, preventive maintenance and improvement-related maintenance.
- It requires the participation of equipment designers, equipment operators and maintenance department workers.
- It involves every employee from top management down.
- It promotes and implements PM based on autonomous, small group activities.

This definition covered all aspects of this study.

In small group activities the importance of autonomous maintenance was discussed. Autonomous maintenance activities will ensure that minor stoppages are prevented and early detection of problems. This is done by daily cleaning, lubrication and tightening and inspection of equipment.

The importance of planned maintenance to prevent equipment failure was discussed. This will increase the availability of equipment for production.

The importance of effective usage of a Computerised Maintenance Management System (CMMS) was discussed. A CMMS will enhance planned maintenance in that maintenance activities are recorded and historical maintenance data can be used for analysis to improve equipment.

The literature study revealed that Overall Equipment Effectiveness (OEE) is a measure that shows how well the equipment is running. OEE is used in TPM to indicate how effectively machines are running. Three factors are used to determine OEE and the factors are **Performance, Availability** and **Quality.**

The formula to calculate OEE:

OEE = availability x performance x quality

This study focused on availability and the factors that impact on availability. These factors contribute to downtime losses and some of them are equipment failures, setup time and tool losses. Ways to improve OEE were discussed and they included improvement approaches and tools such as 5 Why analysis, focused equipment improvement and quick changeovers.

Ford Total Productive Maintenance (FTPM) was discussed and it is one element of Ford Production Systems (FPS) that is a lean, flexible and disciplined production system. FTPM is the concept of a never-ending improvement process that is included in maintenance activities with the goal of improving quality of products and productivity. FTPM is defined as a work group centred effort to eliminate the major losses in production and manufacturing equipment through the seven steps of TPM.

FTPM is achieved through the application of planned maintenance, autonomous maintenance and a maintenance management system. Planned maintenance is achieved by having a maintenance organisation with supporting structure, planning and inspection, scheduling and completion of tasks, verification and optimisation of tasks and data collection, analysis and document control.

5.3 FTPM FUNCTION

One of the sub-problems of this study was to investigate if the FTPM function is effectively applied. A section of the questionnaire survey was to measure the FTPM function. The empirical results are an indication if the function is effectively applied.

From the survey results it was found that eight FTPM statements received positive responses (over 70 per cent). The best FTPM responses were about safety information and training, maintenance tasks that are captured and documented and that work groups are implemented and functioning.

Nine statements were rated higher than 50 per cent but less than 70 per cent, which indicates that although positive, it can still be improved. Important responses that require attention are about autonomous maintenance, spare usage control and collection and use of maintenance historical data.

Three statements results were less positive with less than 50 per cent of respondents agreeing. These statements are:

- FTPM4: Maintenance tasks are scheduled and completed on time;
- FTPM10: I have received training how to use a computerised maintenance system;
- FTPM20: I have access to a computerised maintenance system.

The three statements that were answered negatively indicate that there is a problem with the scheduling and completion of the maintenance tasks. This also reveals that training how to use a computerised maintenance system and access to a CMMS for team leaders needs to be improved.

The results from the descriptive statistics showed that the group that impacts most negatively on FTPM was the skilled worker group. It is therefore important for management to engage with skilled workers to ensure FTPM is effective. The results from the exploratory analysis showed that FTPM did not impact negatively on whether TPM is effectively applied.

In conclusion the research indicates that the FTPM is functioning but can improve specifically by providing training and managing the computerised maintenance management system.

5.4 AUTONOMOUS MAINTENANCE

Autonomous maintenance was measured in all three of the sections. The results are displayed in table 5.1. Five statements were used to measure autonomous maintenance.

Table 5.1: Autonomous maintenance results

No.	Statement	Strongly agree/ Agree	Neutral	Disagree/ Strongly disagree
TPM6	Daily cleaning, lubrication and inspection of all equipment are conducted	49%	20%	31%
TPM14	I am aware what the purpose of autonomous maintenance is	84%	7%	9%
OEE17	Autonomous maintenance can help to improve production performance	92%	5%	3%
FTPM9	Autonomous maintenance is recorded in a computerised maintenance system	55%	25%	19%
FTPM19	Daily autonomous maintenance of all equipment is conducted	60%	20%	20%

Source: Researcher's own construction from survey data

The results indicate that most of the respondents are aware of what the purpose of autonomous maintenance is and agree that it can help to improve production performance. There is, however, a significant portion of the respondents that do not agree that autonomous maintenance is conducted. In Chapter Four, in the TPM analysis, it was found that the majority of the skilled workers are the ones that do not agree.

The data also show that not all autonomous maintenance tasks are recorded in a computerised maintenance system. The purpose of recording autonomous maintenance in a CMMS, as revealed in the FTPM section of Chapter Two, is for lubrication management to identify products and frequency and also to use scheduled cleaning as inspection time and record the results.

It is important for the company to ensure that effective implementation of autonomous maintenance takes place and to involve skilled worker with coaching and training of operators. Skilled workers will then have first-hand knowledge if autonomous maintenance is conducted.

5.5 SPARES MANAGEMENT

The results of the statements that measured spares management are displayed in table 5.2. Five statements were asked to measure spares management.

Table 5.2: Spares management results

No.	Statement	Strongly agree/ Agree	Neutral	Disagree/ Strongly disagree
TPM16	Equipment spare parts are readily available	32%	14%	54%
TPM17	I have received training in the replacement of spare parts	23%	9%	68%
TPM18	I have received training to use the stores management system of spares	18%	8%	74%
FTPM5	Failure Reporting and Corrective Action (FRACAS) procedures are adhered to.	52%	25%	23%
FTPM17	Spare usage is controlled and logged	52%	22%	27%

Source: Researcher's own construction from survey data

The results show that the availability of spares is a problem. The response to TPM16 shows that 54 per cent of respondents do not agree that spares are available for equipment repairs. One of the factors, described in Chapter Two, that affects availability is equipment failure and repair time is affected by the availability of spares. Mean time to repair (MTTR) is also affected by the knowledge of repair men to replace spares and to identify the correct spare.

Spare usage, as discussed in the FTPM section of Chapter Two, must also be tracked and recorded. This allows for analysis to be used for preventative maintenance and timeously replacement.

The results indicate that spares management must be addressed as an urgent concern.

5.6 COMPUTERISED MAINTENANCE MANAGEMENT SYSTEM (CMMS)

The results of the statements that measured effective utilisation of CMMS are displayed in table 5.3. Six statements were asked to effective utilisation of CMMS.

Table 5.3: CMMS results

No.	Statement	Strongly agree/ Agree	Neutral	Disagree/ Strongly disagree
TPM9	I have access to a computerised maintenance system	48%	7%	45%
TPM20	I received training on how to use a computerised maintenance system	29%	6%	65%
FTPM9	Autonomous maintenance is recorded in a computerised maintenance system	55%	25%	19%
FTPM10	I have received training on how to use a computerised maintenance system	30%	3%	67%
FTPM18	My team use historical maintenance data from the computerised maintenance system to improve equipment	51%	37%	13%
FTPM20	I have access to a computerised maintenance system	43%	6%	51%

Source: Researcher's own construction from survey data

The results show that training to use and access to a CMMS was consistently answered negatively. In Chapter Four in the analysis of statements TPM9, TPM20, FTPM10 and FTPM20, it was stated that the majority of respondents who answered negatively were the operators and skilled workers. Those two groups, however, do not require having training and access to use a CMMS. There was evidence that the team leaders who require it the most, have not all been trained and do not all have access to a CMMS.

The results also show that half or more respondents used historical maintenance data to improve equipment. Extra effort should be made to ensure data are recorded and the information used for analysis.

Management should ensure that all team leaders are trained and have access to a computerised maintenance management system.

5.7 MAIN PROBLEM

Based on the empirical results and addressing sub-problems this research study found that TPM is functioning but it can be improved.

5.8 RECOMMENDATIONS

The following recommendations are made for management to consider:

- Ensure autonomous maintenance activities are conducted by all relevant personnel and include skilled workers to coach and train operators.
- Ensure an effective spares management system for spares availability and usage analysis
- Provide training for all team leaders on how to use a computerised maintenance management system (CMMS).
- Provide access for relevant personnel to use a computerised maintenance management system (CMMS).

5.9 RESEARCH PROBLEMS AND LIMITATIONS

No major problems were encountered in this study. Literature information was easily available. Company management provided access to respondents although a higher response rate would have been preferred.

5.10 OPPORTUNITIES FOR FUTURE RESEARCH

Opportunities for future research proposed by the researcher could include the following:

- Skilled workers motivation;
- Effective spares management system;
- Investigation to improve effective usage of a computerised maintenance management system (CMMS);

REFERENCE LIST

Babbitt, B. A. and Nystrom, C.O. 1989. Questionnaire Construction Manual. *U.S. Army Research Institute for the Behavioral and Social Sciences*, pp 22333-5600.

Bacula, V. 2008. Developing Planned Maintenance For The Shop. *American Machinist* [Online]. Available from: http://americanmachinist.com/shop-operations/developing-planned-maintenance-shop (accessed 12 March 2012).

Bagadia, K. 2008. Turning maintenance into a profit center with CMMS. *Plant Engineering* [Online]. Available from: http://www.plantengineering.com/single-article/turning-maintenance-into-a-profit-center-with-cmms/ (accessed 12 March 2012).

Bagadia, K. 2009a. CMMS: 7 Steps to success. *Plant Engineering* [Online]. Available from: http://www.plantengineering.com/cmms-7-steps-to-success/ (accessed 12 March 2012).

Bagadia, K. 2009b. Mobilize your assets. *Plant Engineering* [Online]. Available from: http://www.csemag.com/mobilize-your-assets/ (accessed 12 March 2012).

Bartlett, J. E., Kotrlik, J. W., Higgins, C. C. 2001. Organizational Research: Determining Appropriate Sample Size in Survey Research. *Information Technology, Learning, and Performance Journal*, 19 (1), 43 - 50.

Branska, L. 2011. Maintenance Management in quick response systems. *Economics and Management*. 16, 676 – 682.

Collis, J. and Hussey, R. 2009. *Business Research. A Practical Guide for Undergraduate and Postgraduate Students.* Place: Palgrave Macmillan.

Evans, J.R. 2007. *Statistics, Data Analysis, and Decision Modeling*. Place: Pearson Prentice Hall.

Forza, C., 2002. Survey research in operations management: a process-based perspective. *International Journal of Operations & Production Management*, 22 (2), 152-194.

Franz, J. 2000. FPS *@FordOnline* [Online] Available from: http://www.at.ford.com/Pages/default.aspx (accessed 12 March 2012).

Fredendall, L.D., Patterson, J.W., Kennedy, W.J. and Griffin, T. 1997. Maintenance: Modeling Its Strategic Impact. *Journal of Managerial Issues*, 9 (4).

Gliem, J.A. and Gliem, R.R. 2003. *Calculating, Interpreting, and Reporting Cronbach's Alpha Reliability Coefficient for Likert-Type Scales*. Presented at the Midwest Research-to-Practice Conference in Adult, Continuing, and Community Education, The Ohio State University, Columbus, Ohio.

Idhammar, T. 2004. Maintenance Management Legends. *Plant Engineering* [Online]. Available from: http://www.plantengineering.com/maintenance-management-legends/ (accessed 12 March 2012).

Koen, P-J. 2009. *An Investigation into the main causes for poor OEE at the Struandale Engine Plant of Ford Motor Company of Southern Africa.* Unpublished MBA Treatise. Nelson Mandela Metropolitan University. Port Elizabeth.

Lyles, B.D. 1984. An Innovative Approach to Planned Maintenance. *Journal Water Pollution Control Federation*, 56 (5), 408 – 416.

Nakajima, S. 1988. *Introduction to total productive maintenance (TPM).* Cambridge, MA: Productivity Press.

Pinsonneault, A. and Kraemer, K. L. 1992. Survey Research Methodology In Management Information Systems: An Assessment. *Journal of Management Information Systems*. 10, 75 – 105.

Peng, K. 2005. A new era dawns. *IEE Manufacturing Engineer*. 84 (4), 44 – 47.

Pfeil, G., Holcomb, R., Muir C.T. and Taj, S. 2000. Visteon's Sterling Plant Uses Simulation-Based Decision Support in Training, Operations, and Planning. *Interfaces*, 30 (1), 115 - 133

Pohlmann, J. T. 2004. Use and Interpretation of Factor Analysis in "The Journal of Educational Research":1992–2002. *The Journal of Educational Research*, 98 (1), pp. 14-22.

Rich, N. 1999. *Total Productive Maintenance: The Lean Approach*. Wirral, England: Tudor Business Publishing Limited.

Seth, D. and Tripath, D. 2006. A Critical Study of TQM and TPM Approaches on Business Performance of Indian Manufacturing Industry. *Total Quality Management,* 17 (7), 811–824.

Sharma, R. and Yetton, P. 2003. The Contingent Effects of Management Support and Task Interdependence on Successful Information Systems Implementation*. Management Information Systems Quarterly*, 27 (4), 533 – 556.

Shirose, K. 1992. *TPM for Workshop Leaders.* New York: Productivity Press.

Sills, S. and Song, C. 2002. Innovations in Survey Research: An Application of Web-Based Surveys. *Social Science Computer Review*, 20 (1), 22 - 30.

Swanson. L. 2001. Linking maintenance strategies to performance. *International Journal of Production Economies*. 70, 237 - 244

The Productivity Development Team. 1999. *OEE for Operators.* New York: Productivity Press.

Qweleka, S. 2009. *The Factors that hinder the Overall Equipment Effectiveness at Ford Struandale Engine Pant.* Unpublished MBA Treatise. Nelson Mandela Metropolitan University. Port Elizabeth.

Venkatesh, J. 2005. An Introduction to Total Productive Maintenance (TPM). *The Plant Maintenance Resource Center* [Online] Available from: http://www.plant-maintenance.com/articles/tpm_intro.shtml (accessed 12 March 2012).

Weinsteina, L., Vokurkab, R.J. and Graman, G.A. 2009. Costs of quality and maintenance: Improvement approaches*. Total Quality Management,* 20 (5), 497 – 507.

ANNEXURE 1: PERMISSION LETTER AND QUESTIONNAIRE

Nelson Mandela Metropolitan University

for tomorrow

Dear Respondent

I am a post-graduate student studying towards my MBA (Masters in Business Administration) at the Nelson Mandela Metropolitan University Business School. The topic of my research project involves an investigation if **Total Productive Maintenance (TPM) is effectively applied at an Automotive Plant**. I believe that this study would contribute to increase the effectiveness of maintenance and improve production performance at the plant.

You are part of our selected sample of respondents whose views I seek on the above-mentioned matter. I would therefore appreciate it if you could answer a few questions in this regard, which should not take more than twenty minutes of your time. Please note that the information gathered will not be used against any person in any way and that all your responses will be strictly confidential. Please return the completed questionnaire by the 12th October 2012. I thank you in advance for your highly appreciated contribution towards this study.

There are no correct or incorrect answers. Please answer the questions as accurately as possible. For each statement, tick the column which best describes your experience. For example, if you strongly agree with the statement, tick the column far left. If you strongly disagree with the statement, tick the column far right. **Tick only one column for each statement, and please answer ALL QUESTIONS.**

Thank you.

Louis Wentzel

Cell phone: 082 457 1702

Work: ext. 164 or (041) 406 7164

Research supervisor: Mr Bux Heather

Cell phone: 082 809 5960

Questionnaire

Section A: Classification Information

1. In what age group are you?

18 - 20	
21 - 30	
31 - 40	
41 - 50	
51 - 60	
60+	

2. Gender?

Male	
Female	

3. What is your current position?

Operator	
Skilled worker (electrician, fitter, setter, technician)	
Team leader (Production, Maintenance)	
Salaried Staff (Supervisor, Coordinator, IMT, Engineer)	
Management (Middle, Senior)	

4. How many years have you been in the current position?

0 – 5	
5 - 10	
10 - 15	
15 - 20	
20+	

5. What is your highest qualification?

Matric	
Post-Matric Certificate (For example N1-N6)	
Diploma	
Degree	

6. How many years work experience do you have since qualification?

0 – 5	
5 - 10	
10 - 15	
15 - 20	
20+	

Section B:

	Statement:	Strongly Agree	Agree	Uncertain	Disagree	Strongly Disagree
1	Maintenance is practised by small groups					
2	Production efficiency data are available for my area					
3	FTPM is a work group effort					
4	A maintenance system is implemented company wide					
5	Maintenance can improve production efficiency					
6	Maintenance processes are documented					
7	Maintenance involves all employees					
8	Setup time are recorded					
9	Work groups are involved in equipment and process checks					
10	Planned preventative maintenance is conducted					
11	All downtime are recorded					
12	Maintenance tasks are scheduled and completed on time					
13	My team is involved in improvement of equipment condition					
14	All scrap production parts are recorded					
15	Failure Reporting and Corrective Action (FRACAS) procedures are adhered to.					
16	Daily cleaning, lubrication and inspection of all equipment are conducted					
17	All tooling loss are recorded					
18	My team use computerised maintenance system to record safety issues					
19	Minor stoppages of equipment are recorded					
20	Designed operating speeds of equipment are available to view					
21	Safety Notices and Lock Out Placards are visible on all equipment					

	Statement:	Strongly Agree	Agree	Uncertain	Disagree	Strongly Disagree
22	All equipment breakdowns are recorded					
23	Equipment is operating at less than designed speed					
24	All maintenance tasks are recorded					
25	I have access to a computerised maintenance system					
26	All employees have opportunity to give input to equipment efficiency improvement activities					
27	Autonomous maintenance is recorded in a computerised maintenance system					
28	Safety information is displayed in my area					
29	Equipment efficiency improvement activities are conducted					
30	I have received training how to use a computerised maintenance system					
31	I received training to increase my skills for my current position					
32	Production data is displayed in my area					
33	I am aware of my role and responsibilities in the maintenance of equipment					
34	My work environment allows me to perform my daily tasks to the best of my ability					
35	Production equipment availability, performance data and quality rate are separately displayed					
36	The company has a predictive maintenance programme such as Vibration Analysis, Infrared Thermography, Oil Analysis					
37	I have received training of what TPM is about					
38	I have received training to read and analyse production data					
39	I have received safety and environmental training					
40	I am aware what the purpose of autonomous maintenance is					
41	My team get regular feedback on production performance					

	Statement:	Strongly Agree	Agree	Uncertain	Disagree	Strongly Disagree
42	My team collect and analyse maintenance data					
43	My team has access to spares to repair an equipment failure					
44	My team give input to improve production performance					
45	All maintenance work is requested through the computerised maintenance system					
46	Equipment spare parts are readily available					
47	My team use problem-solving tools to improvement performance					
48	Maintenance data is displayed in my area					
49	I have received training in the replacement of spare parts					
50	Autonomous maintenance can help to improve production performance					
51	Spare usage are controlled and logged					
52	I have received training to use the stores management system of spares					
53	A change over management system is used to change production models					
54	My team use historical maintenance data from the computerised maintenance system to improve equipment					
55	I have received training in the safety system of equipment					
56	Change over times are recorded					
57	Daily autonomous maintenance of all equipment are conducted					
58	I received training how to use a computerised maintenance system					
59	In my area equipment focused improvement are applied to improve production performance					
60	I have access to a computerised maintenance system					